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(54) **OPTICAL PICKUP SYSTEM, OPTICAL HEAD, OPTICAL DISK APPARATUS, ANTIREFLECTION COATING, OPTICAL PICKUP COMPONENTS, AND MANUFACTURING METHOD FOR ANTIREFLECTION COATING**

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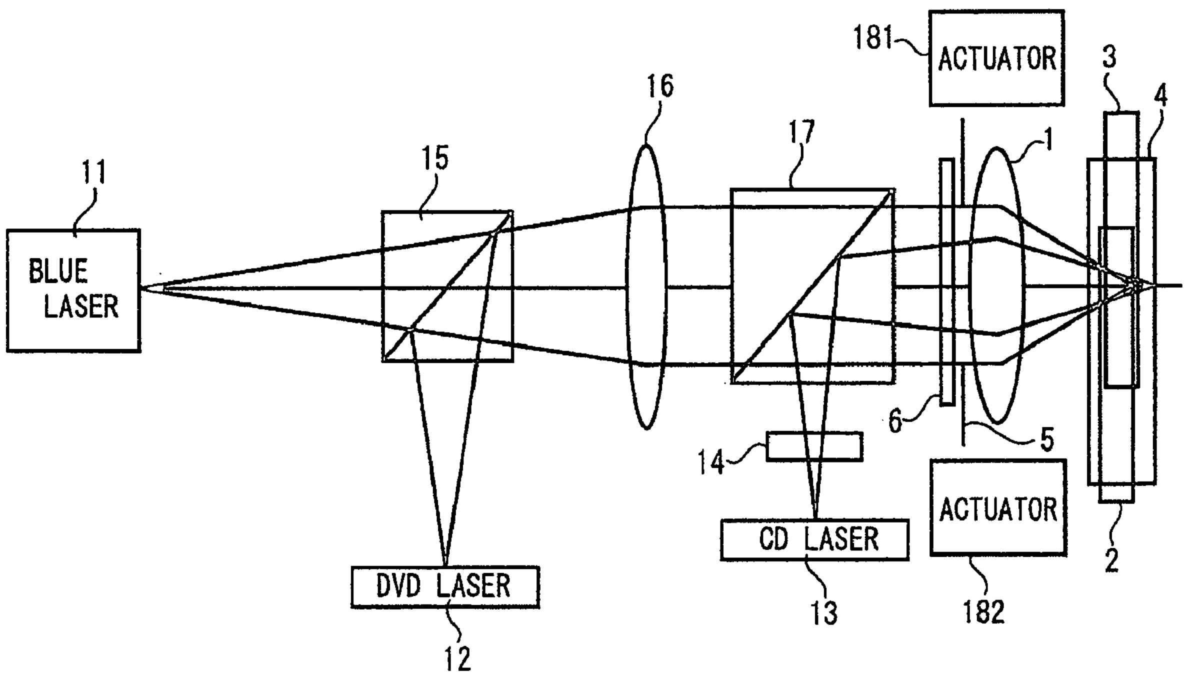
(57) **ABSTRACT**

An optical pickup system for reading information of three kinds of optical recording media. The optical pickup system has a wavelength selective filter that includes an outer area for shielding one light beam of light beams having three kinds of wavelengths and an inner area for allowing all the light beams to pass through. The optical pickup system also has an objective lens that focuses each light beam having passed through the wavelength selective filter on each light recording medium. An optical head and an optical disk apparatus have the optical pickup system.



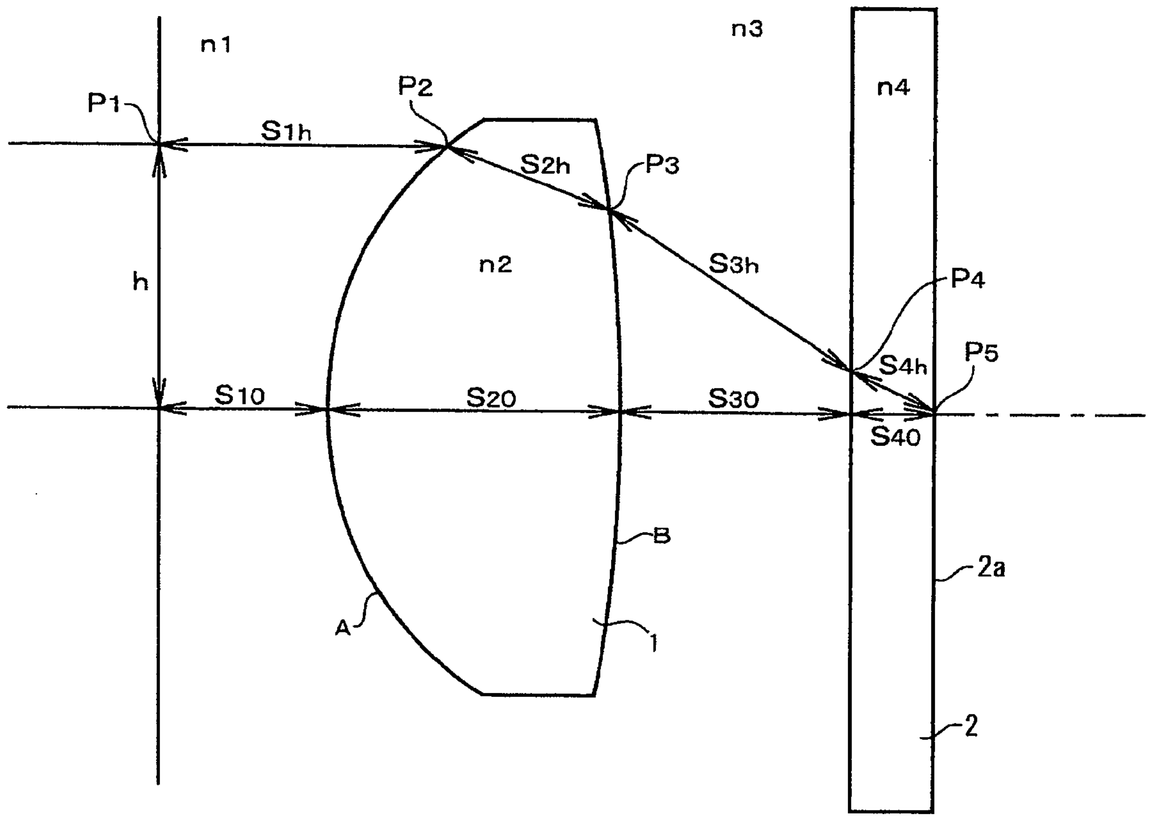


Fig. 1

Fig. 2A

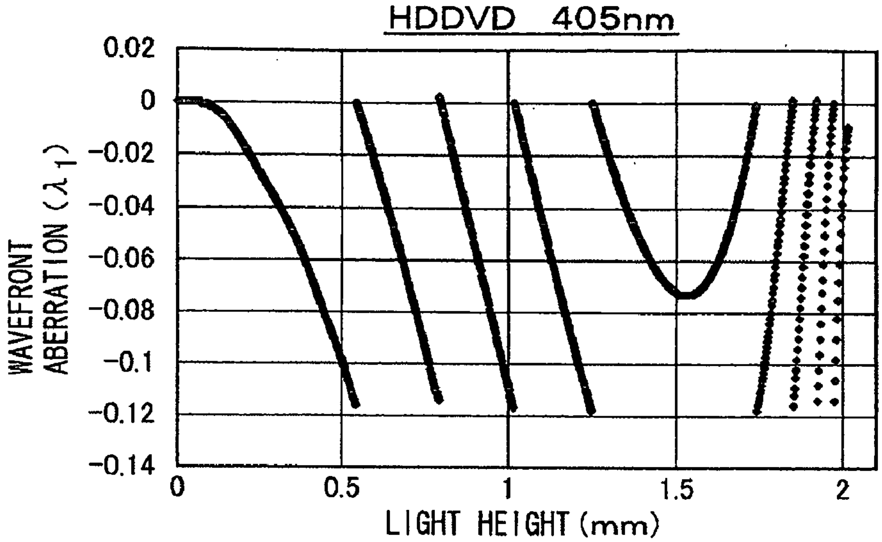


Fig. 2B

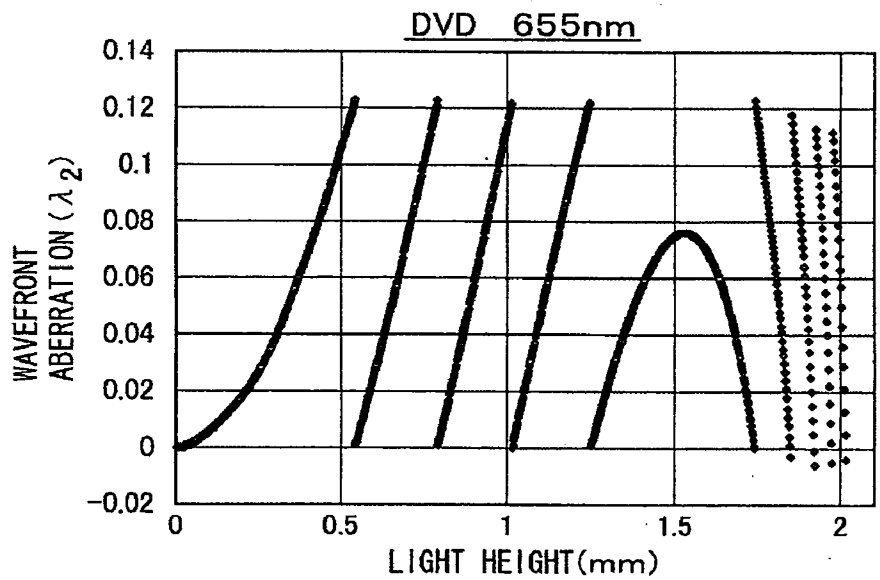


Fig. 2C

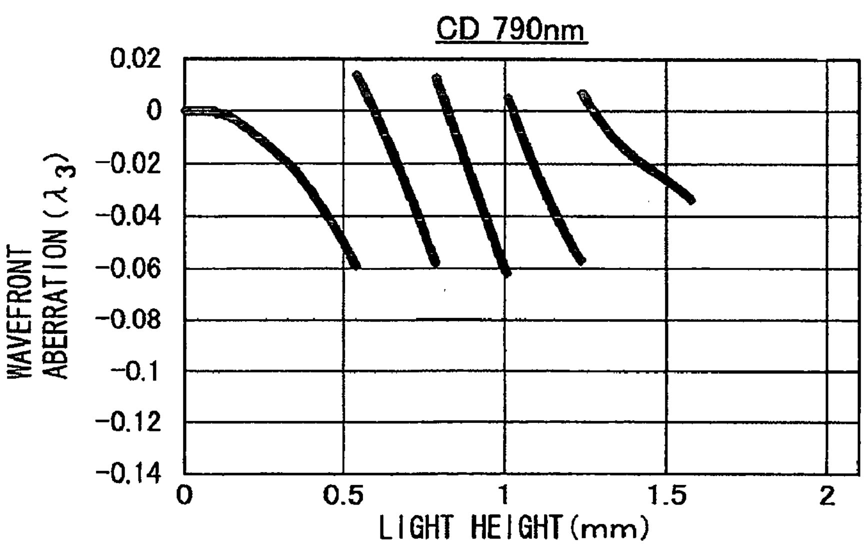


Fig. 3A

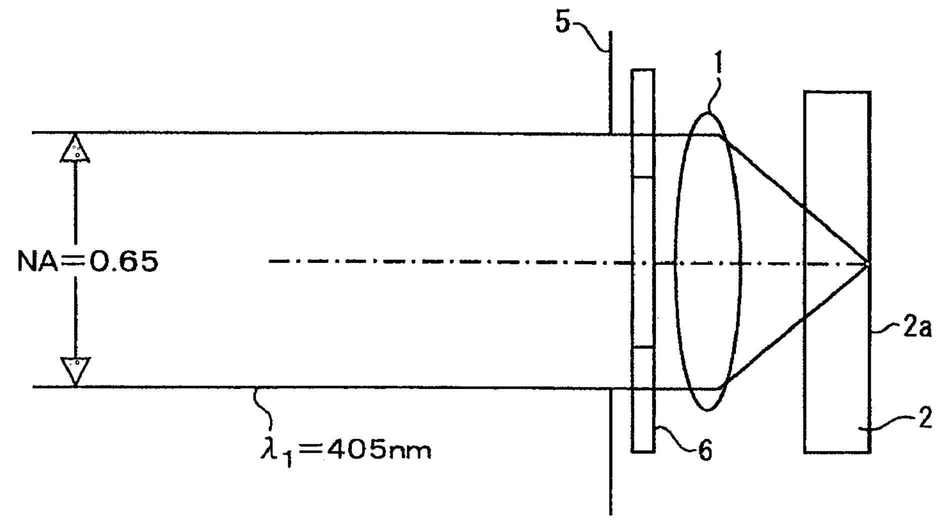


Fig. 3B

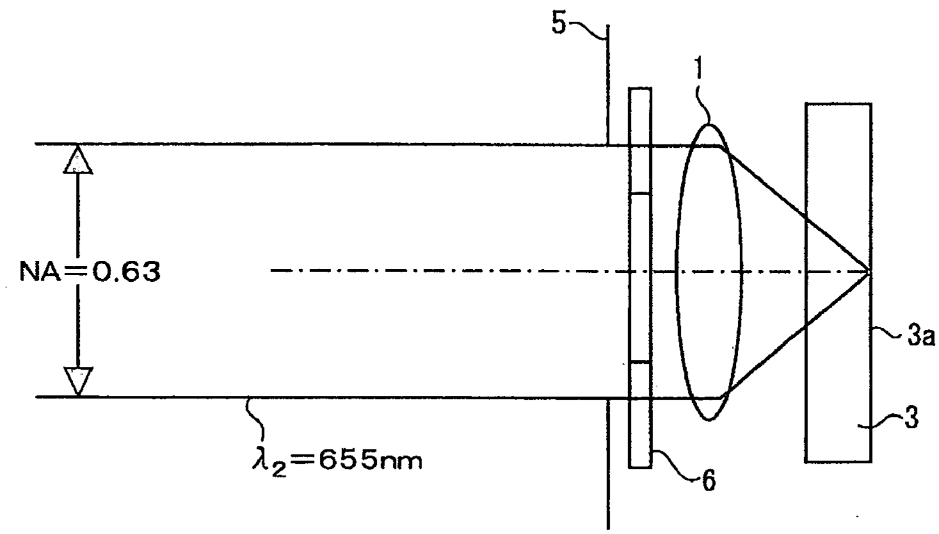


Fig. 3C

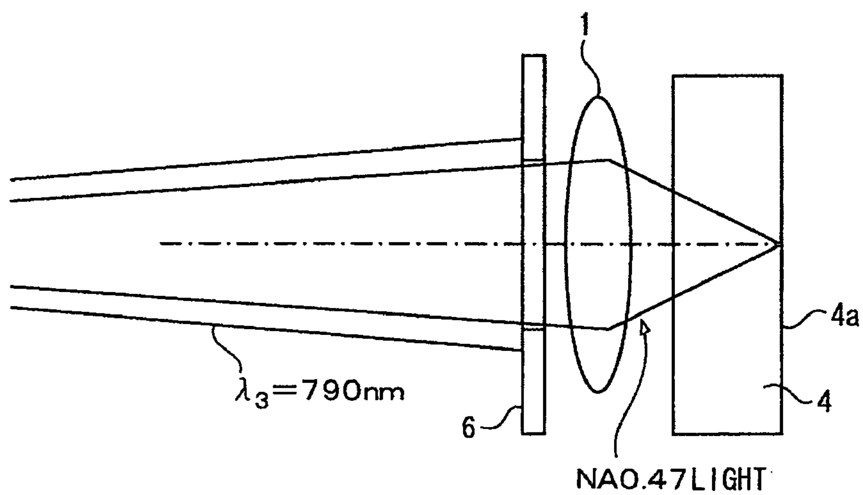


Fig. 4A

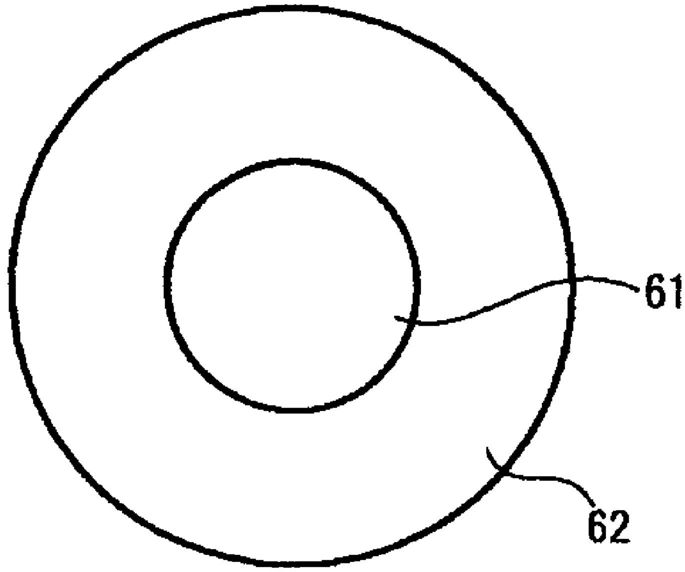
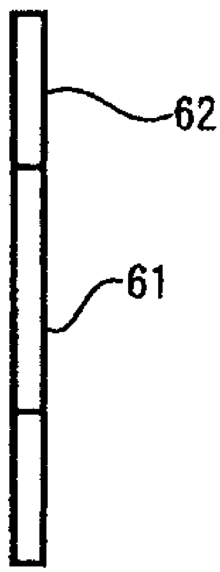


Fig. 4B



SPECTRAL TRANSMITTANCE CHARACTERISTICS OF CD LIGHT SHIELDING AREA OF WAVELENGTH SELECTIVE FILTER

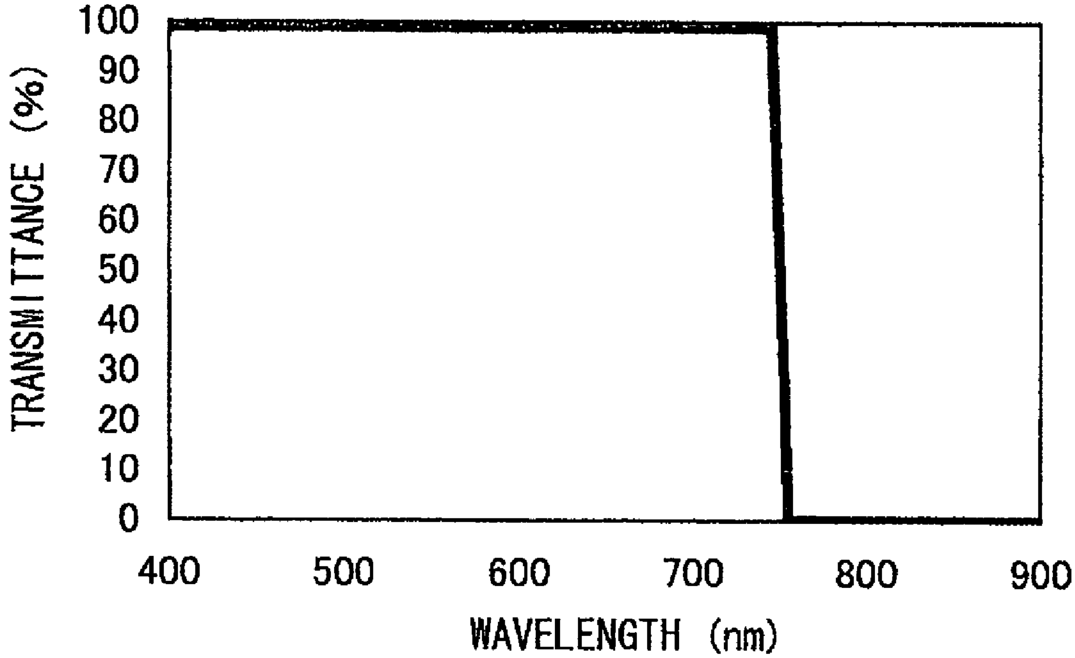


Fig. 5

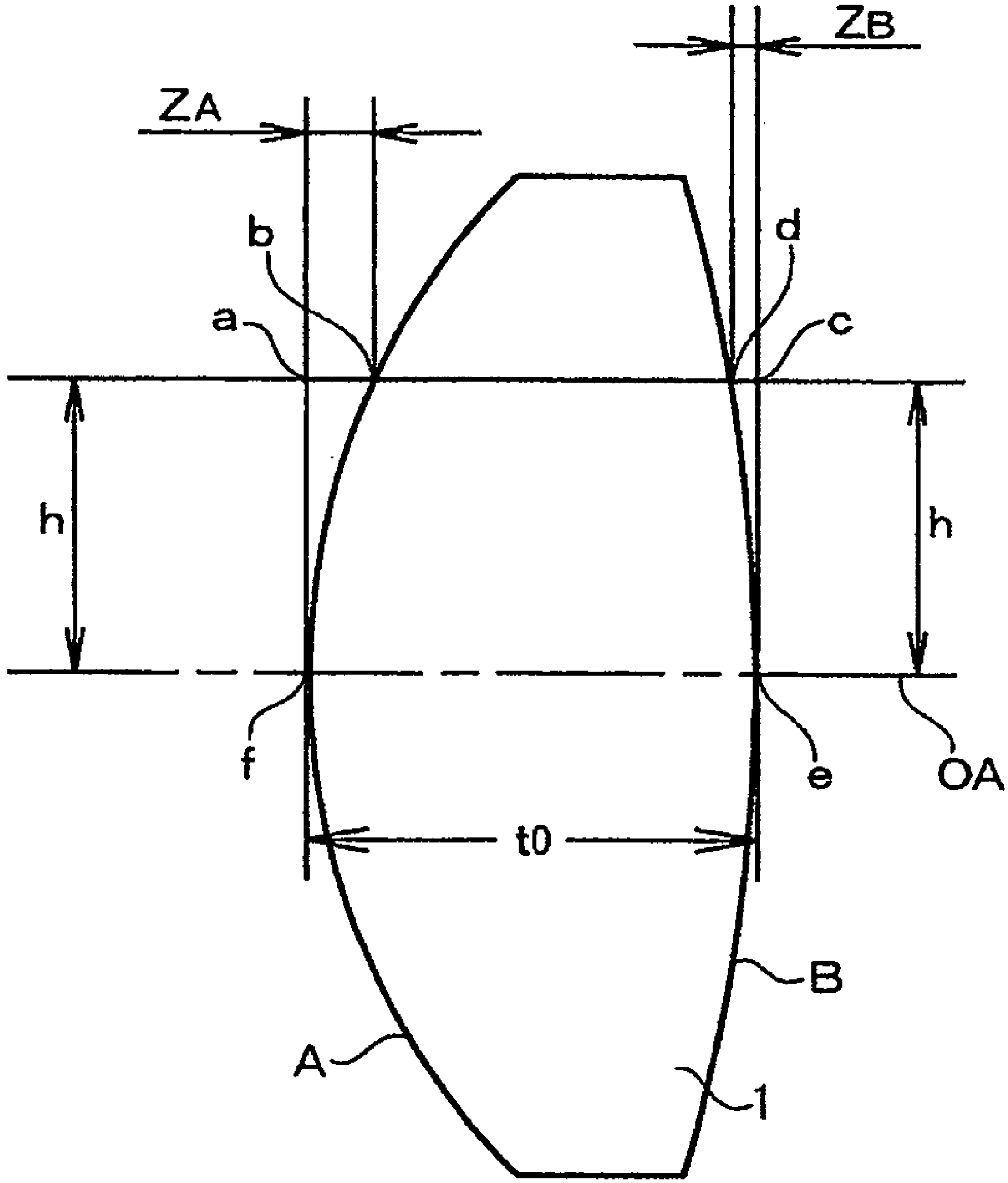


Fig. 6

SIDE A

ZONE j		1	2	3	4	5
RANGE OF h	LOWER LIMIT	0	0.542467	0.792615	1.014927	1.249884
	UPPER LIMIT	0.542467	0.792615	1.014927	1.249884	1.740929
B		0	−0.001473477	−0.002946954	−0.004420431	−0.005893908
C		0.509478595	0.5104812	0.511012577	0.510002683	0.510089832
K		−1.3369195	−0.8287777	−0.8105968	−0.7537146	−0.7469151
A4		−4.16576E−05	0.003116516	0.003289505	0.004372048	0.004157114
A6		0.258242912	0.004761572	0.00191368	0.000112694	0.000283638
A8		−2.171510837	−0.000539419	0.001174357	0.000166003	5.499882E−05
A10		9.398682567	−0.004428822	−0.001259228	3.098863E−05	−3.950521E−06
A12		−19.60835322	0.003469841	−0.001086548	−4.170906E−05	−1.297888E−05
A14		13.07840955	−0.003183954	0.00149111	−6.216377E−06	5.481453E−06
A16		6.844157513	0.003264944	−0.000424563	5.927209E−06	−6.448557E−07

ZONE j		6	7	8	9
RANGE OF h	LOWER LIMIT	1.740929	1.850763	1.92125	1.975027
	UPPER LIMIT	1.850763	1.92125	1.975027	2.2
B		−0.004420431	−0.002946954	−0.001473477	0
C		0.508291764	0.518471856	0.51922374	0.513715431
K		−0.7212068	−0.7734512	−0.7752421	−0.7540451
A4		0.005173403	0.004007756	0.003997983	0.004280322
A6		−8.23490E−05	−0.000307572	−0.000302425	−0.000136405
A8		−3.19440E−05	5.267685E−06	4.8548173E−06	2.5114717E−05
A10		4.50425E−06	3.460593E−05	3.3523674E−05	2.7589154E−05
A12		−6.74502E−06	−1.429376E−06	−2.6102373E−06	−5.8345645E−06
A14		6.84527E−06	3.389613E−06	3.3068712E−06	2.6646516E−06
A16		−1.13608E−06	−7.976428E−07	−6.9376700E−07	−4.5308929E−07

Fig. 7

SIDE B

C		−0.118642624
K		−95.56799
A4		0.00129653
A6		4.3291237E−05
A8		−1.1572493E−05
A10		−2.0639003E−06

Fig. 8

Fig. 9A

FIRST EMBODIMENT HDDVD (BLUE; 405nm) OBJECTIVE LENS FOCAL LENGTH 3.1015mm, NA0.650

PLANE		CURVATURE RADIUS (mm)	INTERPLANAR DISTANCE (mm) ON OPTICAL AXIS	MATERIAL BETWEEN PLANES	REFRACTIVE INDEX	EFFECTIVE DIAMETER (mm)
1	OBJECT SURFACE	∞	∞	AIR	1	—
2	APERTURE SURFACE	∞	0	AIR	1	4.032
3	LENS SURFACE; OBJECT SIDE	ASPHERICAL SURFACE	1.94	RESIN OR EQUIVALENT	1.54972	—
4	LENS SURFACE; IMAGE SURFACE SIDE	ASPHERICAL SURFACE	1.59296	AIR	1	—
5	DISK SURFACE; OBJECT SIDE	∞	0.6	PC	1.6235	—
6	DISK INFORMATION RECORDING SURFACE	∞	—	—	—	—

Fig. 9B

FIRST EMBODIMENT DVD (655nm) OBJECTIVE LENS FOCAL LENGTH 3.2116mm, NA0.628

PLANE		CURVATURE RADIUS (mm)	INTERPLANAR DISTANCE (mm) ON OPTICAL AXIS	MATERIAL BETWEEN PLANES	REFRACTIVE INDEX	EFFECTIVE DIAMETER (mm)
1	OBJECT SURFACE	∞	∞	AIR	1	—
2	APERTURE SURFACE	∞	0	AIR	1	4.032
3	LENS SURFACE; OBJECT SIDE	ASPHERICAL SURFACE	1.94	RESIN OR EQUIVALENT	1.53	—
4	LENS SURFACE; IMAGE SURFACE SIDE	ASPHERICAL SURFACE	1.741631	AIR	1	—
5	DISK SURFACE; OBJECT SIDE	∞	0.6	PC	1.58	—
6	DISK INFORMATION RECORDING SURFACE	∞	—	—	—	—

Fig. 9C

FIRST EMBODIMENT CD (790nm) OBJECTIVE LENS FOCAL LENGTH 3.2327mm, NA0.470

PLANE		CURVATURE RADIUS (mm)	INTERPLANAR DISTANCE (mm) ON OPTICAL AXIS	MATERIAL BETWEEN PLANES	REFRACTIVE INDEX	EFFECTIVE DIAMETER (mm)
1	OBJECT SURFACE	∞	49.4	AIR	1	—
2	APERTURE SURFACE	∞	0	AIR	1	3.15
3	LENS SURFACE; OBJECT SIDE	ASPHERICAL SURFACE	1.94	RESIN OR EQUIVALENT	1.5263653	—
4	LENS SURFACE; IMAGE SURFACE SIDE	ASPHERICAL SURFACE	1.59296	AIR	1	—
5	DISK SURFACE; OBJECT SIDE	∞	1.2	PC	1.57163	—
6	DISK INFORMATION RECORDING SURFACE	∞	—	—	—	—

Fig. 10A

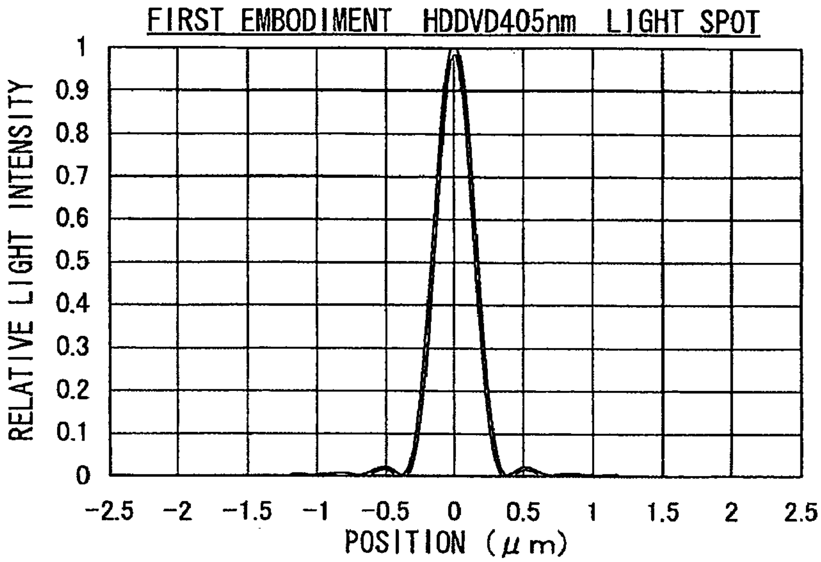


Fig. 10B

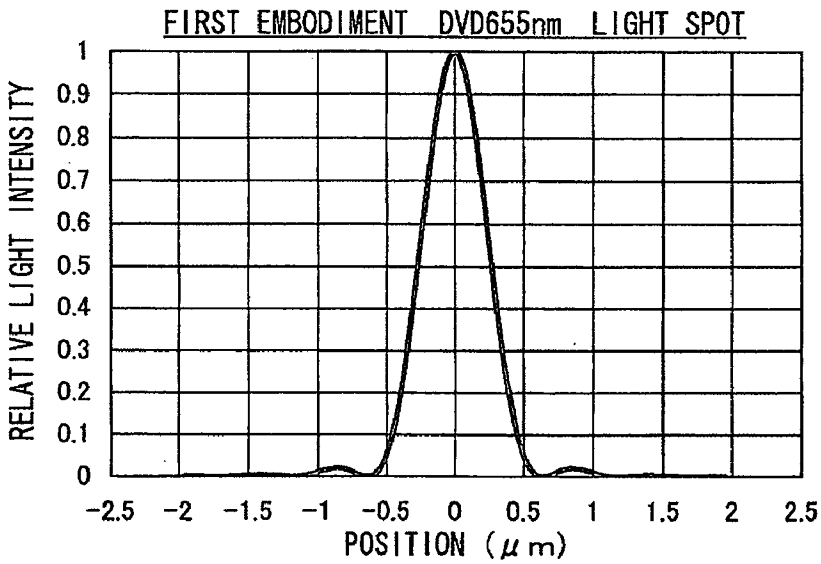
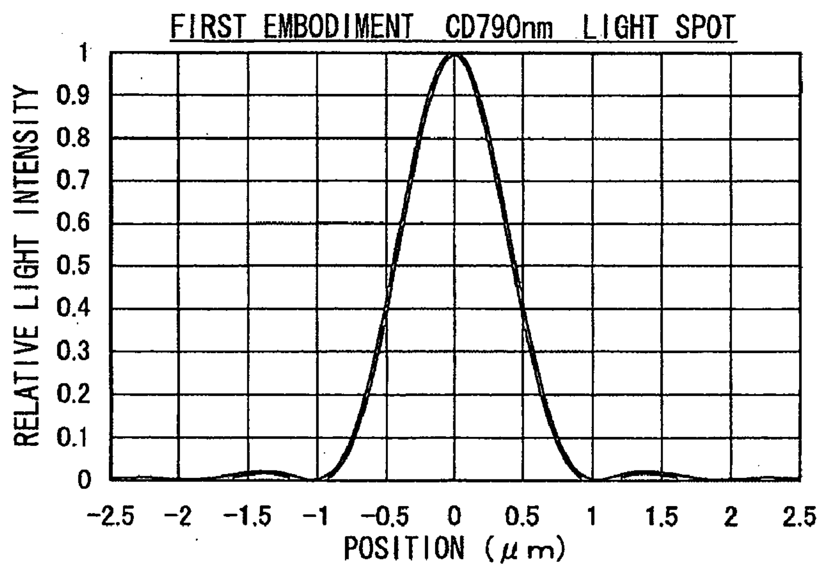


Fig. 10C



DIFFERENCE IN OPTICAL PATH LENGTH(λ)
BETWEEN ZONE 1 AND ZONE 2 TO 9

ZONE j	OPTICAL PATH LENGTH DIFFERENCE FROM ZONE 1		
	WAVELENGTH 405nm, HDDVD	WAVELENGTH 655nm, DVD	WAVELENGTH 790nm, CD
1	REFERENCE	REFERENCE	REFERENCE
2	2	1	1
3	4	2	2
4	6	3	3
5	8	4	4
6	6	3	3
7	4	2	2
8	2	1	1
9	0	0	0

Fig. 11

SIDE A:ZONE j=1 TO 6

ZONE j								
BLU-RAY /DVD COMMON USE AREA 1	R	1.452864	C	0.68829567	K	−11.13817		
	A4	0.06646855	A6	34.47225	A8	−1552.963	A10	31931.42
	A12	−248870.6	A14	2.016486	A16	0.2784295		
			B	0				
		RANGE OF h	SMALL	0				
			LARGE	0.202346				
BLU-RAY /DVD COMMON USE AREA 2	R	1.442098	C	0.693434149	K	−3.02541		
	A4	−0.008186124	A6	1.33109	A8	2.765864	A10	−174.465
	A12	−468.2288	A14	31346.47	A16	−179034.6		
			B	−0.000973979				
		RANGE OF h	SMALL	0.202346				
			LARGE	0.289741				
BLU-RAY /DVD COMMON USE AREA 3	R	1.447296	C	0.690943663	K	−1.714515		
	A4	0.03441157	A6	−0.05859795	A8	0.3488139	A10	5.326697
	A12	0.8872806	A14	−387.4022	A16	1405.46		
			B	−0.001947958				
		RANGE OF h	SMALL	0.289741				
			LARGE	0.359911				
BLU-RAY /DVD COMMON USE AREA 4	R	1.430321	C	0.699143759	K	−2.292213		
	A4	0.0129148	A6	−0.07704655	A8	1.431743	A10	10.77500
	A12	−18.11912	A14	−642.5188	A16	2182.917		
			B	−0.002921937				
		RANGE OF h	SMALL	0.359911				
			LARGE	0.422437				
BLU-RAY /DVD COMMON USE AREA 5	R	1.403155	C	0.71267964	K	−3.023571		
	A4	−0.009439812	A6	−0.002444696	A8	1.481634	A10	6.132152
	A12	−15.28571	A14	−216.8429	A16	602.3758		
			B	−0.003895916				
		RANGE OF h	SMALL	0.422437				
			LARGE	0.48152				
BLU-RAY /DVD COMMON USE AREA 6	R	1.449731	C	0.689783139	K	−1.614642		
	A4	0.04004518	A6	0.004864501	A8	0.06055667	A10	0.06327539
	A12	−0.7934222	A14	−3.623215	A16	13.15235		
			B	−0.004869895				
		RANGE OF h	SMALL	0.48152				
			LARGE	0.540151				

Fig. 12

SIDE A:ZONE j=7 TO 12

ZONE j								
BLU-RAY /DVD COMMON USE AREA 7	R	1.465183	C	0.682508601	K	−1.209382		
	A4	0.04189799	A6	0.003042637	A8	0.01239711	A10	−0.04691002
	A12	−0.4820431	A14	−1.389654	A16	5.490768		
			B	−0.005843874				
	RANGE OF h		SMALL	0.540151				
			LARGE	0.601857				
BLU-RAY /DVD COMMON USE AREA 8	R	1.497529	C	0.667766701	K	−0.2636307		
	A4	0.04816469	A6	−0.03285523	A8	−0.1304645	A10	−0.2188387
	A12	0.3546703	A14	1.950679	A16	−2.685101		
			B	−0.006817853				
	RANGE OF h		SMALL	0.601857				
			LARGE	0.681364				
BLU-RAY /DVD COMMON USE AREA 9	R	1.451697	C	0.688848982	K	−1.526474		
	A4	0.04116413	A6	6.63077E−05	A8	0.003644628	A10	0.000808626
	A12	−0.0016948	A14	−0.002234693	A16	0.0015451		
			B	−0.007791832				
	RANGE OF h		SMALL	0.681364				
			LARGE	0.885179				
BLU-RAY /DVD COMMON USE AREA 10	R	1.412014	C	0.708208276	K	−1.58977		
	A4	0.0342354	A6	−0.01041381	A8	−0.000792472	A10	0.00701932
	A12	0.02025544	A14	0.01798688	A16	−0.03202835		
			B	−0.006817853				
	RANGE OF h		SMALL	0.885179				
			LARGE	0.932581				
BLU-RAY /DVD COMMON USE AREA 11	R	1.407132	C	0.710665382	K	−1.631541		
	A4	0.0342231	A6	−0.01054141	A8	0.000512931	A10	0.01440142
	A12	0.009329735	A14	0.006135766	A16	−0.01637014		
			B	−0.005843874				
	RANGE OF h		SMALL	0.932581				
			LARGE	0.964545				
BLU-RAY /DVD COMMON USE AREA 12	R	1.477124	C	0.676991234	K	−1.420435		
	A4	0.04344266	A6	0.001178248	A8	0.002890162	A10	0.000169676
	A12	−0.000524148	A14	−0.000838883	A16	−0.001111756		
			B	−0.004869895				
	RANGE OF h		SMALL	0.964545				
			LARGE	0.989576				

Fig. 13

SIDE A:ZONE j=13 TO 18

ZONE j								
BLU-RAY /DVD COMMON USE AREA 13	R	1.472551	C	0.679093627	K	-1.474817		
	A4	0.04286711	A6	0.001223663	A8	0.003137876	A10	0.00100637
	A12	0.000376189	A14	-0.00027401	A16	-0.002176412		
			B	-0.003895916				
		RANGE OF h	SMALL	0.989576				
			LARGE	1.010537				
BLU-RAY /DVD COMMON USE AREA 14	R	1.479586	C	0.675864735	K	-1.479376		
	A4	0.04342354	A6	0.001816119	A8	0.003664101	A10	0.001093464
	A12	0.000266176	A14	-0.00059659	A16	-0.001962815		
			B	-0.002921937				
		RANGE OF h	SMALL	1.010537				
			LARGE	1.028706				
BLU-RAY /DVD COMMON USE AREA 15	R	1.478826	C	0.676212076	K	-1.517098		
	A4	0.04317621	A6	0.001526801	A8	0.003972736	A10	0.00186178
	A12	0.001132504	A14	-0.000262064	A16	-0.002771862		
			B	-0.001947958				
		RANGE OF h	SMALL	1.028706				
			LARGE	1.044816				
BLU-RAY /DVD COMMON USE AREA 16	R	1.487809	C	0.672129285	K	-1.502858		
	A4	0.04302065	A6	0.002339277	A8	0.004401671	A10	0.001988357
	A12	0.001054724	A14	-0.000447515	A16	-0.002656759		
			B	-0.000973979				
		RANGE OF h	SMALL	1.044816				
			LARGE	1.059373				
BLU-RAY /DVD COMMON USE AREA 17	R	1.490775	C	0.670792038	K	-1.518012		
	A4	0.04357986	A6	0.002311069	A8	0.004485633	A10	0.001973824
	A12	0.001019069	A14	-0.00041868	A16	-0.002449741		
			B	0				
		RANGE OF h	SMALL	1.059373				
			LARGE	1.072659				
BLU-RAY /DVD COMMON USE AREA 18	R	1.49491	C	0.668936592	K	-1.512174		
	A4	0.04303999	A6	0.002567525	A8	0.004827089	A10	0.002098906
	A12	0.001056827	A14	-0.0003381	A16	-0.002472669		
			B	0.000973979				
		RANGE OF h	SMALL	1.072659				
			LARGE	1.084911				

Fig. 14

SIDE A:ZONE j=19 TO 22

ZONE j								
BLU-RAY /DVD COMMON USE AREA 19	R	1.495096	C	0.668853371	K	−1.523511		
	A4	0.04347325	A6	0.002492273	A8	0.004554101	A10	0.001998625
	A12	0.001000807	A14	−0.000467157	A16	−0.002084074		
			B	0.001947958				
		RANGE OF h	SMALL	1.084911				
			LARGE	1.096299				
BLU-RAY /DVD COMMON USE AREA 20	R	1.498038	C	0.667539809	K	−1.519756		
	A4	0.04341198	A6	0.002629952	A8	0.004521274	A10	0.001896512
	A12	0.000890141	A14	−0.000200778	A16	−0.002048661		
			B	0.002921937				
		RANGE OF h	SMALL	1.096299				
			LARGE	1.106922				
BLU-RAY /DVD COMMON USE AREA 21	R	1.489031	C	0.67157769	K	−1.480843		
	A4	0.0430581	A6	0.002140375	A8	0.003454773	A10	0.000944453
	A12	0.000311511	A14	−6.29334E−05	A16	−0.00122241		
			B	0.003895916				
		RANGE OF h	SMALL	1.106922				
			LARGE	1.113847				
BLU-RAY EXCLUSIVE USE AREA 22	R	1.452877	C	0.688289511	K	−1.471891		
	A4	0.04243736	A6	−0.000396819	A8	0.001322548	A10	−0.000844585
	A12	1.94922E−05	A14	0.000190882	A16	−9.60884E−05		
			B	−0.000022402				
		RANGE OF h	SMALL	1.113847				
			LARGE	1.6				

Fig. 15

SIDE B

R2	R	49.99325	C	0.0200027	K	0		
	A4	0.02999406	A6	−0.05280596	A8	−0.03201307	A10	0.04411468
	A12	0.01911437	A14	−0.03938952	A16	0.01328156		
			B	2.076				
		RANGE OF h	SMALL	0				
			LARGE	1.6				

Fig. 16

Fig. 17A

SECOND EMBODIMENT BLU-RAY (BLUE; 405nm) OBJECTIVE LENS FOCAL LENGTH 1.765mm, NA0.850

PLANE		CURVATURE RADIUS (mm)	INTERPLANAR DISTANCE (mm) ON OPTICAL AXIS	MATERIAL BETWEEN PLANES	REFRACTIVE INDEX	EFFECTIVE DIAMETER (mm)
1	OBJECT SURFACE	∞	∞	AIR	1	—
2	APERTURE SURFACE	∞	0	AIR	1	3.000
3	LENS SURFACE; OBJECT SIDE	ASPHERICAL SURFACE	2.076	GLASS OR EQUIVALENT	1.83164	—
4	LENS SURFACE; IMAGE SURFACE SIDE	ASPHERICAL SURFACE	0.558308	AIR	1	—
5	DISK SURFACE; OBJECT SIDE	∞	0.6	PC	1.6235	—
6	DISK INFORMATION RECORDING SURFACE	∞	—	—	—	—

Fig. 17B

SECOND EMBODIMENT DVD (655nm) OBJECTIVE LENS FOCAL LENGTH 1.8564mm, NA0.600

PLANE		CURVATURE RADIUS (mm)	INTERPLANAR DISTANCE (mm) ON OPTICAL AXIS	MATERIAL BETWEEN PLANES	REFRACTIVE INDEX	EFFECTIVE DIAMETER (mm)
1	OBJECT SURFACE	∞	∞	AIR	1	—
2	APERTURE SURFACE	∞	0	AIR	1	2.228
3	LENS SURFACE; OBJECT SIDE	ASPHERICAL SURFACE	2.076	GLASS OR EQUIVALENT	1.7911	—
4	LENS SURFACE; IMAGE SURFACE SIDE	ASPHERICAL SURFACE	0.325341	AIR	1	—
5	DISK SURFACE; OBJECT SIDE	∞	0.6	PC	1.58	—
6	DISK INFORMATION RECORDING SURFACE	∞	—	—	—	—

Fig. 17C

SECOND EMBODIMENT CD (790nm) OBJECTIVE LENS FOCAL LENGTH 1.8745mm, NA0.469

PLANE		CURVATURE RADIUS (mm)	INTERPLANAR DISTANCE (mm) ON OPTICAL AXIS	MATERIAL BETWEEN PLANES	REFRACTIVE INDEX	EFFECTIVE DIAMETER (mm)
1	OBJECT SURFACE	∞	15.5	AIR	1	—
2	APERTURE SURFACE	∞	0	AIR	1	1.88
3	LENS SURFACE; OBJECT SIDE	ASPHERICAL SURFACE	2.076	GLASS OR EQUIVALENT	1.783555	—
4	LENS SURFACE; IMAGE SURFACE SIDE	ASPHERICAL SURFACE	0.186156	AIR	1	—
5	DISK SURFACE; OBJECT SIDE	∞	1.2	PC	1.573	—
6	DISK INFORMATION RECORDING SURFACE	∞	—	—	—	—

DIFFERENCE IN OPTICAL PATH LENGTH(λ) BETWEEN ZONE 1 AND ZONE 2 TO 22

ZONE j	OPTICAL PATH LENGTH DIFFERENCE FROM ZONE 1		
	WAVELENGTH 405nm, BLU-RAY	WAVELENGTH 655nm, DVD	WAVELENGTH 790nm, CD
1	REFERENCE	REFERENCE	REFERENCE
2	2	1	1
3	4	2	2
4	6	3	3
5	8	4	4
6	10	5	5
7	12	6	6
8	14	7	7
9	16	8	8
10	14	7	7
11	12	6	6
12	10	5	—
13	8	4	—
14	6	3	—
15	4	2	—
16	2	1	—
17	0	0	—
18	−2	−1	—
18	−4	−2	—
20	−6	−3	—
21	−8	−4	—
22	−10	—	—

Fig. 18

Fig. 19A

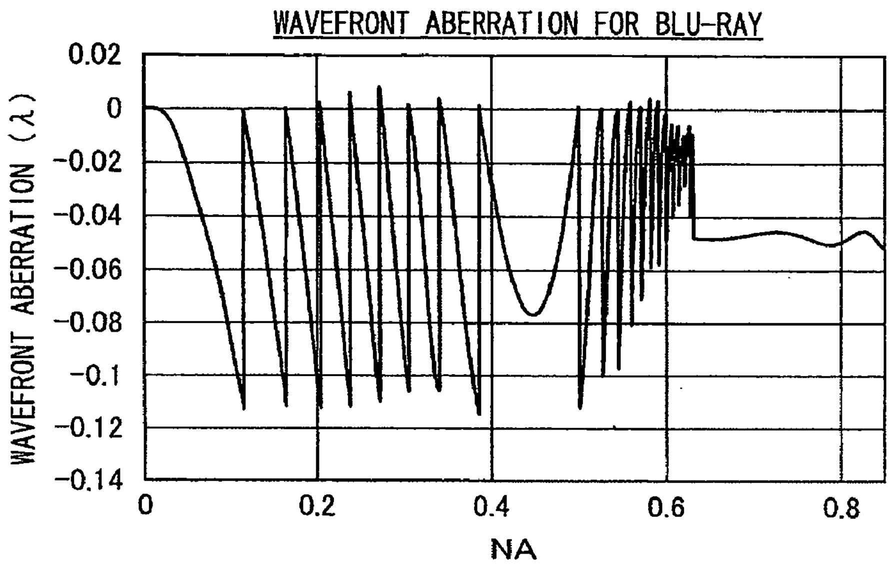


Fig. 19B

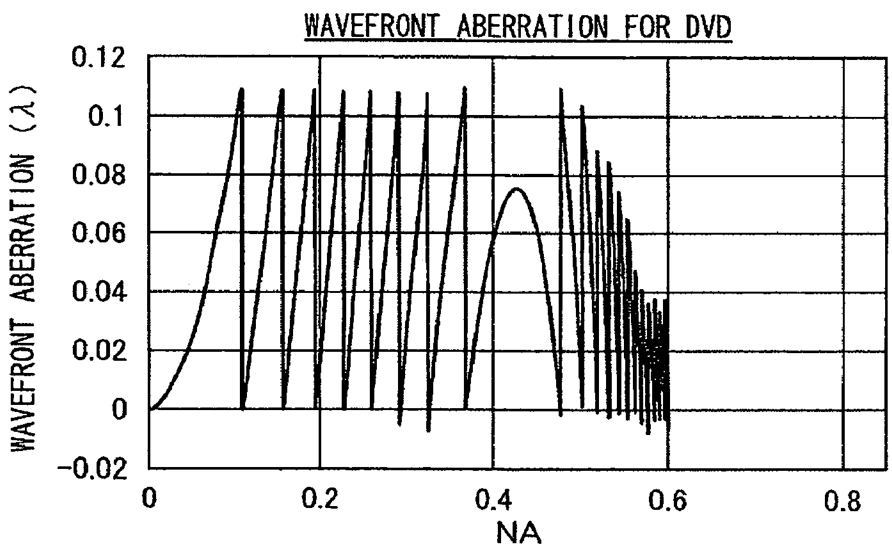


Fig. 19C

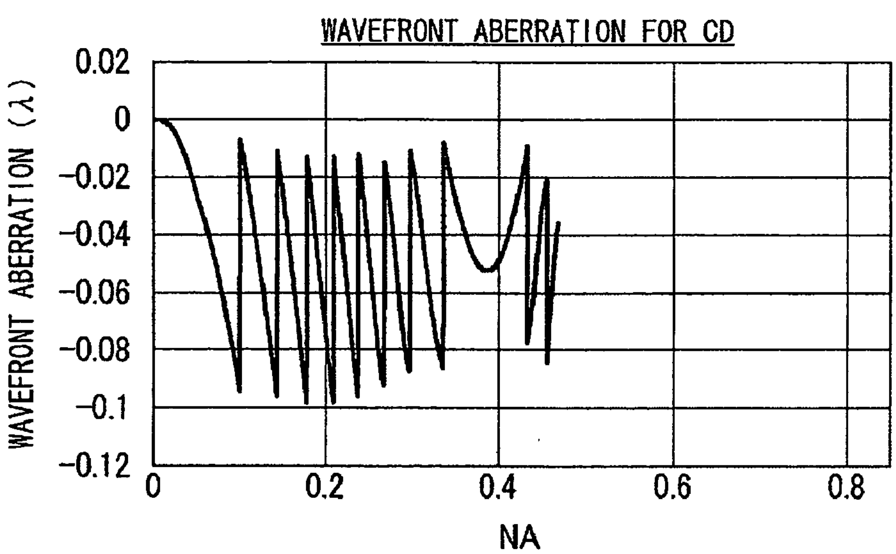


Fig. 20A

	AREA1	AREA2	AREA3	AREA4	AREA5	AREA6	AREA7
ΔVd(λ405)(λ)	0.112663	0.11076	0.11228	0.113728	0.115647	0.113824	0.106881
ΔVd(λ655)(λ)	0.108923	0.108855	0.108527	0.107989	0.108017	0.107648	0.112463
ΔVd(λ655)/ΔVd(λ405)	0.966804	0.982801	0.966575	0.949537	0.934023	0.945741	1.052226
ΔVd(λ405)/ΔVd(λ655)	1.034336	1.0175	1.034581	1.053144	1.070637	1.057372	0.950366

Fig. 20B

	AREA8	AREA9	AREA10	AREA11	AREA12	AREA13	AREA14
ΔVd(λ405)(λ)	0.118205	0.077986	0.112089	0.099994	0.099557	0.081079	0.074496
ΔVd(λ655)(λ)	0.116795	0.076682	0.107916	0.104221	0.090406	0.085492	0.076735
ΔVd(λ655)/ΔVd(λ405)	0.988072	0.983279	0.962771	1.042273	0.908083	1.054428	1.030055
ΔVd(λ405)/ΔVd(λ655)	1.012072	1.017005	1.038669	0.959442	1.101221	0.948381	0.970822

Fig. 20C

	AREA15	AREA16	AREA17	AREA18	AREA19	AREA20	AREA21
ΔVd(λ405)(λ)	0.061884	0.05554	0.042557	0.033961	0.025566	0.022087	0.029899
ΔVd(λ655)(λ)	0.065213	0.051423	0.048405	0.039528	0.040547	0.036301	0.043709
ΔVd(λ655)/ΔVd(λ405)	1.053794	0.925873	1.137416	1.163923	1.585974	1.643546	1.461888
ΔVd(λ405)/ΔVd(λ655)	0.948952	1.080061	0.879186	0.859163	0.630528	0.608441	0.684047

Fig. 21A

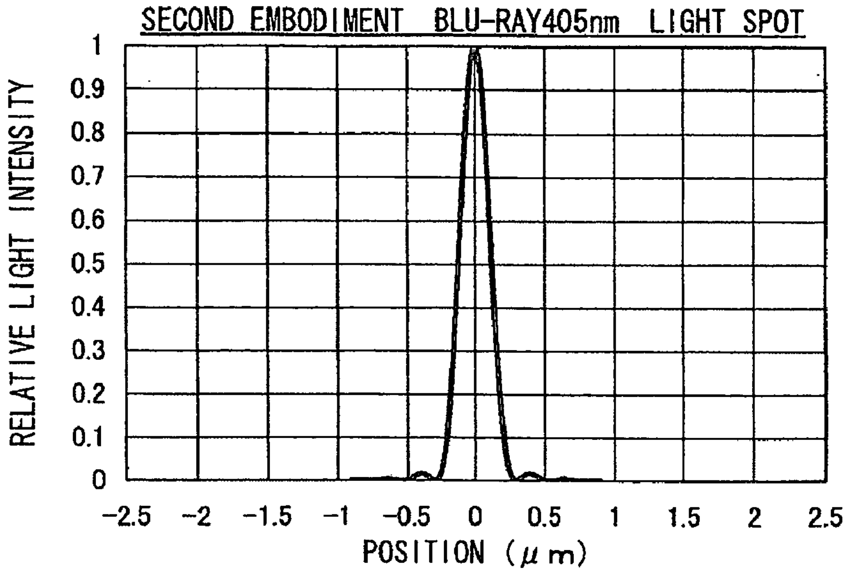


Fig. 21B

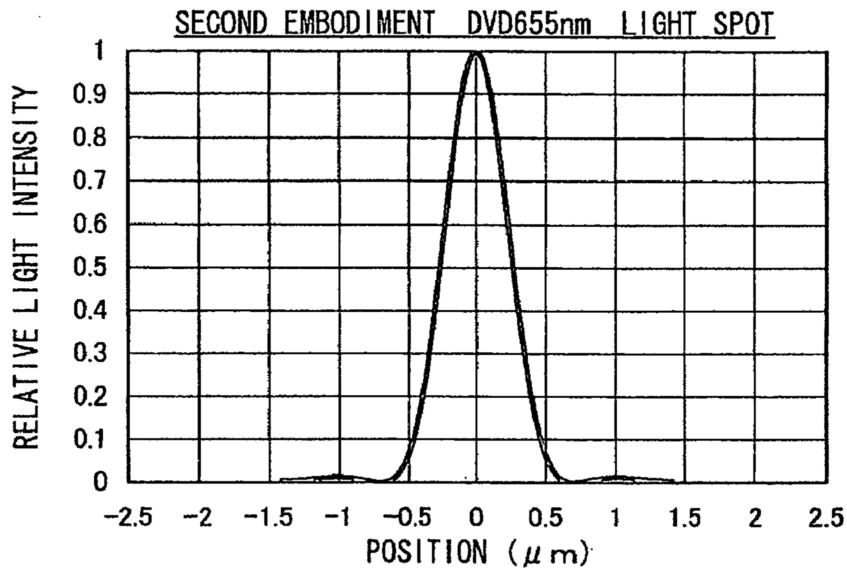
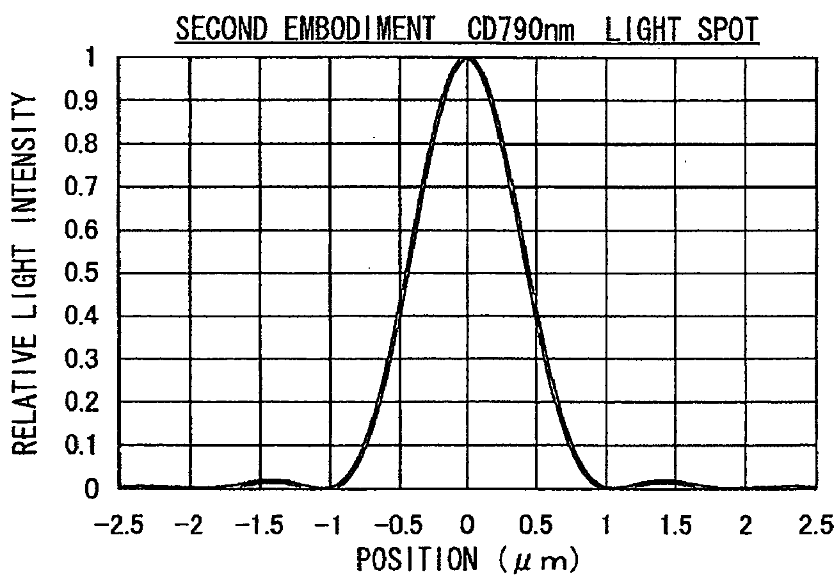


Fig. 21C



SIDE A

ZONE j		1 (HDDVD/DVD COMMON AREA)	2 (HDDVD/DVD COMMON AREA)	3 (HDDVD/DVD COMMON AREA)	4 (HDDVD/DVD COMMON AREA)	5 (HDDVD/DVD COMMON AREA)	6 (HDDVD/DVD COMMON AREA)	7 (DVD EXCLUSIVE AREA)
RANGE OF h	LOWER LIMIT	0	0. 638449737	0. 890527411	1. 129434779	1. 70935057	1. 878647359	1. 946519408
	UPPER LIMIT	0. 638449737	0. 890527411	1. 129434779	1. 70935057	1. 878647359	1. 946519408	2. 084
B		0	0. 001474416	0. 002942583	0. 004408376	0. 002957205	0. 001512596	-7. 14171E-05
C		0. 52590795	0. 526058409	0. 526208979	0. 526359917	0. 526209609	0. 526058529	0. 526624092
K		-0. 40705603	-0. 406804912	-0. 406592578	-0. 406143073	-0. 406099759	-0. 40669695	-0. 408309722
A4		0. 002711618	0. 002709128	0. 002707203	0. 002700042	0. 002695751	0. 002706514	0. 002935526
A6		-0. 001445731	-0. 001447425	-0. 001448762	-0. 00144888	-0. 001445026	-1. 44639E-03	-0. 001662801
A8		0. 000329808	0. 000328816	0. 000327636	0. 000324254	3. 219105E-04	3. 27356E-04	4. 123773E-04
A10		-6. 23626E-05	-6. 15714E-05	-6. 06962E-05	-5. 85948E-05	-5. 756254E-05	-6. 07796E-05	-9. 292706E-05
A12		-1. 26611E-05	-1. 30457E-05	-1. 34442E-05	-1. 42604E-05	-1. 447367E-05	-1. 33008E-05	-4. 239090E-06
A14		5. 68E-06	5. 76392E-06	5. 84826E-06	6. 00572E-06	6. 022988E-06	5. 80646E-06	4. 415430E-06
A16		-6. 38098E-07	-6. 45806E-07	-6. 53374E-07	-6. 66496E-07	-6. 661790E-07	-6. 48857E-07	-5. 634218E-07

SIDE B		
C		-0. 139072037
K		-114. 0147181
A4		0. 005616797
A6		-0. 002269237
A8		0. 000525999
A10		3. 76121E-05
A12		-4. 43187E-05
A14		8. 21847E-06
A16		-5. 02326E-07

Fig. 22

Fig. 23A

THIRD EMBODIMENT HDDVD(408nm) OBJECTIVE LENS FOCAL LENGTH 3.1010mm, NA0.650

PLANE		CURVATURE RADIUS (mm)	INTERPLANAR DISTANCE (mm) ON OPTICAL AXIS	MATERIAL BETWEEN PLANES	REFRACTIVE INDEX	EFFECTIVE DIAMETER (mm)
1	OBJECT SURFACE	∞	-93.9	AIR	1	—
2	APERTURE SURFACE	∞	0	AIR	1	4.168
3	LENS SURFACE; OBJECT SIDE	ASPHERICAL SURFACE	1.92	RESIN OR EQUIVALENT	1.5229	—
4	LENS SURFACE; IMAGE SURFACE SIDE	ASPHERICAL SURFACE	1.552869	AIR	1	—
5	DISK SURFACE; OBJECT SIDE	∞	0.6	PC	1.622	—
6	DISK INFORMATION RECORDING SURFACE	∞	—	—	—	—

Fig. 23B

THIRD EMBODIMENT DVD(658nm) OBJECTIVE LENS FOCAL LENGTH 3.2059mm, NA0.650

PLANE		CURVATURE RADIUS (mm)	INTERPLANAR DISTANCE (mm) ON OPTICAL AXIS	MATERIAL BETWEEN PLANES	REFRACTIVE INDEX	EFFECTIVE DIAMETER (mm)
1	OBJECT SURFACE	∞	∞	AIR	1	—
2	APERTURE SURFACE	∞	0	AIR	1	4.168
3	LENS SURFACE; OBJECT SIDE	ASPHERICAL SURFACE	1.92	RESIN OR EQUIVALENT	1.5048	—
4	LENS SURFACE; IMAGE SURFACE SIDE	ASPHERICAL SURFACE	1.736136	AIR	1	—
5	DISK SURFACE; OBJECT SIDE	∞	0.6	PC	1.5774	—
6	DISK INFORMATION RECORDING SURFACE	∞	—	—	—	—

Fig. 23C

THIRD EMBODIMENT CD(785nm) OBJECTIVE LENS FOCAL LENGTH 3.2246mm, NA0.470

PLANE		CURVATURE RADIUS (mm)	INTERPLANAR DISTANCE (mm) ON OPTICAL AXIS	MATERIAL BETWEEN PLANES	REFRACTIVE INDEX	EFFECTIVE DIAMETER (mm)
1	OBJECT SURFACE	∞	113.0	AIR	1	—
2	APERTURE SURFACE	∞	0	AIR	1	3.066
3	LENS SURFACE;OBJECT SIDE	ASPHERICAL SURFACE	1.92	RESIN OR EQUIVALENT	1.50176	—
4	LENS SURFACE;IMAGE SURFACE SIDE	ASPHERICAL SURFACE	1.476309	AIR	1	—
5	DISK SURFACE;OBJECT SIDE	∞	1.2	PC	1.57204	—
6	DISK INFORMATION RECORDING SURFACE	∞	—	—	—	—

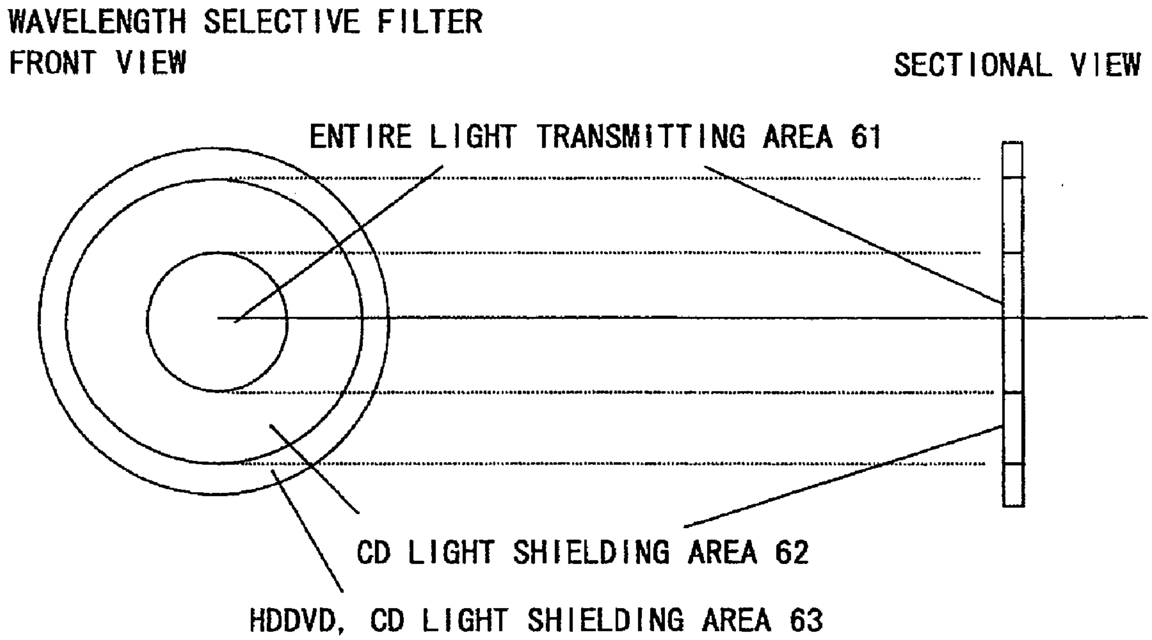

WAVELENGTH SELECTIVE FILTER
FRONT VIEW
SECTIONAL VIEW
ENTIRE LIGHT TRANSMITTING AREA 61
CD LIGHT SHIELDING AREA 62
HDDVD, CD LIGHT SHIELDING AREA 63

Fig. 24

Fig. 25A

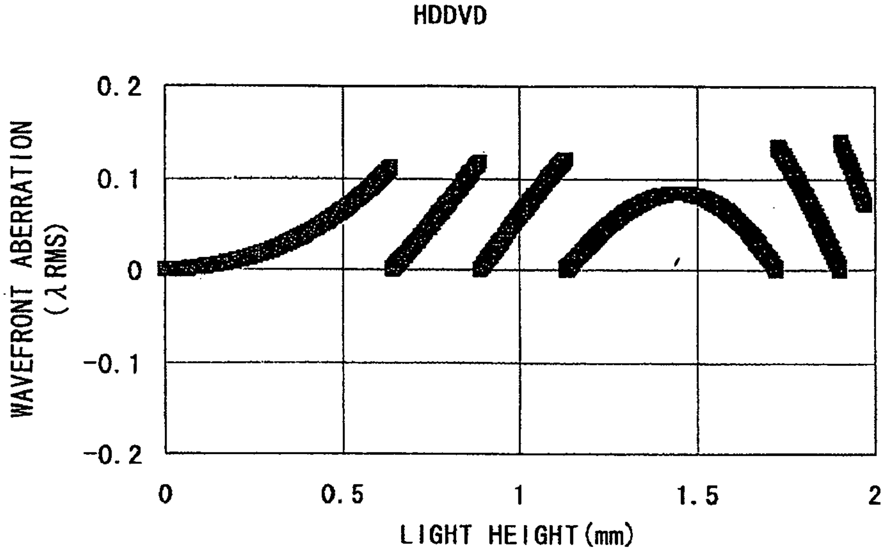


Fig. 25B

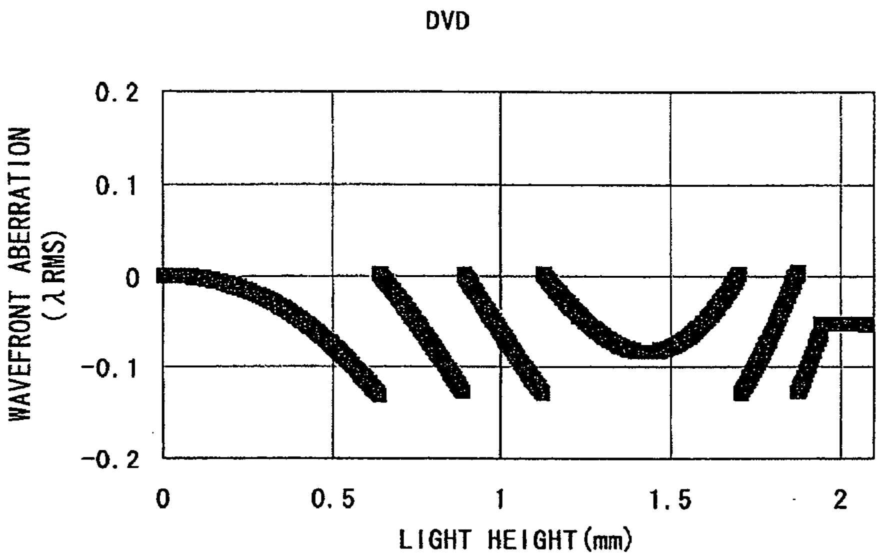
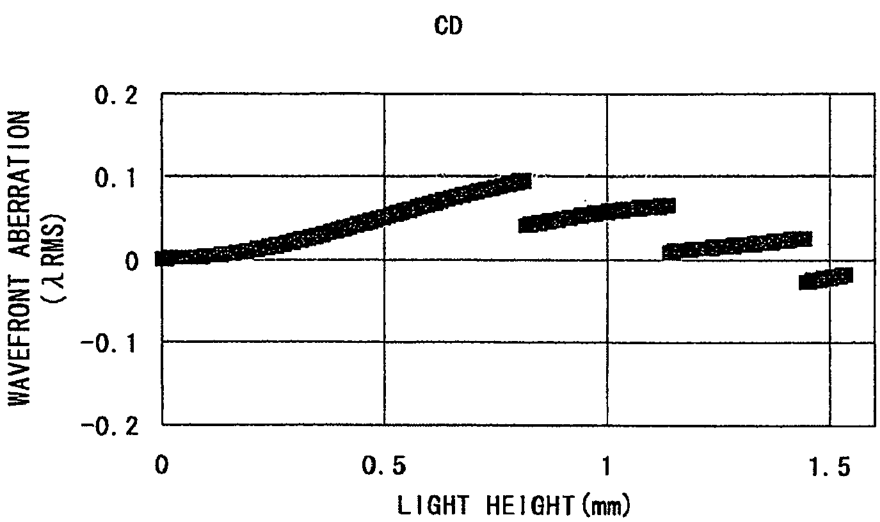


Fig. 25C



	OBJECT DISTANCE (mm)	COMA ABERRATION (λ RMS)
FIRST EMBODIMENT	49.4	0.0469
THIRD EMBODIMENT	113.0	0.0177

Fig. 26

DIFFERENCE IN OPTICAL PATH LENGTH (λ) BETWEEN ZONE 1 AND ZONE 2 TO 7

ZONE j	OPTICAL PATH LENGTH DIFFERENCE FROM ZONE 1		
	WAVELENGTH 408nm、HDDVD	WAVELENGTH 658nm、DVD	WAVELENGTH 785nm、CD
1	REFERENCE	REFERENCE	REFERENCE
2	2	1	1
3	4	2	2
4	6	3	3
5	4	2	–
6	2	1	–
7	0	0	–

Fig. 27

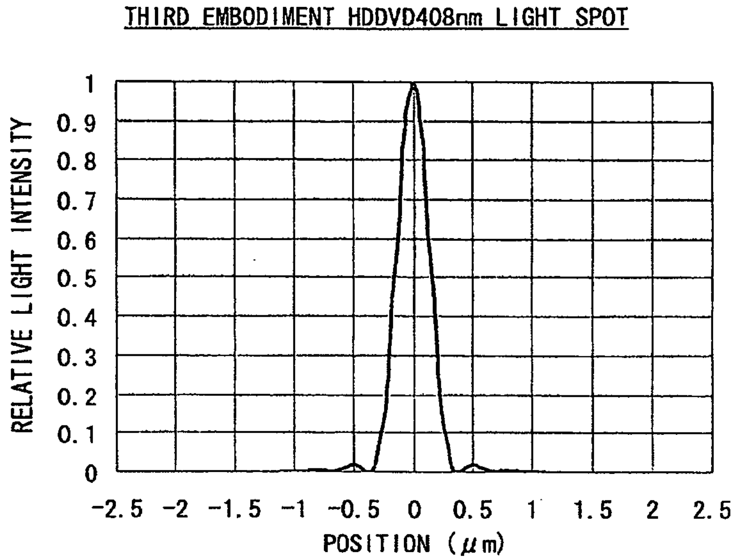


Fig. 28A

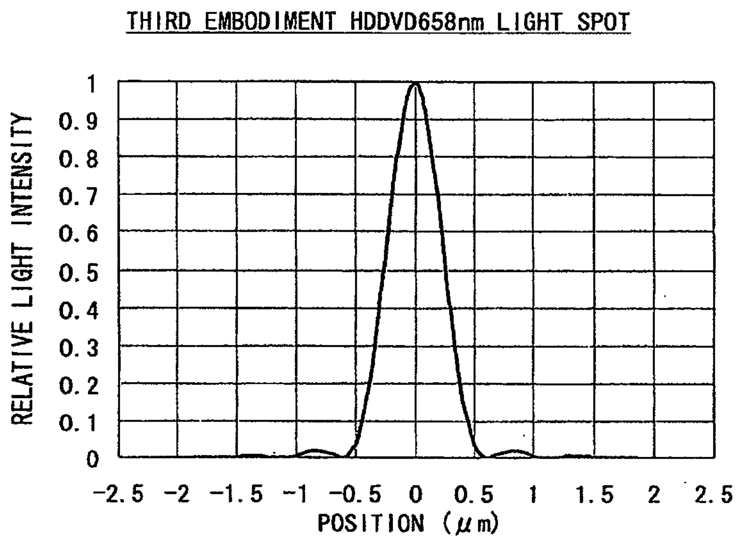


Fig. 28B

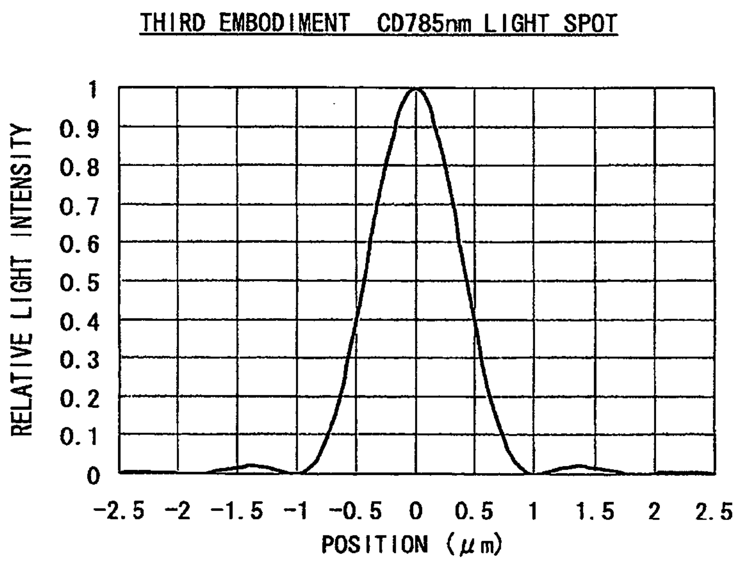


Fig. 28C

SIDE A:ZONE j =1 TO 6

ZONE j								
BLU-RAY/DVD COMMON USE AREA 1	R	1. 483996664	C	0. 673855962	K	-16. 3972459		
	A4	0. 094660411	A6	39. 11539292	A8	-1505. 37515	A10	26018. 3113
	A12	-170114. 543	A14	2. 252424464	A16	0. 287207077		
			B	0				
		RANGE OF h	SMALL	0				
			LARGE	0. 21762238				
BLU-RAY/DVD COMMON USE AREA 2	R	1. 53567174	C	0. 651180831	K	-6. 65802029		
	A4	0. 817293994	A6	-9. 14557483	A8	-17. 2690536	A10	979. 9972387
	A12	2483. 17142	A14	-118851. 816	A16	524155. 6559		
			B	-0. 0015919				
		RANGE OF h	SMALL	0. 21762238				
			LARGE	0. 31022235				
BLU-RAY/DVD COMMON USE AREA 3	R	1. 599112109	C	0. 625347025	K	1. 433878527		
	A4	0. 396330904	A6	-0. 63776774	A8	-18. 796398	A10	-54. 5171068
	A12	636. 3429712	A14	5925. 017186	A16	-32751. 9962		
			B	-0. 00318377				
		RANGE OF h	SMALL	0. 31022235				
			LARGE	0. 3829029				
BLU-RAY/DVD COMMON USE AREA 4	R	1. 434551701	C	0. 697081882	K	-7. 52479429		
	A4	0. 085767596	A6	0. 423482479	A8	2. 603767797	A10	-3. 81841
	A12	-69. 3580366	A14	-133. 809602	A16	1225. 44831		
			B	-0. 00477565				
		RANGE OF h	SMALL	0. 3829029				
			LARGE	0. 44551105				
BLU-RAY/DVD COMMON USE AREA 5	R	1. 23702856	C	0. 808388773	K	-13. 8934328		
	A4	-0. 04197071	A6	0. 627402525	A8	3. 888321541	A10	5. 882855892
	A12	-59. 9644373	A14	-237. 861474	A16	855. 430159		
			B	-0. 00636754				
		RANGE OF h	SMALL	0. 44551105				
			LARGE	0. 50184088				
BLU-RAY/DVD COMMON USE AREA 6	R	1. 166760899	C	0. 857073631	K	-12. 1244823		
	A4	-0. 07888418	A6	0. 308580202	A8	2. 682470381	A10	4. 183538737
	A12	-19. 9011704	A14	-99. 0700446	A16	237. 2207005		
			B	-0. 00795942				
		RANGE OF h	SMALL	0. 50184088				
			LARGE	0. 55384699				

Fig. 29

SIDE A:ZONE j =7 TO 12

ZONE j								
BLU-RAY/DVD COMMON USE AREA 7	R	1. 244427233	C	0. 803582542	K	-8. 08545341		
	A4	-0. 02845717	A6	0. 108380327	A8	1. 076913034	A10	1. 964356292
	A12	-3. 75981137	A14	-31. 8120777	A16	53. 25002802		
			B	-0. 00955131				
		RANGE OF h	SMALL	0. 55384699				
			LARGE	0. 60271631				
BLU-RAY/DVD COMMON USE AREA 8	R	1. 327355868	C	0. 753377466	K	-5. 19465131		
	A4	0. 010760779	A6	0. 039032865	A8	0. 364424321	A10	0. 240003296
	A12	0. 481545028	A14	-6. 16830235	A16	5. 8148765		
			B	-0. 01114319				
		RANGE OF h	SMALL	0. 60271631				
			LARGE	0. 64925904				
BLU-RAY/DVD COMMON USE AREA 9	R	1. 409106927	C	0. 709669352	K	-2. 38637377		
	A4	0. 027844963	A6	-0. 04544383	A8	-0. 01694078	A10	0. 15663804
	A12	0. 5162377	A14	0. 721501213	A16	-2. 66990743		
			B	-0. 01273508				
		RANGE OF h	SMALL	0. 64925904				
			LARGE	0. 69409466				
BLU-RAY/DVD COMMON USE AREA 10	R	1. 338005001	C	0. 747381362	K	-3. 56445559		
	A4	0. 014468192	A6	-0. 0220885	A8	0. 097664239	A10	0. 263425333
	A12	0. 030096219	A14	-0. 66685014	A16	0. 110657132		
			B	-0. 01432696				
		RANGE OF h	SMALL	0. 69409466				
			LARGE	0. 73773231				
BLU-RAY/DVD COMMON USE AREA 11	R	1. 348930249	C	0. 741328175	K	1. 348930249		
	A4	0. 019832778	A6	-0. 03230534	A8	0. 023369232	A10	0. 12517188
	A12	0. 188638209	A14	-0. 1012241	A16	-0. 34477055		
			B	-0. 01591885				
		RANGE OF h	SMALL	0. 73773231				
			LARGE	0. 7806433				
BLU-RAY/DVD COMMON USE AREA 12	R	1. 300111546	C	0. 769164771	K	-2. 6569841		
	A4	0. 012719799	A6	-0. 06037886	A8	-0. 02185226	A10	0. 097939601
	A12	0. 252933148	A14	0. 208391643	A16	-0. 58404278		
			B	-0. 01751073				
		RANGE OF h	SMALL	0. 7806433				
			LARGE	0. 82330839				

Fig. 30

SIDE A:ZONE j =13 TO 18

ZONE j								
BLU-RAY/DVD COMMON USE AREA 13	R	1.419047629	C	0.704697982	K	-2.08105117		
	A4	0.03516193	A6	-0.01799753	A8	-0.00592847	A10	0.022874187
	A12	0.055942122	A14	0.043145862	A16	-0.10882687		
			B	-0.01910261				
		RANGE OF h	SMALL	0.82330839				
			LARGE	0.86626825				
BLU-RAY/DVD COMMON USE AREA 14	R	1.546115933	C	0.646782029	K	-1.50835739		
	A4	0.052135072	A6	0.010960979	A8	0.003664849	A10	-0.01231273
	A12	-0.02675421	A14	-0.01946868	A16	0.041244308		
			B	-0.0206945				
		RANGE OF h	SMALL	0.86626825				
			LARGE	0.91020224				
BLU-RAY/DVD COMMON USE AREA 15	R	1.555431411	C	0.642908452	K	-1.51093094		
	A4	0.052553858	A6	0.010222417	A8	0.003114724	A10	-0.00934616
	A12	-0.01836561	A14	-0.01186149	A16	0.023019799		
			B	-0.02228638				
		RANGE OF h	SMALL	0.91020224				
			LARGE	0.95608451				
BLU-RAY/DVD COMMON USE AREA 16	R	1.548209197	C	0.645907544	K	-1.557899		
	A4	0.050747145	A6	0.007188213	A8	0.001961623	A10	-0.00530843
	A12	-0.00949987	A14	-0.00632247	A16	0.010317907		
			B	-0.0238783				
		RANGE OF h	SMALL	0.95608451				
			LARGE	1.00552917				
BLU-RAY/DVD COMMON USE AREA 17	R	1.544630001	C	0.647404232	K	-1.587942		
	A4	0.049769271	A6	0.005181299	A8	0.001120656	A10	-0.00330778
	A12	-0.00510844	A14	-0.0029516	A16	0.004507299		
			B	-0.02547015				
		RANGE OF h	SMALL	1.00552917				
			LARGE	1.061859				
BLU-RAY/DVD COMMON USE AREA 18	R	1.580184659	C	0.632837431	K	-1.19506424		
	A4	0.052025599	A6	-0.00032127	A8	-0.00515099	A10	-0.00463934
	A12	0.000134763	A14	0.002926451	A16	-0.00064826		
			B	-0.02706204				
		RANGE OF h	SMALL	1.061859				
			LARGE	1.13567132				

Fig. 31

SIDE A:ZONE j=19 TO 24

ZONE j								
BLU-RAY/DVD COMMON USE AREA 19	R	1.555954904	C	0.642692148	K	-1.34639801		
	A4	0.050919564	A6	-0.00350483	A8	-0.00416339	A10	-0.00096262
	A12	0.001201134	A14	0.000745264	A16	-0.00036526		
			B	-0.02865392				
		RANGE OF h	SMALL	1.13567132				
			LARGE	1.33034626				
BLU-RAY/DVD COMMON USE AREA 20	R	1.44416631	C	0.692441025	K	-1.80761473		
	A4	0.042529601	A6	-0.00258023	A8	-0.00093988	A10	0.000261275
	A12	0.000673281	A14	0.000111189	A16	-0.00013072		
			B	-0.02706204				
		RANGE OF h	SMALL	1.33034626				
			LARGE	1.38585801				
BLU-RAY/DVD COMMON USE AREA 21	R	1.49455004	C	0.669097704	K	-1.76648975		
	A4	0.045003624	A6	-0.00045278	A8	-0.000255	A10	2.25736E-05
	A12	0.00024333	A14	-8.7995E-05	A16	5.22662E-06		
			B	-0.02547015				
		RANGE OF h	SMALL	1.38585801				
			LARGE	1.42287845				
BLU-RAY/DVD COMMON USE AREA 22	R	1.566237953	C	0.638472588	K	-1.66992176		
	A4	0.048479042	A6	0.001490439	A8	-2.1408E-05	A10	-0.00028489
	A12	-2.1435E-05	A14	-0.00016441	A16	7.00167E-05		
			B	-0.02387827				
		RANGE OF h	SMALL	1.42287845				
			LARGE	1.45193712				
BLU-RAY/DVD COMMON USE AREA 23	R	1.647620951	C	0.606935715	K	-1.58171714		
	A4	0.052010933	A6	0.003244997	A8	0.000258507	A10	-0.00051211
	A12	-0.00019464	A14	-0.0002237	A16	0.000107794		
			B	-0.02228638				
		RANGE OF h	SMALL	1.45193712				
			LARGE	1.47627483				
BLU-RAY/DVD COMMON USE AREA 24	R	1.575125725	C	0.634869956	K	-1.65403728		
	A4	0.049162687	A6	0.001405863	A8	-0.00010388	A10	-0.00027842
	A12	6.52617E-06	A14	-0.00015409	A16	6.11741E-05		
			B	-0.0206945				
		RANGE OF h	SMALL	1.47627483				
			LARGE	1.49740483				

Fig. 32

SIDE A:ZONE j=25 TO 29

ZONE j								
BLU-RAY/DVD COMMON USE AREA 25	R	1.479508128	C	0.675900308	K	-1.76273653		
	A4	0.04538464	A6	-0.00073096	A8	-0.00041136	A10	-3.5704E-05
	A12	0.000224223	A14	-8.5864E-05	A16	1.51987E-05		
			B	-0.01910261				
		RANGE OF h	SMALL	1.49740483				
			LARGE	1.51618144				
BLU-RAY/DVD COMMON USE AREA 26	R	1.552307326	C	0.644202332	K	-1.69655271		
	A4	0.048007259	A6	0.000678304	A8	-0.00015887	A10	-0.00013321
	A12	0.000117908	A14	-0.00012678	A16	3.42952E-05		
			B	-0.01751073				
		RANGE OF h	SMALL	1.51618144				
			LARGE	1.5331406				
BLU-RAY/DVD COMMON USE AREA 27	R	1.596231378	C	0.626475594	K	-1.65825971		
	A4	0.049354083	A6	0.001377076	A8	-3.2511E-05	A10	-0.0001617
	A12	7.20323E-05	A14	-0.0001368	A16	3.84509E-05		
			B	-0.01591885				
		RANGE OF h	SMALL	1.5331406				
			LARGE	1.54864802				
BLU-RAY/DVD COMMON USE AREA 28	R	1.548556394	C	0.645762727	K	-1.71865614		
	A4	0.047508066	A6	0.000450203	A8	-0.0001415	A10	-5.7179E-05
	A12	0.000165962	A14	-0.00011379	A16	2.16564E-05		
			B	-0.01432696				
		RANGE OF h	SMALL	1.54864802				
			LARGE	1.56296219				
BLU-RAY/DVD COMMON USE AREA 29	R	1.581540106	C	0.632295062	K	-1.68511463		
	A4	0.048533047	A6	0.000963999	A8	-6.4664E-05	A10	-8.9982E-05
	A12	0.000128895	A14	-0.00012105	A16	2.61297E-05		
			B	-0.01273508				
		RANGE OF h	SMALL	1.56296219				
			LARGE	1.57627745				

Fig. 33

SIDE A:ZONE j=30 TO 31

ZONE j								
BLU-RAY EXCLUSIVE USE AREA 30	R	1.443125977	C	0.692940198	K	-2.02113842		
	A4	0.045697032	A6	0.000804706	A8	-0.00021843	A10	-9.9119E-05
	A12	0.000217028	A14	-7.8061E-05	A16	8.11143E-06		
			B	-0.0111852				
		RANGE OF h	SMALL	1.57627745				
			LARGE	1.779083				
BLU-RAY EXCLUSIVE USE AREA 31	R	1.440992543	C	0.693966117	K	-2.0128819		
	A4	0.045497326	A6	0.000855015	A8	-0.0001979	A10	-0.0001015
	A12	0.000215442	A14	-7.7924E-05	A16	8.13734E-06		
			B	-0.00640955				
		RANGE OF h	SMALL	1.779083				
			LARGE	2.016				

Fig. 34

SIDE B

R 2	R	-2.66955809	C	-0.37459383	K	-20.6486848		
	A4	0.068007176	A6	-0.06053298	A8	0.029587666	A10	-0.00861265
	A12	0.001454018	A14	-0.00012305	A16	3.35E-06		
			B	2.642468				
		RANGE OF h	SMALL	0				
			LARGE	1.6473				

Fig. 35

Fig. 36A

FOURTH EMBODIMENT BLU-RAY (BLUE、408nm) OBJECTIVE LENS FOCAL LENGTH 2.3721mm, NA0.850

PLANE		CURVATURE RADIUS (mm)	INTERPLANAR DISTANCE (mm) ON OPTICAL AXIS	MATERIAL BETWEEN PLANES	REFRACTIVE INDEX	EFFECTIVE DIAMETER (mm)
1	OBJECT SURFACE	∞	∞	AIR	1	—
2	APERTURE SURFACE	∞	0	AIR	1	4.032
3	LENS SURFACE; OBJECT SIDE	ASPHERICAL SURFACE	2.642	GLASS OR EQUIVALENT	1.5126	—
4	LENS SURFACE; IMAGE SURFACE SIDE	ASPHERICAL SURFACE	0.8867	AIR	1	—
5	DISK SURFACE; OBJECT SIDE	∞	0.0875	PC	1.6205	—
6	DISK INFORMATION RECORDING SURFACE	∞	—	—	—	—

Fig. 36B

FOURTH EMBODIMENT DVD (655nm) OBJECTIVE LENS FOCAL LENGTH 2.4262mm, NA0.650

PLANE		CURVATURE RADIUS (mm)	INTERPLANAR DISTANCE (mm) ON OPTICAL AXIS	MATERIAL BETWEEN PLANES	REFRACTIVE INDEX	EFFECTIVE DIAMETER (mm)
1	OBJECT SURFACE	∞	∞	AIR	1	—
2	APERTURE SURFACE	∞	0	AIR	1	3.153
3	LENS SURFACE; OBJECT SIDE	ASPHERICAL SURFACE	2.642	GLASS OR EQUIVALENT	1.4987	—
4	LENS SURFACE; IMAGE SURFACE SIDE	ASPHERICAL SURFACE	0.60873	AIR	1	—
5	DISK SURFACE; OBJECT SIDE	∞	0.6	PC	1.5794	—
6	DISK INFORMATION RECORDING SURFACE	∞	—	—	—	—

Fig. 36C

FOURTH EMBODIMENT CD (790nm) OBJECTIVE LENS FOCAL LENGTH 2.4378mm, NA0.510

PLANE		CURVATURE RADIUS (mm)	INTERPLANAR DISTANCE (mm) ON OPTICAL AXIS	MATERIAL BETWEEN PLANES	REFRACTIVE INDEX	EFFECTIVE DIAMETER (mm)
1	OBJECT SURFACE	∞	19.35	AIR	1	—
2	APERTURE SURFACE	∞	0	AIR	1	2.794
3	LENS SURFACE; OBJECT SIDE	ASPHERICAL SURFACE	2.642	GLASS OR EQUIVALENT	1.4958	—
4	LENS SURFACE; IMAGE SURFACE SIDE	ASPHERICAL SURFACE	0.5557	AIR	1	—
5	DISK SURFACE; OBJECT SIDE	∞	1.2	PC	1.5725	—
6	DISK INFORMATION RECORDING SURFACE	∞	—	—	—	—

DIFFERENCE IN OPTICAL PATH LENGTH (λ) BETWEEN ZONE 1 AND ZONE 2 TO 31

ZONE j	OPTICAL PATH LENGTH DIFFERENCE FROM ZONE 1		
	WAVELENGTH 405nm、BLU-RAY	WAVELENGTH 655nm、DVD	WAVELENGTH 790nm、CD
1	REFERENCE	REFERENCE	REFERENCE
2	2	1	1
3	4	2	2
4	6	3	3
5	8	4	4
6	10	5	5
7	12	6	6
8	14	7	7
9	16	8	8
10	18	9	9
11	20	10	10
12	22	11	11
13	24	12	12
14	26	13	13
15	28	14	14
16	30	15	15
17	32	16	16
18	34	17	17
19	36	18	18
20	34	17	17
21	32	16	16
22	30	15	15
23	28	14	—
24	26	13	—
25	24	12	—
26	22	11	—
27	20	10	—
28	18	9	—
29	16	8	—
30	14	—	—
31	8	—	—

Fig. 37

Fig. 38A

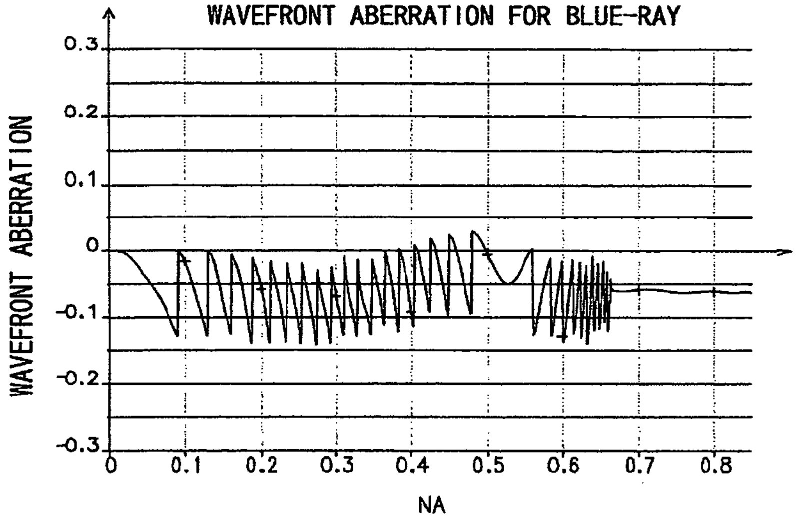


Fig. 38B

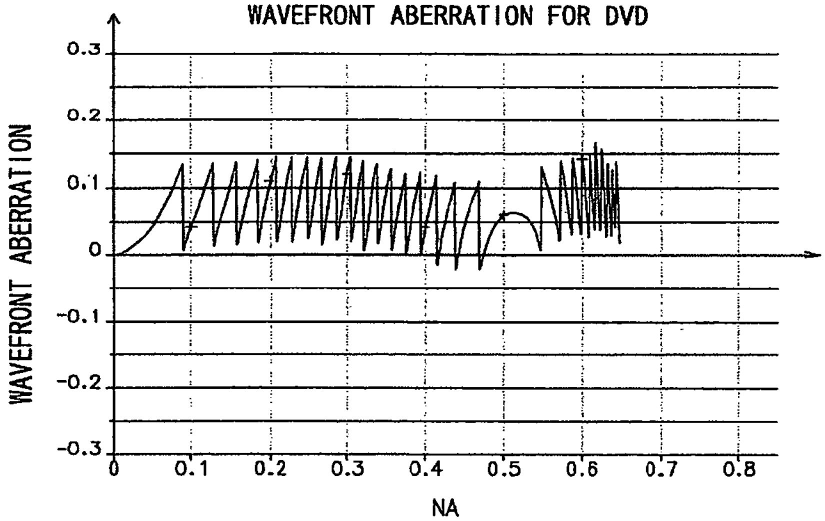
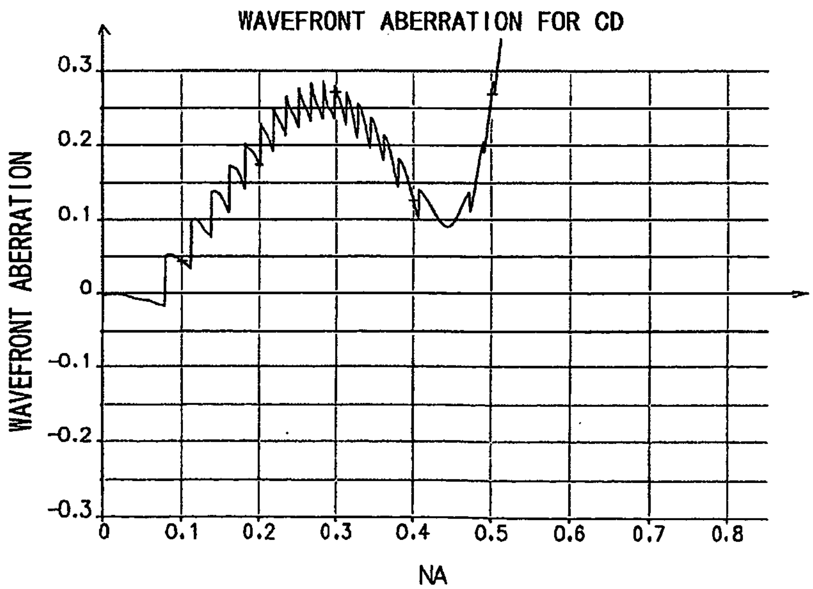


Fig. 38C



	MATERIAL	REFRACTIVE INDEX	THICKNESS (nm)
1	Si02	1.4538	70.2
2	Ta205	2.12	89.76
3	Si02	1.4538	144.23
4	Ta205	2.12	95.08
5	Si02	1.4538	135.86
6	Ta205	2.12	93.14
7	Si02	1.4538	133.93
8	Ta205	2.12	92.16
9	Si02	1.4538	134.42
10	Ta205	2.12	91.38
11	Si02	1.4538	136.65
12	Ta205	2.12	91.19
13	Si02	1.4538	140.11
14	Ta205	2.12	91.52
15	Si02	1.4538	152.03
16	Ta205	2.12	104.38
SUBSTRATE	BK 7	1.51164	

Fig. 39

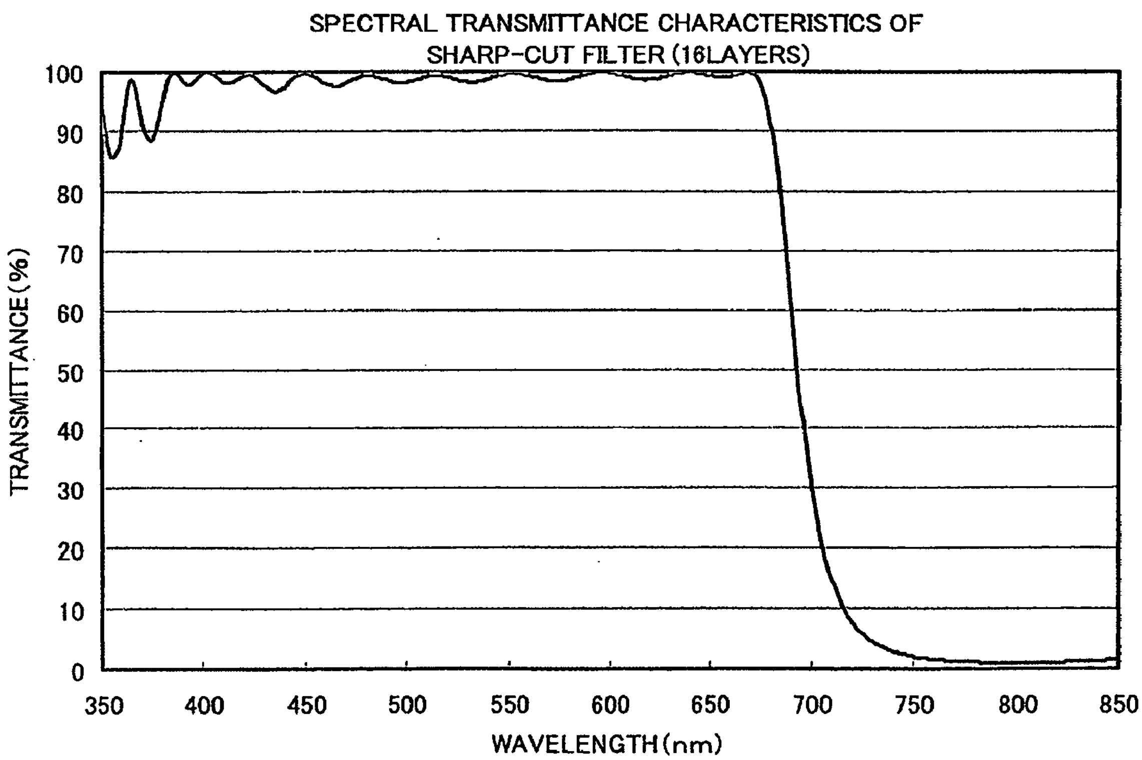


Fig. 40

	MATERIAL	REFRACTIVE INDEX	THICKNESS (nm)
1	SiO2	1.45325	239.03
2	Ta2O5	2.11727	107.85
3	SiO2	1.45325	141.84
4	Ta2O5	2.11727	92.21
5	SiO2	1.45325	141.92
6	Ta2O5	2.11727	89.34
7	SiO2	1.45325	144.57
8	Ta2O5	2.11727	90.17
9	SiO2	1.45325	150.14
10	Ta2O5	2.11727	106.81
SUBSTRATE	BK 7	1.51111	

Fig. 41

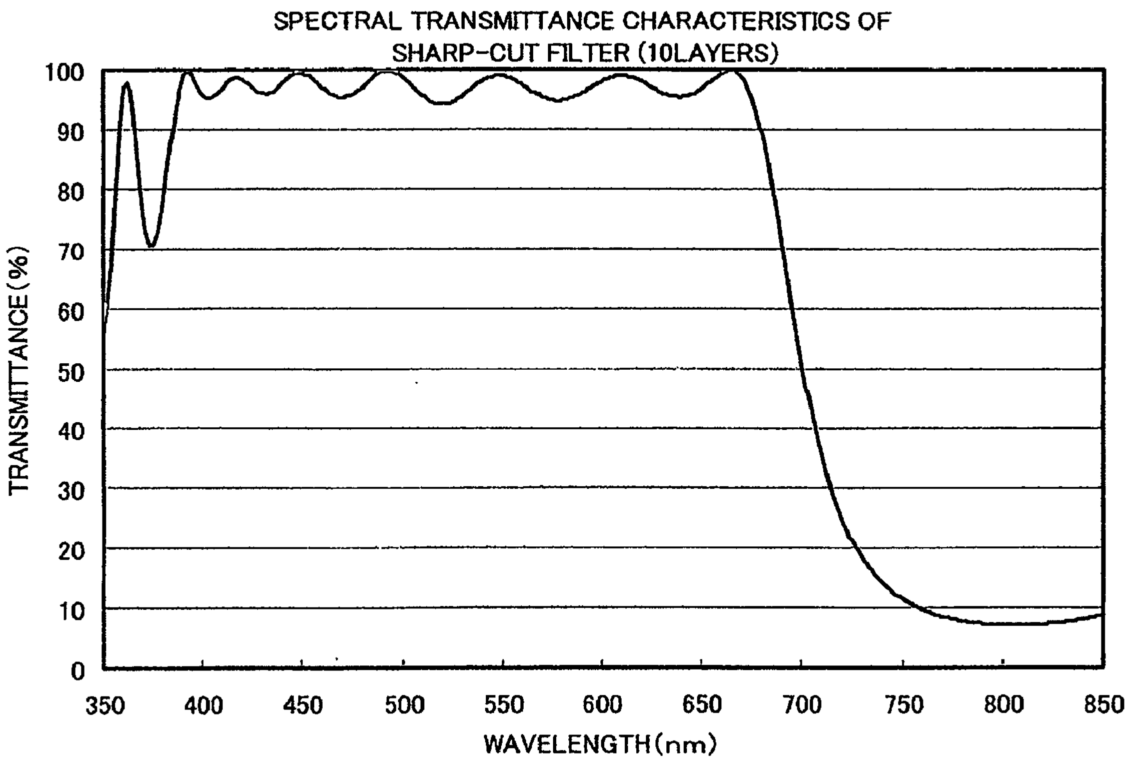


Fig. 42

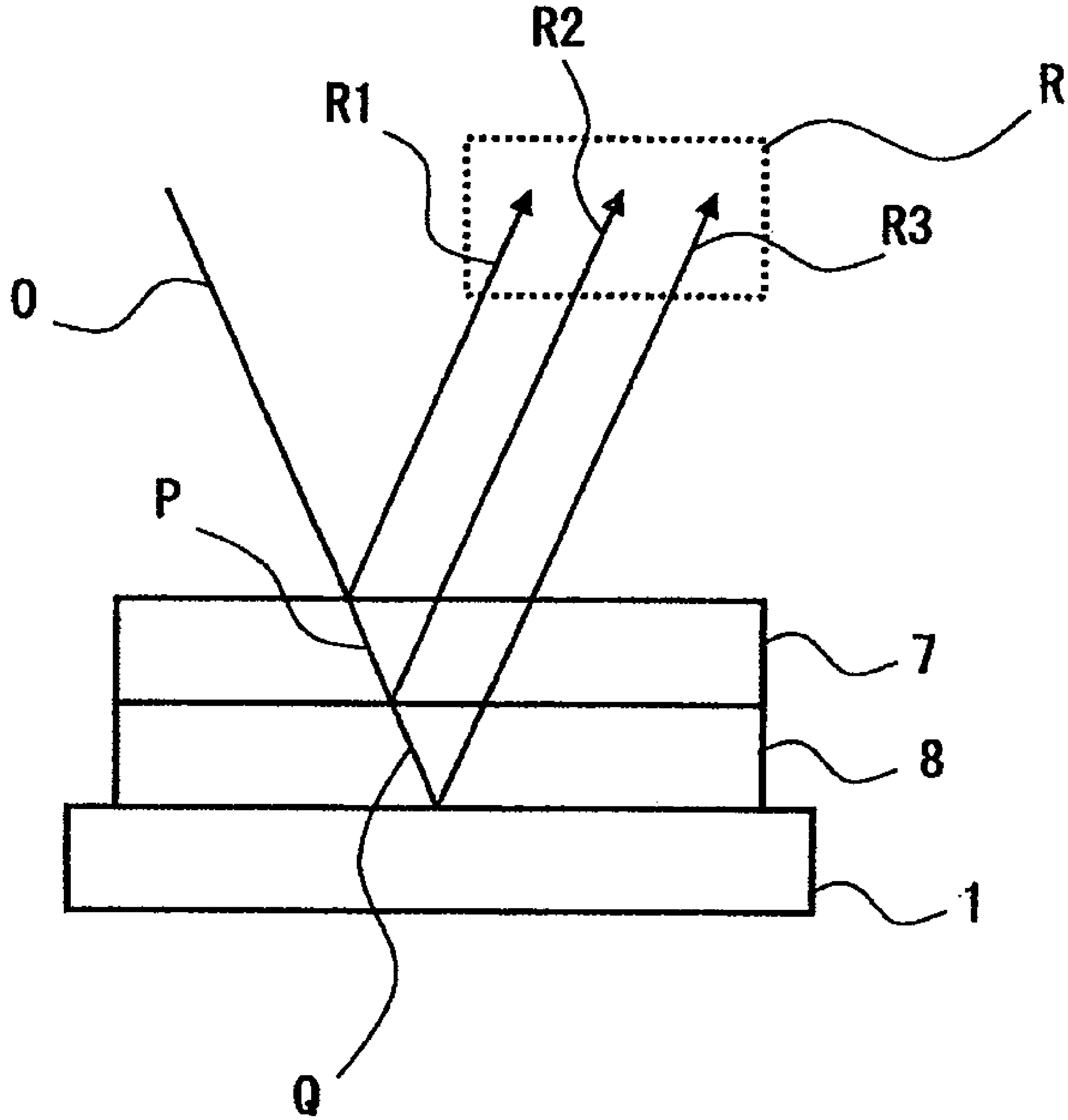


Fig. 43

nL=1.462 (SiO_2) nS=1.54 (APPEL REFLECTANCE : 4.5)

	SINGLE LAYER	1.55	1.65	1.75	1.85	1.95	2.05	2.15	2.25	2.35
405±5	3.08	2.85	1.50	0.77	0.61	0.85	1.18	1.58	2.12	2.79
655±20	2.84	2.75	1.73	1.00	0.63	0.44	0.34	0.57	1.20	2.03
790±20	3.06	2.93	1.88	1.33	1.15	1.45	2.30	3.56	5.14	6.98

Fig. 44A

nL=1.462 (SiO_2) nS=1.70 (REFLECTANCE : 6.7)

	SINGLE LAYER			1.75	1.85	1.95	2.05	2.15	2.25	2.35
405±5	2.28			1.65	1.05	0.89	1.06	1.37	1.78	2.30
655±20	2.14			1.72	0.94	0.48	0.28	0.30	0.72	1.36
790±20	2.79			2.49	2.02	1.94	2.29	3.11	4.26	5.69

Fig. 44B

nL=1.462 (SiO_2) nS=1.85 (REFLECTANCE : 8.9)

	SINGLE LAYER					1.95	2.05	2.15	2.25	2.35	2.45
405±5	1.98					1.37	1.23	1.36	1.68	2.11	2.64
655±20	1.92					1.31	0.91	0.75	0.81	1.17	1.78
790±20	2.96					2.70	2.76	3.19	4.00	5.11	6.46

Fig. 44C

nS=1.54 nL=1.385

	SINGLE LAYER	1.55	1.65	1.75	1.85	1.95	2.05	2.15	2.25	2.35	2.45
405±5	1.78	1.57	0.79	0.59	0.79	1.13	1.60	2.24	3.04	3.96	4.97
655±20	1.65	1.61	0.75	0.33	0.11	0.31	0.87	1.66	2.65	3.84	5.19
790±20	2.06	2.01	1.38	1.22	1.60	2.55	3.89	5.56	7.49	9.62	11.89

Fig. 44D

nS=1.70 nL=1.385

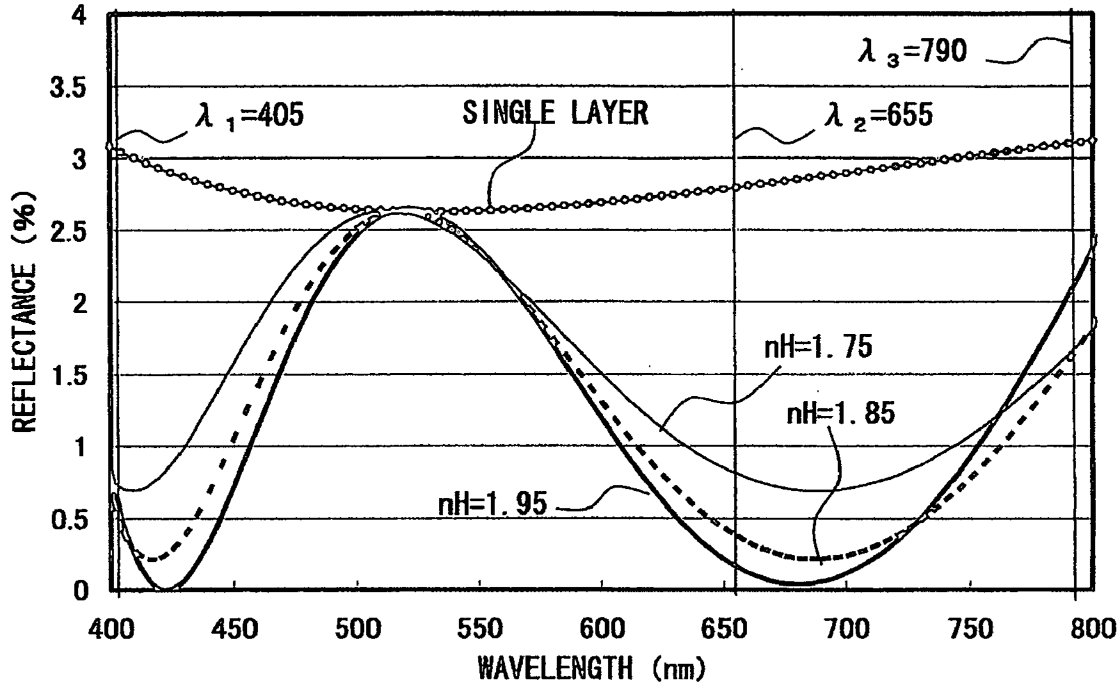
	SINGLE LAYER			1.75	1.85	1.95	2.05	2.15	2.25	2.35	2.45
405±5	1.42			1.09	0.91	1.06	1.41	1.98	2.52	3.28	4.14
655±20	1.40			1.11	0.68	0.55	0.73	1.16	2.00	2.95	4.06
790±20	2.18			2.05	2.03	2.47	3.37	4.57	6.13	7.90	9.86

Fig. 44E

nS=1.85 nL=1.385

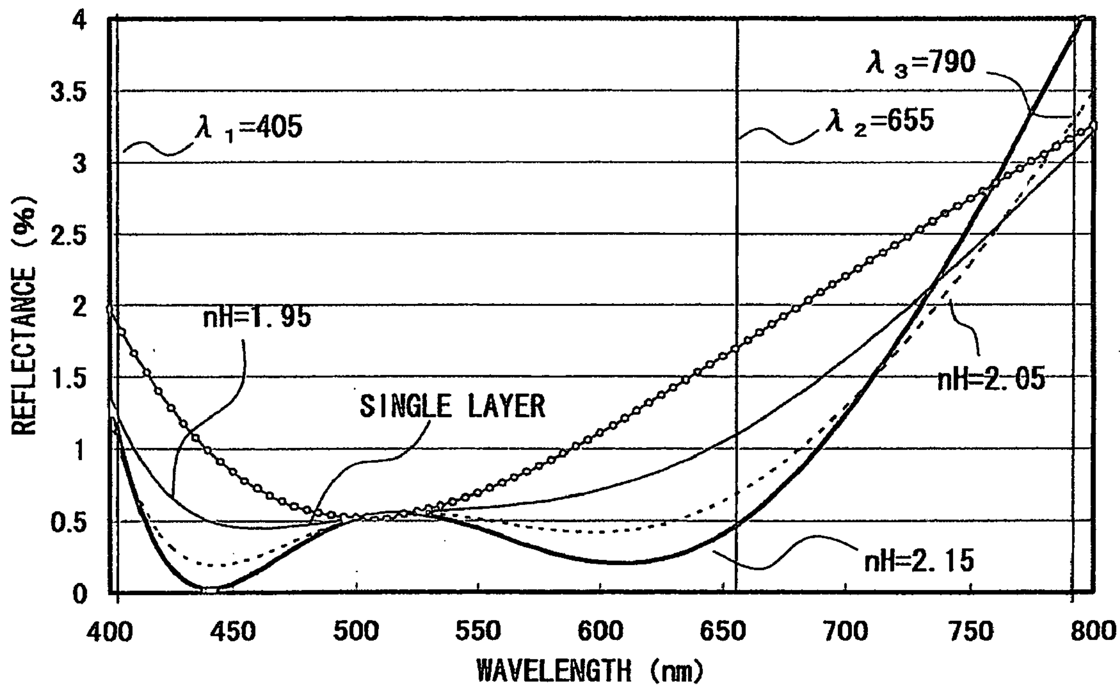
	SINGLE LAYER					1.95	2.05	2.15	2.25	2.35	2.45
405±5	1.50					1.33	1.48	1.85	2.35	2.98	3.71
655±20	1.57					1.25	1.19	1.39	1.87	2.59	3.50
790±20	2.67					2.81	3.33	4.23	5.44	6.89	8.56

Fig. 44F



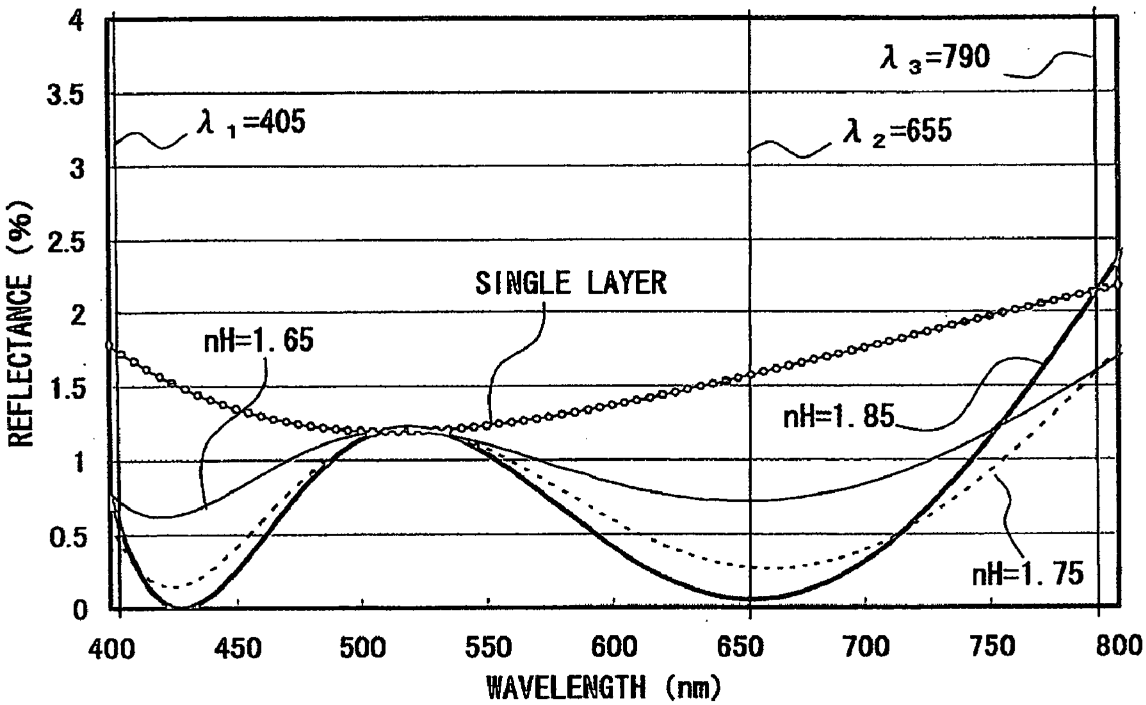
λ 3=790
λ 1=405
SINGLE LAYER
λ 2=655
nH=1.75
nH=1.85
nH=1.95
REFLECTANCE (%)
WAVELENGTH (nm)
0
0.5
1
1.5
2
2.5
3
3.5
4
400
450
500
550
600
650
700
750
800

Fig. 45



λ 3=790
λ 1=405
λ 2=655
nH=1.95
SINGLE LAYER
nH=2.05
nH=2.15
REFLECTANCE (%)
WAVELENGTH (nm)
0
0.5
1
1.5
2
2.5
3
3.5
4
400
450
500
550
600
650
700
750
800

Fig. 46



λ 3=790
λ 1=405
λ 2=655
SINGLE LAYER
nH=1.65
nH=1.85
nH=1.75
REFLECTANCE (%)
4
3.5
3
2.5
2
1.5
1
0.5
0
400
450
500
550
600
650
700
750
800
WAVELENGTH (nm)

Fig. 47

Fig. 48A

	REFRACTIVE INDEX	OPTICAL FILM THICKNESS	PHYSICAL FILM THICKNESS
SiO_2	1.46	0.25 λ	85.5nm
$Al_2O_3+ZrO_2$	1.85	0.50 λ	135.1nm
SUBSTRATE	1.53		

Fig. 48B

	REFRACTIVE INDEX	OPTICAL FILM THICKNESS	PHYSICAL FILM THICKNESS
SiO_2	1.46	0.25 λ	85.5nm
Y_2O_3	1.80	0.50 λ	139.0nm
SUBSTRATE	1.53		

Fig. 48C

	REFRACTIVE INDEX	OPTICAL FILM THICKNESS	PHYSICAL FILM THICKNESS
SiO_2	1.46	0.25 λ	85.5nm
SiN	2.04	0.50 λ	122.5nm
SUBSTRATE	1.53		

Fig. 49A

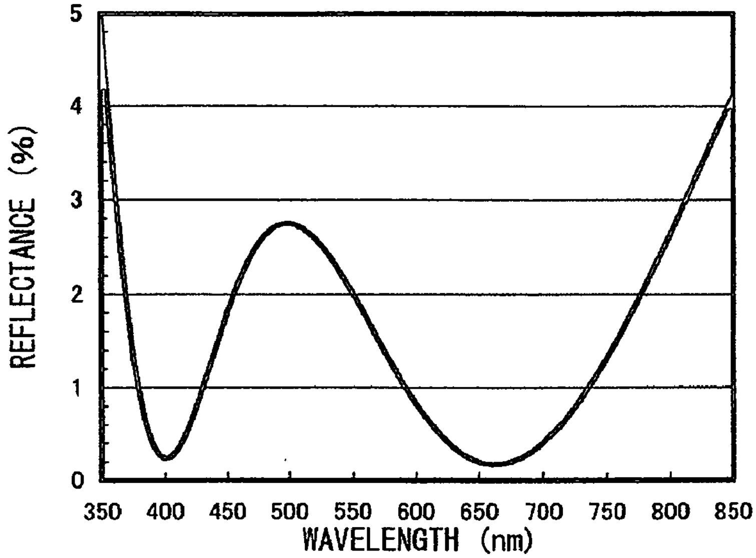


Fig. 49B

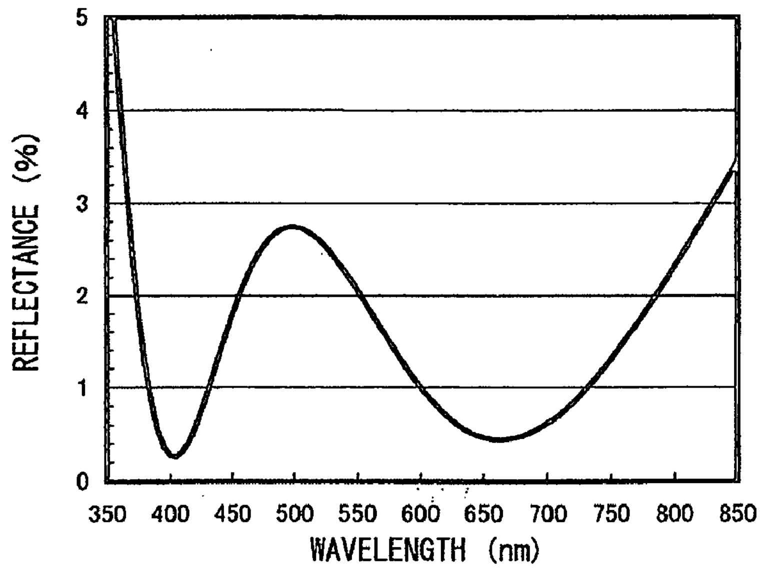
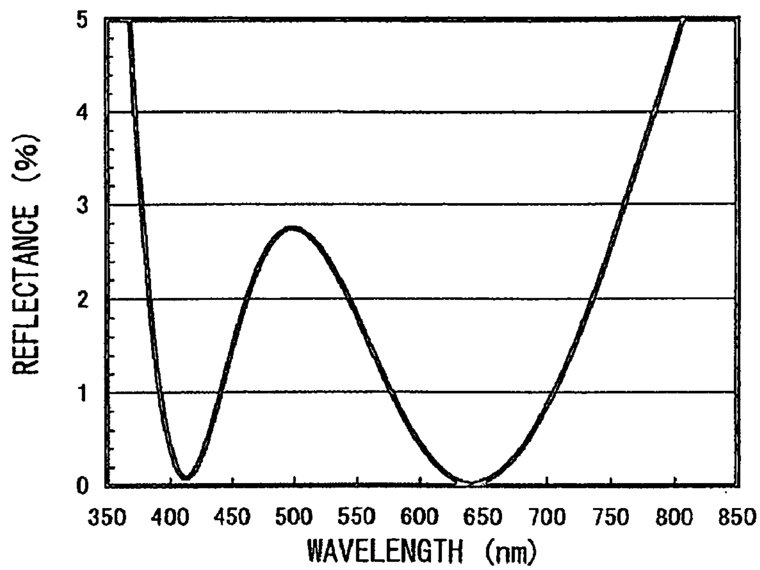
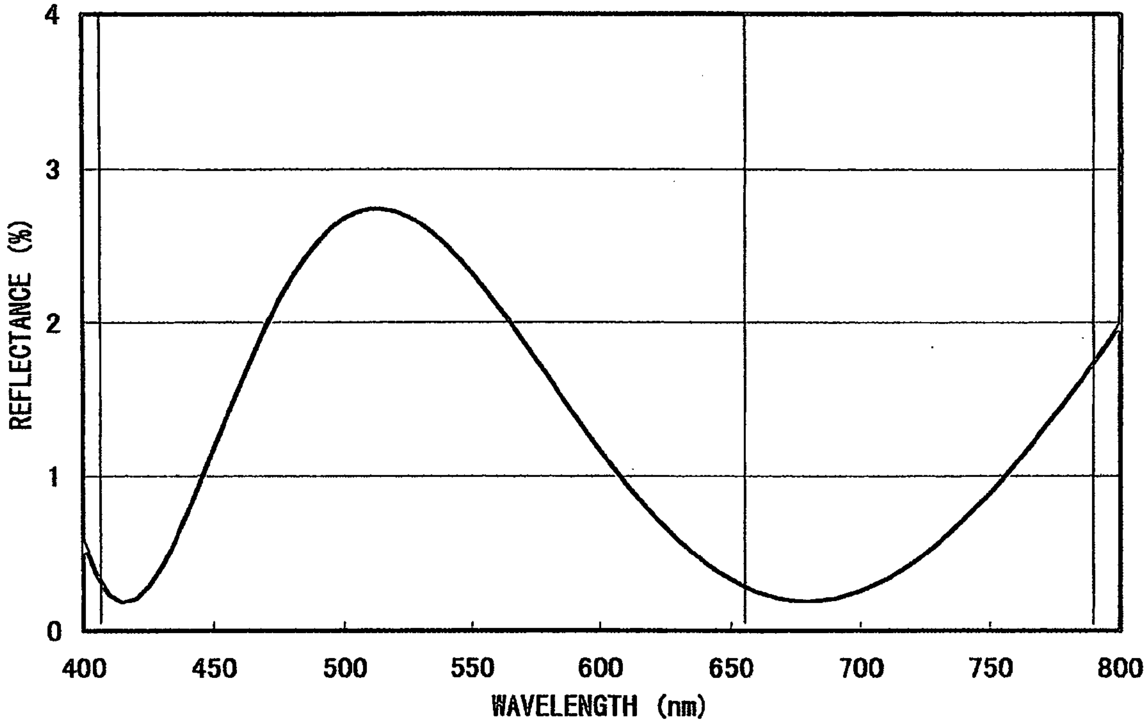


Fig. 49C



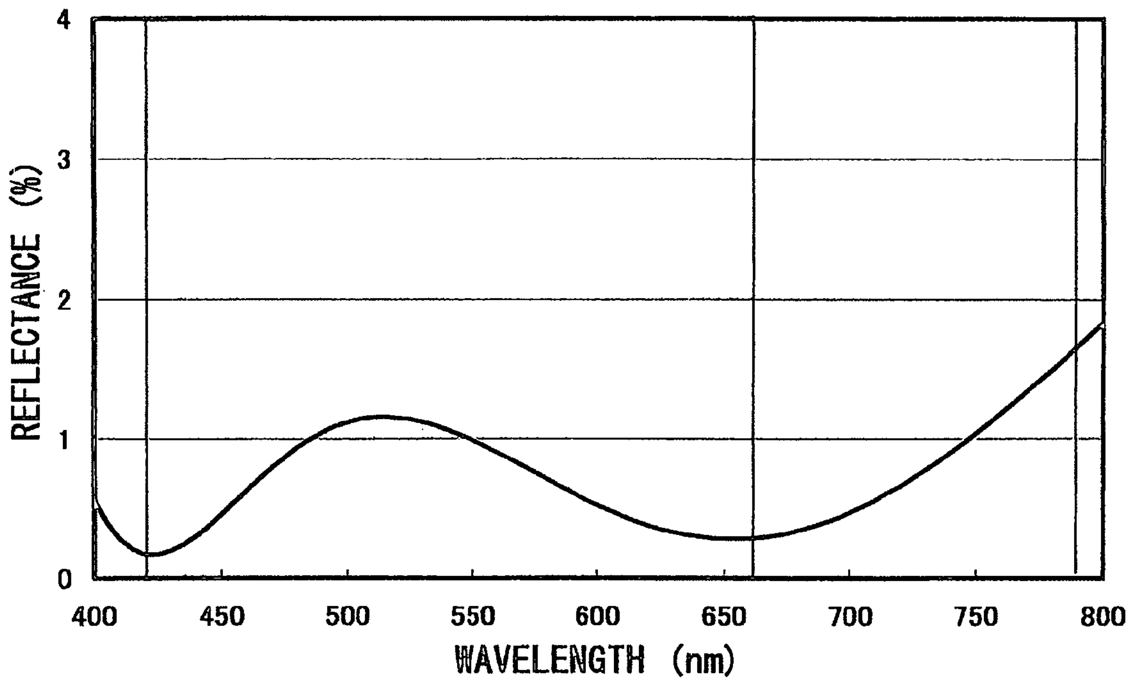
EXAMPLE 4



	MATERIAL	REFLACTIVE INDEX	OPTICAL FILM THICKNESS
LOW REFLACTIVE INDEX LAYER	SiO_2	1.46	129.3
HIGH REFLACTIVE INDEX LAYER	$Al_2O_3+ZrO_2$	1.83	256.3
OBJECTIVE LENS	ZEONEX	1.525	

Fig. 50

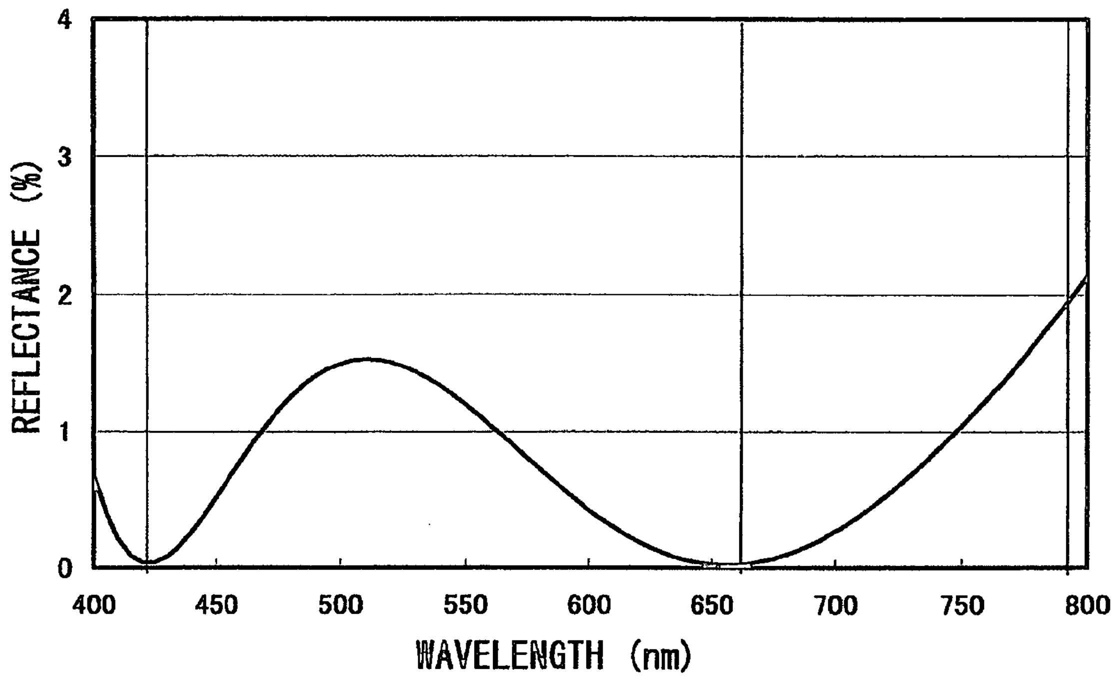
EXAMPLE 5



	MATERIAL	REFLACTIVE INDEX	OPTICAL FILM THICKNESS
LOW REFLACTIVE INDEX LAYER	MgF2	1.38	126.3
HIGH REFLACTIVE INDEX LAYER	MgO	1.74	260.1
OBJECTIVE LENS	APEL	1.54	

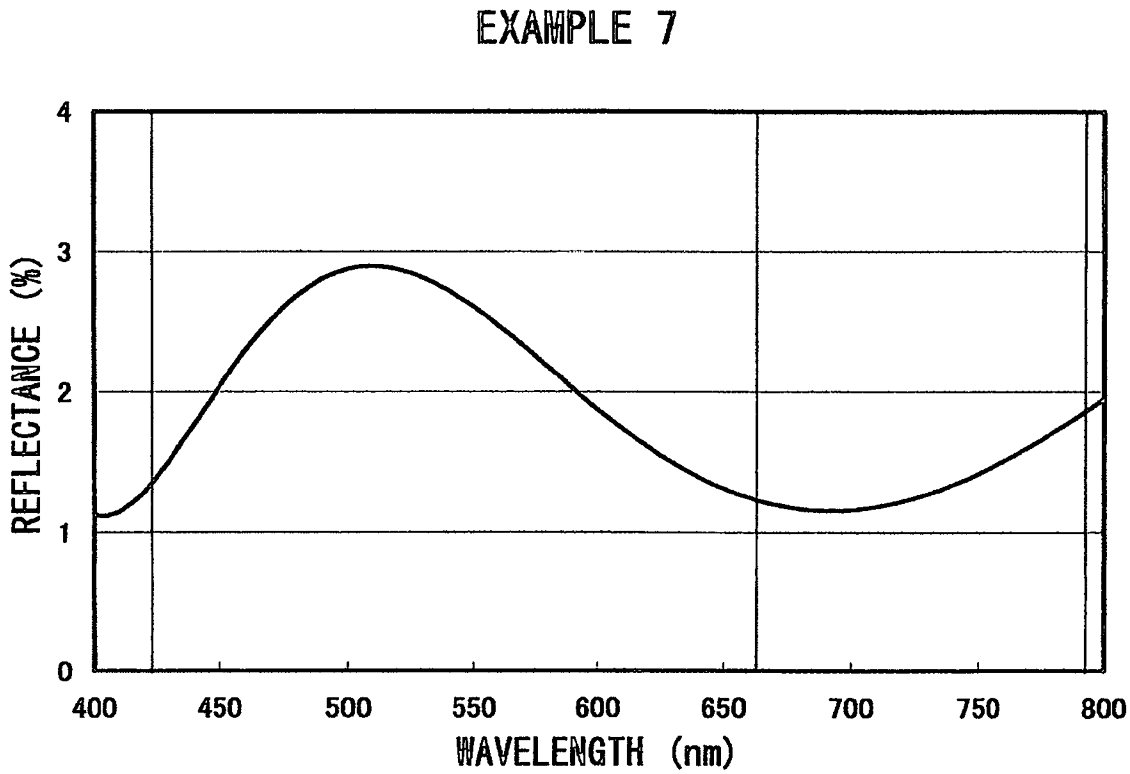
Fig. 51

EXAMPLE 6



	MATERIAL	REFLACTIVE INDEX	OPTICAL FILM THICKNESS
LOW REFLACTIVE INDEX LAYER	MgF2	1.38	129.8
HIGH REFLACTIVE INDEX LAYER	Y_2O_3	1.78	253.8
OBJECTIVE LENS	PMMA	1.49	

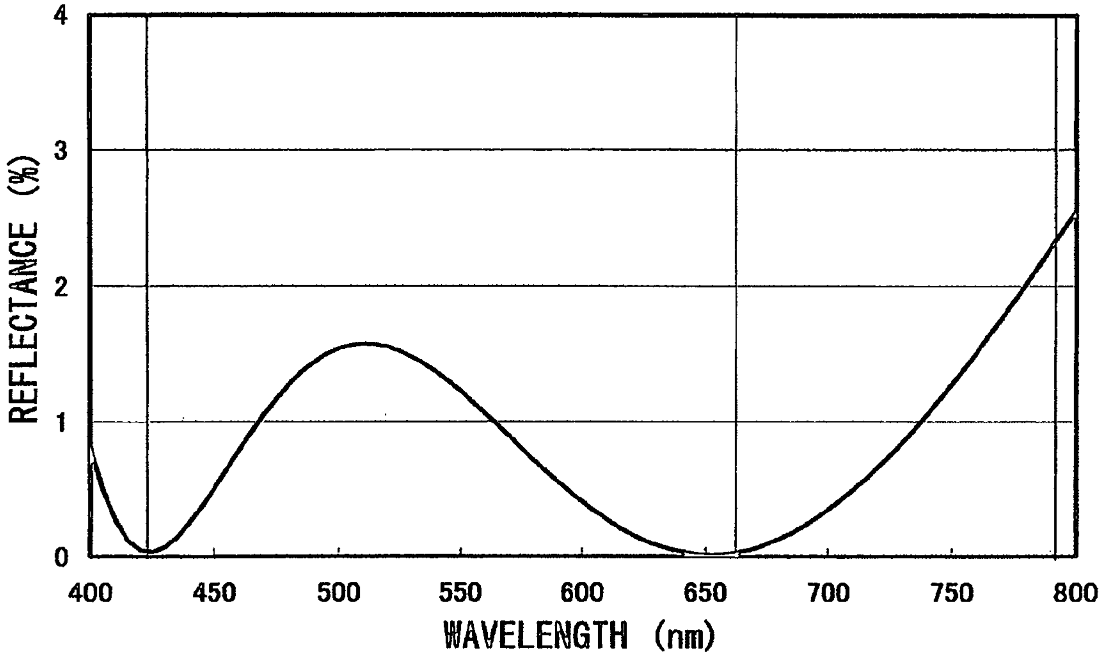
Fig. 52



	MATERIAL	REFLACTIVE INDEX	OPTICAL FILM THICKNESS
LOW REFLACTIVE INDEX LAYER	SiO_2	1.46	123.9
HIGH REFLACTIVE INDEX LAYER	Y_2O_3	1.78	258.1
OBJECTIVE LENS	ARTON	1.51	

Fig. 53

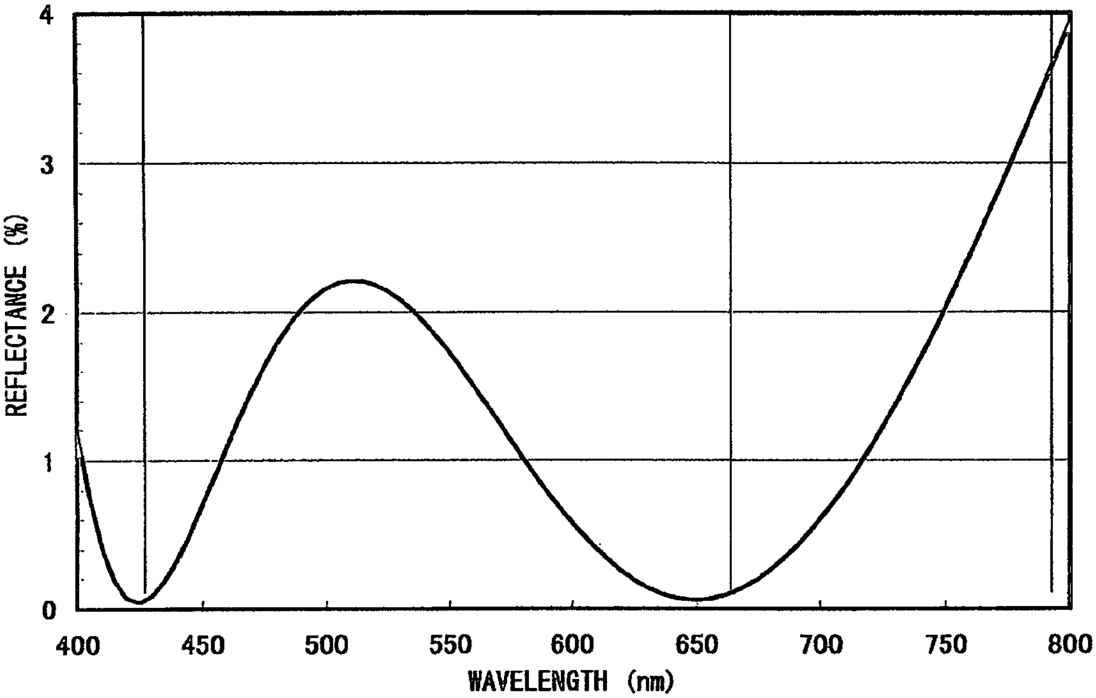
EXAMPLE 8



	MATERIAL	REFLACTIVE INDEX	OPTICAL FILM THICKNESS
LOW REFLACTIVE INDEX LAYER	MgF_2	1.38	132.6
HIGH REFLACTIVE INDEX LAYER	$Al_2O_3+ZrO_2$	1.83	250.3
OBJECTIVE LENS	PMMA	1.49	

Fig. 54

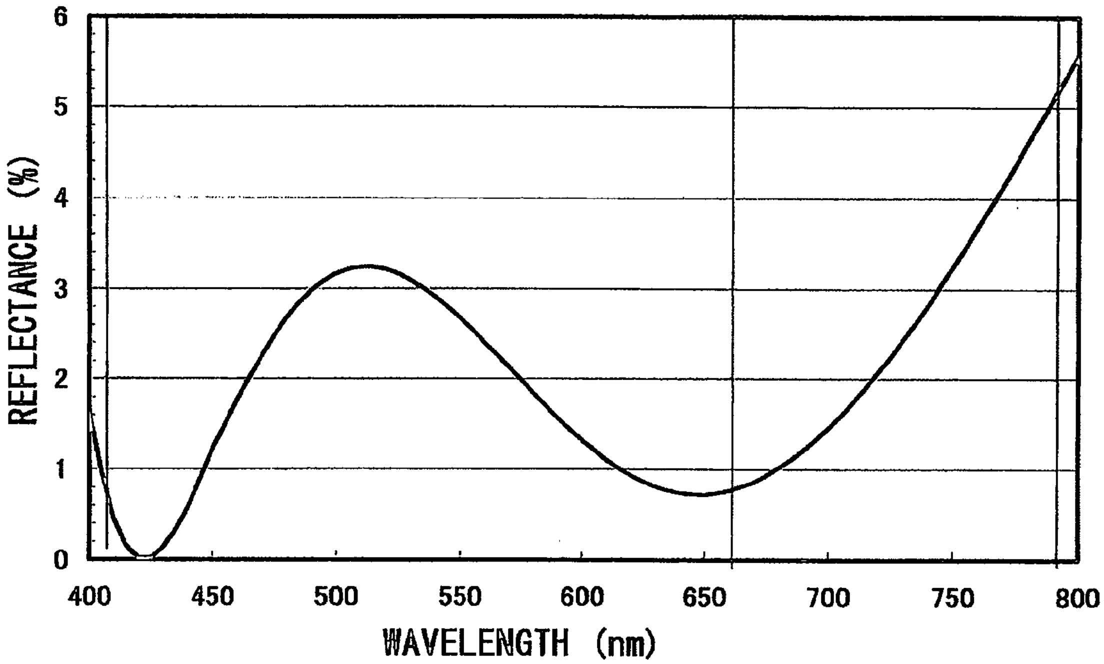
COMPARATIVE EXAMPLE 1



	MATERIAL	REFLACTIVE INDEX	OPTICAL FILM THICKNESS
LOW REFLACTIVE INDEX LAYER	SiO_2	1.46	132.8
HIGH REFLACTIVE INDEX LAYER	ZrO_2	2.05	248.8
OBJECTIVE LENS	PC	1.58	

Fig. 55

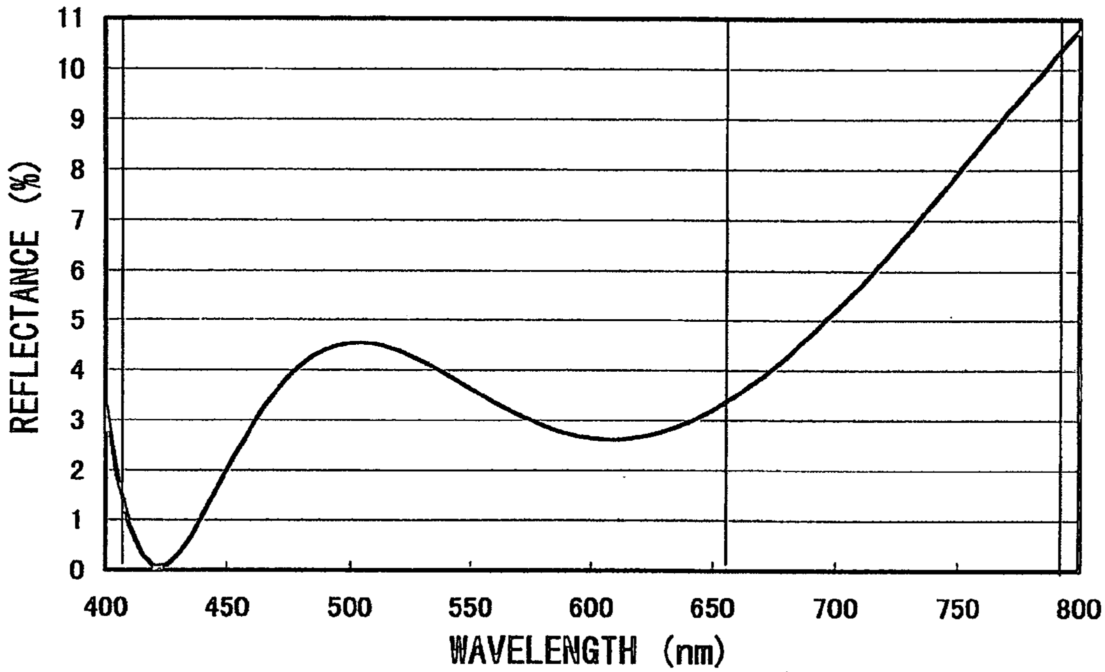
COMPARATIVE EXAMPLE 2



	MATERIAL	REFLACTIVE INDEX	OPTICAL FILM THICKNESS
LOW REFLACTIVE INDEX LAYER	SiO_2	1.46	137.0
HIGH REFLACTIVE INDEX LAYER	Ta_2O_5	2.14	242.0
OBJECTIVE LENS	ZEONEX	1.525	

Fig. 56

COMPARATIVE EXAMPLE 3



	MATERIAL	REFLACTIVE INDEX	OPTICAL FILM THICKNESS
LOW REFLACTIVE INDEX LAYER	SiO_2	1.46	136.0
HIGH REFLACTIVE INDEX LAYER	TiO_2	2.3	226.0
OBJECTIVE LENS	BK_7	1.52	

Fig. 57

	nS	nH	nL	λ1	λ2	λ3
EXAMPLE 4	1.525	1.83	1.46	0.40	0.32	1.75
EXAMPLE 5	1.54	1.74	1.38	0.42	0.30	1.67
EXAMPLE 6	1.49	1.78	1.38	0.43	0.04	1.91
EXAMPLE 7	1.51	1.67	1.46	1.13	1.29	1.84
EXAMPLE 8	1.58	1.92	1.38	0.53	0.04	2.28
COMPARATIVE EXAMPLE 1	1.58	2.05	1.46	0.78	0.10	3.55
COMPARATIVE EXAMPLE 2	1.525	2.14	1.46	1.04	0.78	5.10
COMPARATIVE EXAMPLE 3	1.52	2.3	1.46	2.04	3.41	10.24

Fig. 58A

	A	nH/A	nH-nS	AVERAGE	STANDARD DEVIATION	DETERMINATION VALUE
EXAMPLE 4	1.82	1.01	0.31	0.82	0.81	1.16
EXAMPLE 5	1.73	1.00	0.20	0.79	0.76	1.04
EXAMPLE 6	1.70	1.05	0.29	0.79	0.98	1.32
EXAMPLE 7	1.81	0.92	0.16	1.42	0.37	2.11
EXAMPLE 8	1.76	1.09	0.34	0.95	1.18	1.89
COMPARATIVE EXAMPLE 1	1.85	1.11	0.47	1.48	1.82	4.53
COMPARATIVE EXAMPLE 2	1.82	1.18	0.62	2.31	2.42	9.47
COMPARATIVE EXAMPLE 3	1.81	1.27	0.78	5.23	4.39	40.85

Fig. 58B

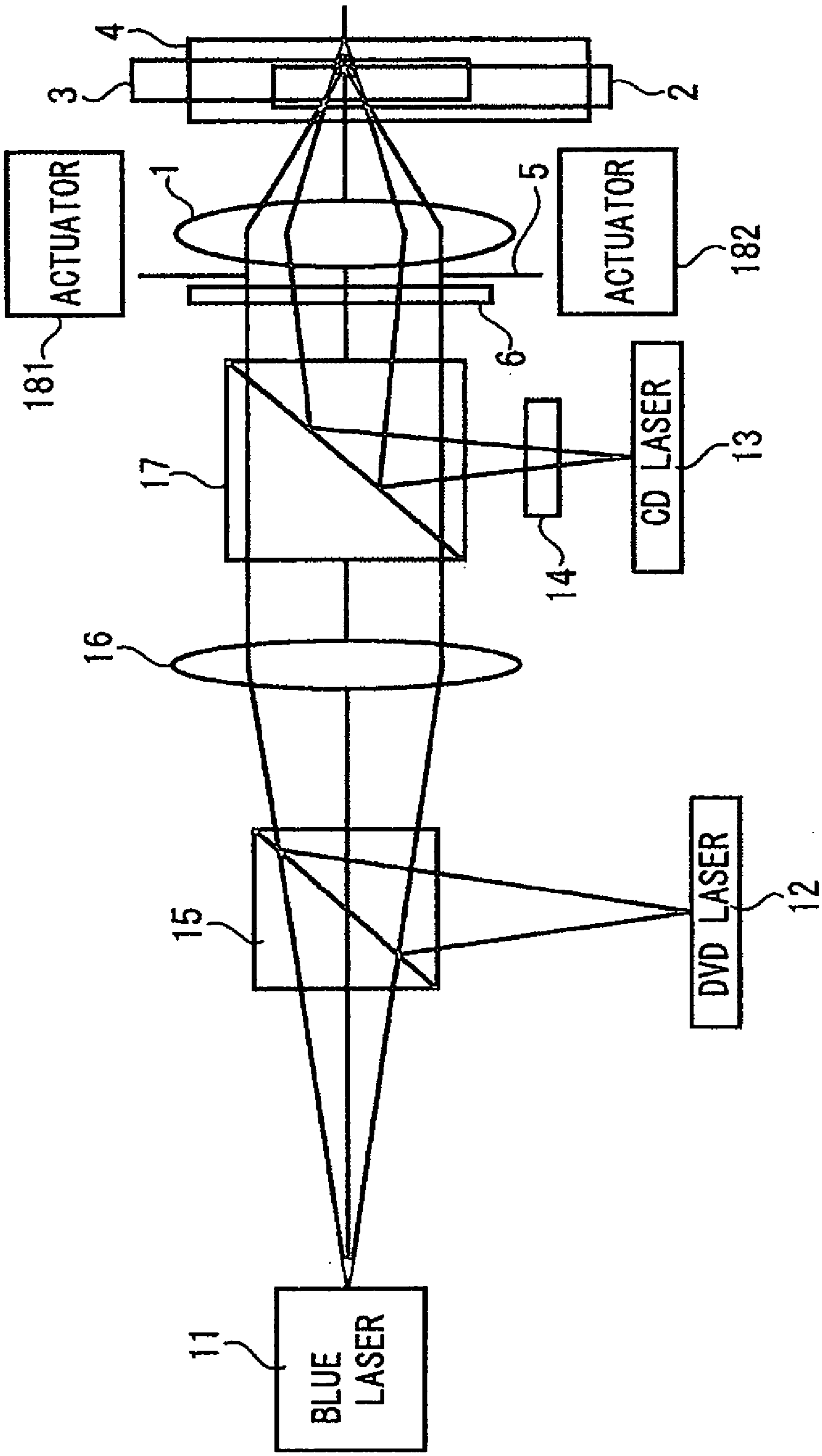

4
3
2
1
5
ACTUATOR
181
ACTUATOR
182
6
17
CD LASER
13
14
16
15
DVD LASER
12
11
BLUE LASER

Fig. 59

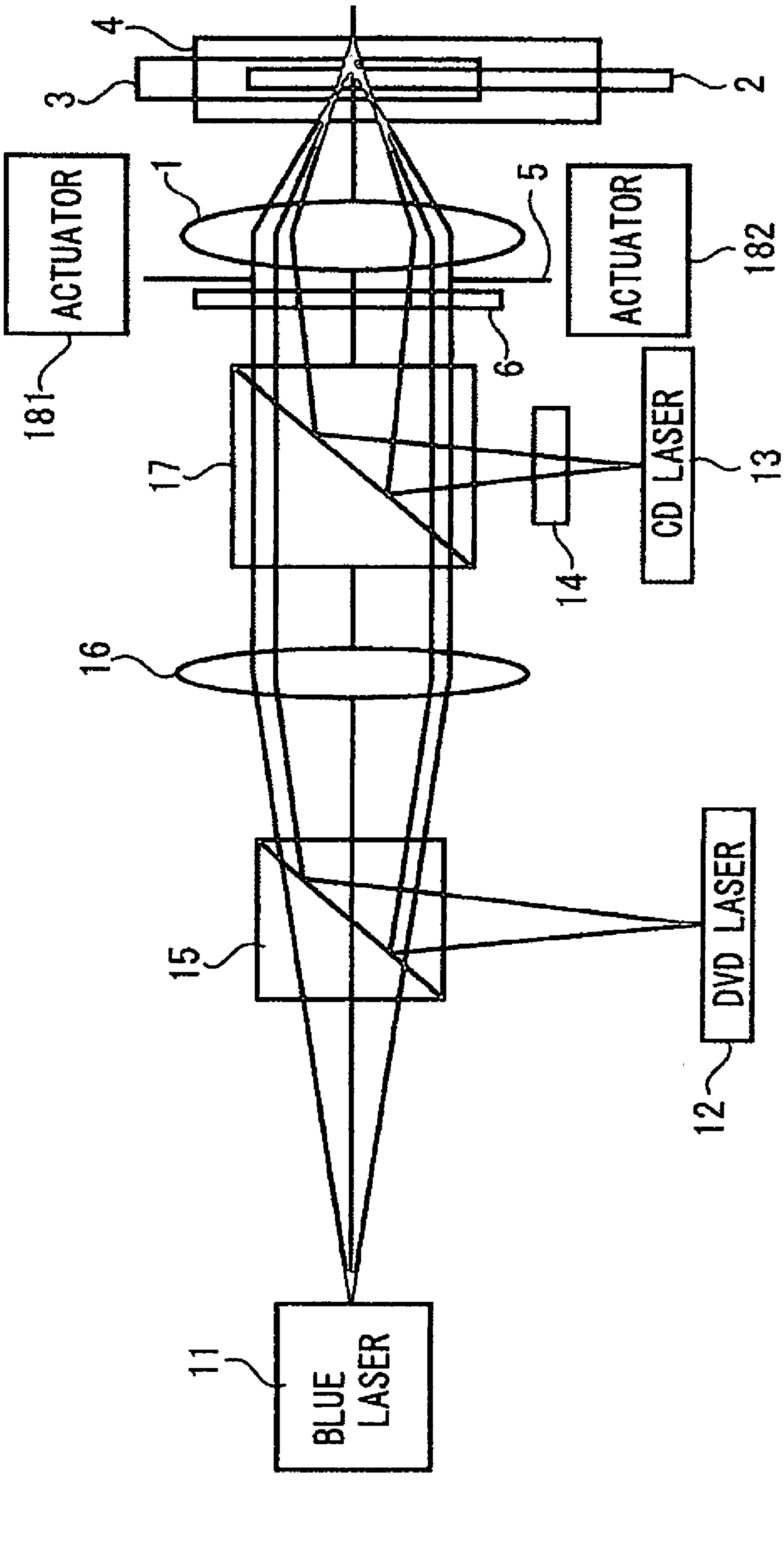

4
3
2
1
5
ACTUATOR
181
ACTUATOR
182
6
17
CD LASER
13
14
16
15
DVD LASER
12
11
BLUE
LASER

Fig. 60

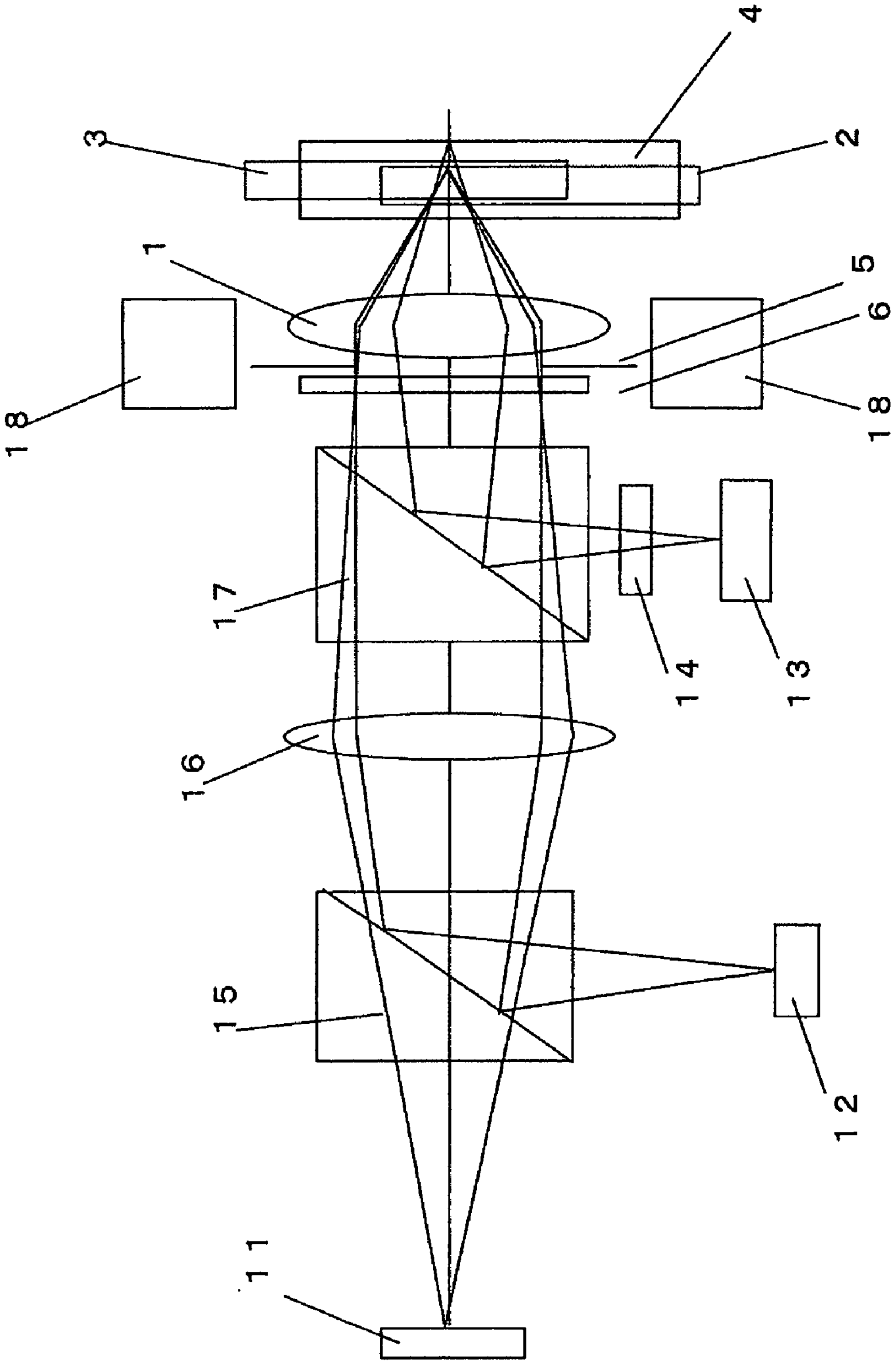


Fig. 61

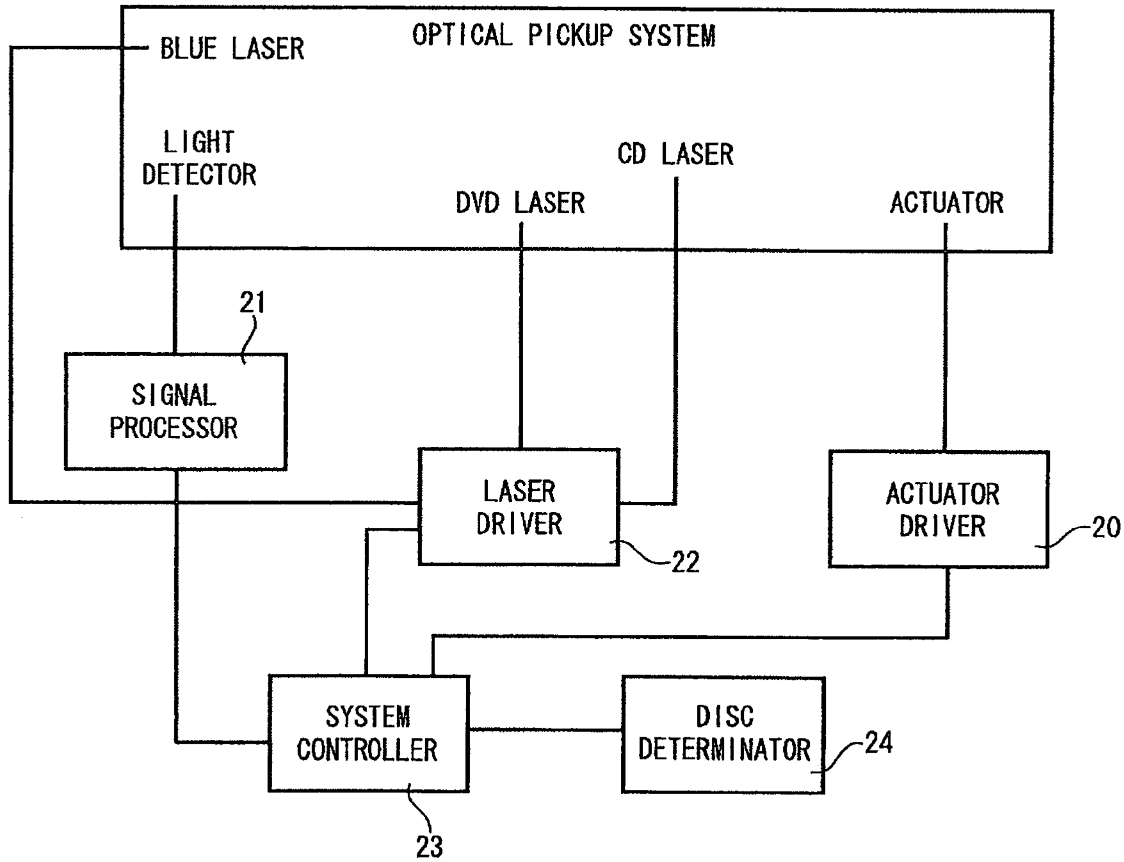

OPTICAL PICKUP SYSTEM
BLUE LASER
LIGHT DETECTOR
CD LASER
DVD LASER
ACTUATOR
21
SIGNAL PROCESSOR
LASER DRIVER
22
ACTUATOR DRIVER
20
SYSTEM CONTROLLER
23
DISC DETERMINATOR
24

Fig. 62

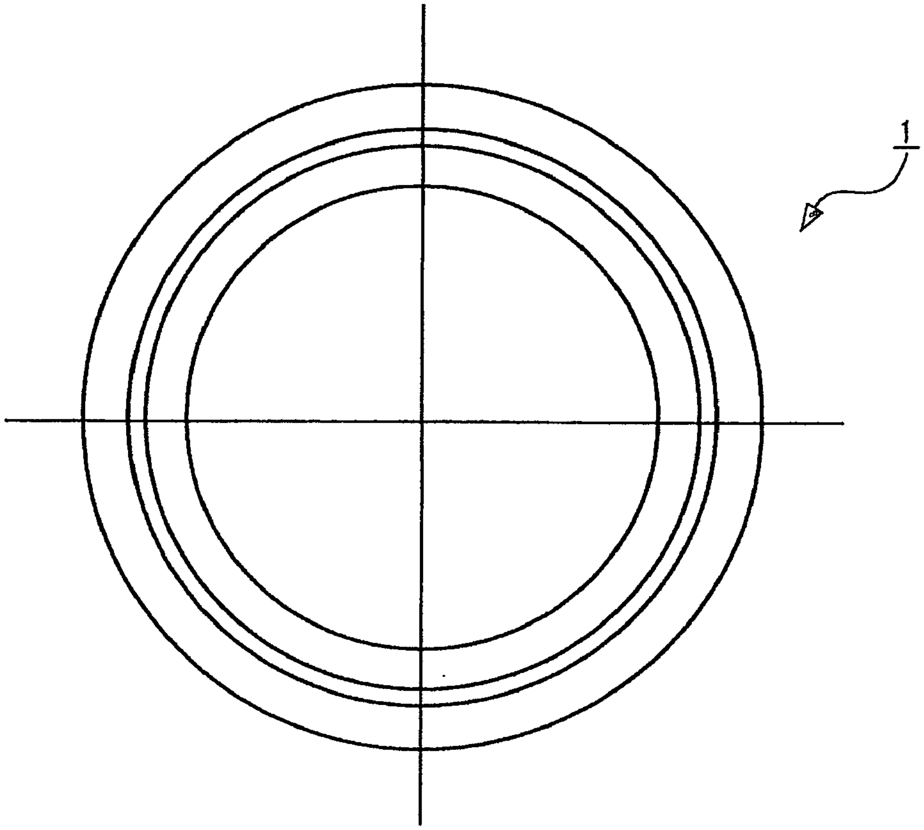


Fig. 63A

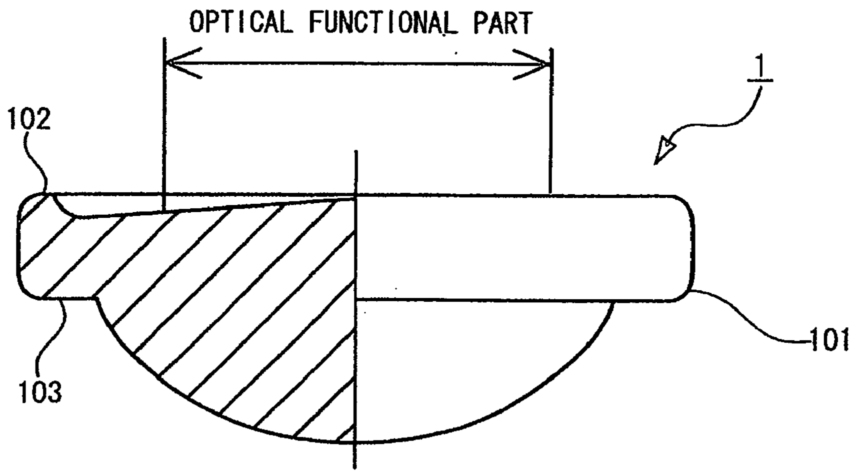


Fig. 63B

OPTICAL PICKUP SYSTEM, OPTICAL HEAD, OPTICAL DISK APPARATUS, ANTIREFLECTION COATING, OPTICAL PICKUP COMPONENTS, AND MANUFACTURING METHOD FOR ANTIREFLECTION COATING

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to an optical pickup system, an optical head, an optical disk apparatus, an antireflection coating for optical pickup application, optical components for optical pickup application, and a method for manufacturing an antireflection coating.

[0003] 2. Description of Related Art

[0004] Conventionally, a compatible optical disk apparatus capable of reproducing different types of optical disks such as compact disks (CDs) and digital versatile disks (DVDs) has been proposed. The CD and DVD (which is hereinafter collectively called the optical disk) both have a transparent substrate whose one side is an information recording surface. The optical disk is composed of a combination of two transparent substrates adhered together with their information recording surfaces facing each other, or a combination of the information recording surface and a transparent protection substrate adhered together with the information recording surface facing the protection substrate.

[0005] To reproduce information signals stored in the optical disk, the optical disk apparatus focuses a laser beam from a light source on the information recording surface of the optical disk through the transparent substrate. As detailed later, the wavelength of the laser beam differs between CD and DVD. The optical disk apparatus normally uses an objective lens for focusing the laser beam. In some cases, the thickness of the transparent substrate having the information recording surface differs according to the type of the optical disk or a difference in laser beam wavelength. For example, while the transparent substrate of a CD may be 1.2 mm in thickness, that of a DVD may be 0.6 mm.

[0006] For the optical disk apparatus to reproduce optical disks of different types, it is required to focus the laser beam on the information recording surface despite that the thickness of the transparent substrate varies by the type of the optical disk. Besides, a new optical disk apparatus that uses a blue laser of approximately 400 nm wavelength to reproduce information is recently proposed. Therefore, there is a need for the optical disk apparatus to be compatible with the new optical disk in addition to CD and existing DVD.

[0007] To meet this need, an optical disk apparatus may have objective lenses for different types of optical disks in a pickup so that the objective lenses are changed in accordance with the type of the optical disk in use. Alternatively, it may have pickups for different types of optical disks so that the pickups are changed in accordance with the type of the optical disk in use. However, in terms of cost and size reduction, it is preferred to use the same objective lens for any type of optical disk.

[0008] An example of the objective lens is disclosed in Japanese Unexamined Patent Publication No. 09-145995. This objective lens has a lens surface that is radially sectioned into three or more loop zones. Every other loop zonal lens surfaces and the other every other loop zonal lens surfaces have a different refractive power. The every other loop zonal lens surfaces focus a laser beam on the information recording surface of the optical disk (DVD) having a thin transparent substrate (0.6 mm). The other every other zonal lens surfaces focus the laser beam having the same wavelength, for example, on the information recording surface of the optical disk (CD) having a thick transparent substrate (1.2 mm).

[0009] Another example disclosed in Japanese Unexamined Patent Publication No. 2000-81566 (U.S. Pat. No. 6,118,594). It discloses an optical disk apparatus that uses a laser beam having a short wavelength (635 nm or 650 nm) for a DVD with a thinner transparent substrate and uses a laser beam having a long wavelength (780 nm) for a CD with a thicker transparent substrate.

[0010] This optical disk apparatus has an objective lens used in common for these laser beams. The objective lens has a diffractive lens structure with a plurality of minute loop zonal steps thickly formed on one side of a refractive lens having a positive refractive power. The diffractive lens structure is designed so as to focus diffracted light of a laser beam having a short wavelength on the information recording surface of a DVD with a thinner transparent substrate, and focus diffracted light of a laser beam having a long wavelength on the information recording surface of a CD with a thicker transparent substrate. Further, it is designed so as to focus the diffracted light having the same diffractive order on the information recording surface. A laser beam with a short wavelength is used for DVD because the recording density of the DVD is higher than that of the CD, thus requiring a small beam spot. As well known, the diameter of an optical spot is proportional to a wavelength and inversely proportional to a numerical aperture (NA).

[0011] The above optical disk apparatus allows use of a common objective lens for both DVD and CD. It eliminates the need for replacing components such as an objective lens for each use of DVD and CD. This is effective in reducing costs and simplifying the structure.

[0012] Further, Blu-ray disk and High Definition DVD (HD DVD) are appeared as optical recording media in the next of CD and DVD, and optical pickup apparatus that are compatible with the three optical recording media are under development. The optical pickup apparatus is required to transmit the output of a laser light source to a disk of a recording medium at high efficiency. An important point of development to meet this requirement is an antireflection coating that is formed on an optical component such as an objective lens included in the apparatus.

[0013] The wavelength of light used in CD is approximately 790 nm, the wavelength of light used in DVD is approximately 655 nm, and the wavelength of light used in Blu-ray disk and HD DVD is approximately 405 nm. Thus, an objective lens placed in the optical pickup apparatus preferably has an antireflection coating that has the optical property that a reflectance is low in the vicinity of these three wavelengths. As an antireflection coating compatible with a plurality of wavelengths an antireflection coating that is compatible with the wavelengths used in DVD and Blu-ray disk is disclosed in Japanese Unexamined Patent Publication No. 2005-38581.

[0014] However, since the technique disclosed in Japanese Unexamined Patent Publication No. 09-145995 uses different loop zonal lens surface of the objective lens for DVD and CD, a large area remains ineffective for an incident laser beam, which extremely lowers light use efficiency.

[0015] Further, since the technique disclosed in Japanese Unexamined Patent Publication No. 2000-81566 uses the diffracted light by the diffractive lens structure, it is impossible that the diffractive efficiencies for different wavelengths reach 100% at the same time. This diffractive lens is designed so that the diffractive efficiency reaches 100% at an intermediate wavelength between the laser beam with a short wavelength (635 nm or 650 nm) used in DVD and the laser beam with a long wavelength (780 nm) used in CD, thereby making the diffractive efficiency well balanced for the laser beams in use.

[0016] Besides, this technique requires minute steps to be formed on the lens surface to create the diffraction lens structure, which is vulnerable to processing error. If the diffractive structure is not formed as designed, it causes a decrease in diffractive efficiently. When the diffractive efficiency decreases or it does not reach 100%, it means incapability of focusing entire incident light on the information recording surface of the transparent substrate in the optical disk, which results in light loss.

[0017] Further, Blu-ray format that uses a blue laser having a still shorter wavelength is proposed recently. Backward compatibility is also required for this case. In this case, a wavelength difference is larger than that between DVD and CD, and a difference in the refractive index of a lens is also large. Therefore, in the conventional techniques described above, it is even more difficult to obtain a suitable wavefront aberration in any medium.

[0018] The antireflection coating described in Japanese Unexamined Patent Publication No. 2005-38581 defines light transmittance by focusing on two kinds of wavelengths: the wavelength of light used in DVD and the wavelength of light used in Blu-ray disk. In this case, it is possible to form an antireflection coating with low reflectance in the wavelength region of the light used in DVD and Blu-ray disk. However, since the reflectance in the wavelength region of the light used in CD becomes higher than that before formation of the antireflection coating in this example disclosed therein, defect can occur when a CD is used as a recording medium.

[0019] For example, when writing information to CD by raising the magnification of a writing speed, use of an antireflection coating that has high reflectance in the wavelength region of the light used in CD is likely to cause a writing error. The magnification of the writing speed of a CD-R drive is increased to as high as 52, and writing at a high magnification is expected.

[0020] Further, the technique of Japanese Unexamined Patent Publication No. 2005-38581 expects the use of three or more layers of antireflection coating as well. Since a time to form an antireflection coating in a manufacturing process is proportional to the number of layers of the antireflection coating, the number of antireflection coating is preferably small. When forming a film with low reflectance in two or more kinds of wavelength regions, two layers of antireflection coating called V-coat having V-shaped spectral reflection characteristics can be used if the two kinds of expected wavelength regions are relatively close to each other. However, since the wavelength region of the light used in Blu-ray disk and the wavelength region of the light used in DVD and CD are not close to each other, it is impossible to achieve a purpose with the V-coat.

[0021] The antireflection coating is normally placed in the objective lens surface in the optical pickup apparatus. The objective lens is generally made of plastic material fir its high optical performance and low costs. Though the lens made of plastic material is weak against heat, the antireflection coating is formed by vapor deposition or sputtering, and a temperature on the formation surface thereby increases. Since a film formation time is proportional to the number of layers of the antireflection coating, it is preferred that the number of antireflection coating is smaller also in terms of shortening a formation time to reduce effects such as heat deformation on the formation surface.

SUMMARY OF THE INVENTION

[0022] The present invention has been accomplished to solve the above problems and an object of the present invention is thus to provide an optical pickup system, an optical head, and an optical disk apparatus that can focus an optical beam on an information recording surface of each of a plurality of kinds of optical recording media using different wavelength with possibly lowest wavefront aberration and at high light use efficiency. Particularly, a first object of the invention is to provide an optical pickup system that is most suitable for three kinds of optical information recording media.

[0023] A second object of the invention is to provide a two-layer antireflection coating achieving low reflectance in three kinds of wavelength regions and an optical pickup component.

[0024] According to one aspect of the invention, there is provided an objective lens receiving light beams with different wavelengths λn ($n \geqq 3$) for at least three kinds of optical recording media and having a positive power to focus each light beam on an information recording surface of a transparent substrate of each optical recording medium by refraction, wherein, if distances between points Pn ($n \geqq 3$) where incident light beams or extension lines of incident light beams with wavelengths λn ($n \geqq 3$) to the objective lens crosses an optical axis and a point Q where a lens surface of the objective lens located farther from each optical recording medium than another lens surface crosses the optical axis is expressed by Sn ($n \geqq 3$), and a sign of the distance Sn is defined as positive if a position of the point Pn is located in a different side from the optical recording medium with respect to the point Q, and defined as negative if the position of the point Pn is located in the same side as the optical recording medium with respect to the point Q, an incident light beam satisfying following expressions enters the objective lens:

$$\lambda_1<\lambda_3 \text{ and } (1/S_1)<(1/S_3) \quad \text{Expression 1:}$$

$$\lambda_2<\lambda_3(\lambda_2>\lambda_1) \text{ and } (1/S_2)<(1/S_3), \text{ and} \quad \text{Expression 2:}$$

each light beam is focused on the information recording surface with RMS wavefront aberration of 0.035 λRMS or below.

[0025] In this objective lens, at least one lens surface is preferably radially sectioned into a plurality of zones. It is also preferred that an optical path length of a light beam passing through each zone of the objective lens is different from an optical path length passing through another zone by substantially 2 mλ (m is an integral number) for a light beam selected from light beams consisting of a first light beam, a second light beam, and a third light beam, and by substantially mλ (m is an integral number) for a rest of the light beams. Particularly, the wavelength with a difference of substantially 2 mλ is preferably λ_1. In a preferred embodiment, the wavelength λ_1 is approximately 405 nm, the wavelength λ_2 is approximately 655 nm, and the wavelength λ_3 is approximately 790 nm. Particularly, S_1 and S_3 preferably respectively satisfy expressions: $S_1<0$, $S_3>0$

[0026] According to another aspect of the invention, there is provided an optical pickup system receiving a first light beam with a wavelength λ_1 corresponding to a first optical recording medium, a second light beam with a wavelength λ_2 corresponding to a second optical recording medium, and a third light beam with a wavelength λ_3 corresponding to a third optical recording medium, having an objective lens that focuses the first light beam on the first optical recording medium, the second light beam on the second optical recording medium, and the third light beam on the third optical recording medium, and being capable of reading information recorded in the first optical recording medium, the second optical recording medium, and the third optical recording medium, wherein the objective lens has a positive power to focus each light beam on an information recording surface of a transparent substrate of each optical recording medium by refraction, and if distances between points P_1, P_2, P_3 where incident light beams or extension lines of incident light beams with wavelengths λ_1, λ_2, λ_3 to the objective lens cross an optical axis and a point Q where a lens surface of the objective lens located farther from each optical recording medium than another lens surface crosses the optical axis are expressed as S_1, S_2, S_3, and signs of the distances S_1, S_2, S_3, are defined as positive if positions of the points P_1, P_2, P_3 are located in a different side from the optical recording medium with respect to the point Q, and defined as negative if the positions of the points P_1, P_2, P_3 are located in the same side as the optical recording medium with respect to the point Q, following expressions are satisfied.:

$$\lambda_1<\lambda_3 \text{ and } (1/S_1)<(1/S_3); \qquad \text{Expression 1:}$$

$$\lambda_2<\lambda_3(\lambda_2>\lambda_1 l) \text{ and } (1/S_2)<(1/S_3). \qquad \text{Expression 2:}$$

[0027] Each of the first, the second and the third light beams is preferably focused on each information recording surface with RMS wavefront aberration of 0.035 λRMS or below. It is preferred in the objective lens that at least one lens surface of the objective lens is radially sectioned into a plurality of zones, and an optical path length of a light beam passing through each zone is different from an optical path length passing through another zone by substantially mλ (m is an integral number) for a light beam selected from light beams consisting of the first light beam, the second light beam, and the third light beam, and by substantially 2mλ (m is an integral number) for a rest of the light beams. The wavelength with a difference of substantially 2 mλ is preferably λ_1. Preferably, the wavelength λ_1 is approximately 405 nm, the wavelength λ_2 is approximately 655 nm, and the wavelength λ_3 is approximately 790 nm.

[0028] It is possible to constitute an optical head and an optical disk with the optical pickup system of this structure.

[0029] Preferably, each of the first light beam, the second light beam, and the third light beam is focused on each optical recording medium after passing through a wavelength selective filter having an outer area that allows the first light beam and the second light beam to pass through and shields the third light beam, and an inner area that allows the first light beam, the second light beam, and the third light beam to pass through.

[0030] Particularly, a numerical aperture of a light beam after passing through the objective lens is preferably largest in the first light beam, second-largest in the second light beam, and smallest in the third light beam.

[0031] S_1 and S_3 preferably respectively satisfy expressions: $S_1<0$, $S_3>0$. Further, magnification m**1** of the first light beam and magnification m**3** of the third light beam respectively preferably satisfy expressions of $0<m1\leqq 1/10$ and $-1/10<m3\leqq 0$, and more preferably $0<m1\leqq 1/20$ and $-1/20<m3\leqq 0$.

[0032] Preferably, the wavelength selective filter is formed in a surface of the objective lens. A refractive index of the wavelength selective filter is within a range of 0.9 to 1.1 with respect to a refractive index of the objective lens. The objective lens is made of material mainly composed of glass with a refractive index of 1.49 to 1.70.

[0033] According to another aspect of the invention, there is provided an objective lens receiving light beams with different wavelengths λn ($n\geqq 3$) for at least three kinds of optical recording media and having a positive power to focus each light beam on an information recording surface of a transparent substrate of each optical recording medium by refraction, wherein, if distances between points Pn ($n\geqq 3$) where incident light beams or extension lines of incident light beams with wavelengths λn ($n\geqq 3$) to the objective lens crosses an optical axis and a point Q where a lens surface of the objective lens located farther from each optical recording medium than another lens surface crosses the optical axis is expressed by Sn ($n\geqq 3$), and a sign of the distance Sn is defined as positive if a position of the point Pn is located in a different side from the optical recording medium with respect to the point Q, and defined as negative if the position of the point Pn is located in the same side as the optical recording medium with respect to the point Q, an incident light beam satisfying following expressions enters the objective lens:

$$\lambda_1<\lambda_3 \text{ and } (1/S_1)<(1/S_3) \qquad \text{Expression 1:}$$

$$\lambda_2<\lambda_3(\lambda_2>\lambda_1) \text{ and } (1/S_2)<(1/S_3), \qquad \text{Expression 2:}$$

each light beam is focused on the information recording surface with RMS wavefront aberration of 0.050 λRMS or below, and the objective lens is made of material mainly composed of glass with a refractive indexof 1.49 to 1.70 and a thermal deformation temperature of 300° C. or below.

[0034] According to an aspect of the invention, there is provided an antireflection coating formed on a light transmitting surface of an optical component with a refractive index of n_s used in an optical pickup device using at least two wavelengths of approximately 405 nm and 655 nm, the antireflection coating comprising two layers of a high refractive index layer with a refractive index of n_H and an optical coating thickness of $n_H d_H$ formed on the optical component; and a low refractive index layer with a refractive index of n_L, and an optical coating thickness of $n_L d_L$ formed on the high refractive index layer, wherein a reflectance is lowest only in two regions of approximately 405 nm and 655 nm and highest in one region between the two lowest regions.

[0035] According to another aspect of the invention, there is provided an antireflection coating used in an optical pickup device using at least three wavelengths of approximately 405 nm, 655 nm, and 790 nm and formed on a light transmitting surface of an optical component with a refractive index of n_s, the antireflection coating comprising two layers of: a high refractive index layer with a refractive index of n_H and an optical film thickness of $n_H d_H$ formed on the optical component; and a low refractive index layer with a refractive index of n_L, and an optical film thickness of $n_L d_L$ formed on the high refractive index layer, wherein a reflectance is lowest only in two regions of approximately 405 nm and 655 nm and highest in one region between the two lowest regions.

[0036] The antireflection coating preferably satisfies following conditions: $0.9 \leqq n_H/A \leqq 1.1$, $0.1 \leqq n_H - n_s$, $225\ nm \leqq n_H d_H \leqq 275\ nm$, $100\ nm \leqq n_L d_L \leqq 150\ nm$, where $A=(1.21*n_s+0.84*n_L*n_L)/2$. More preferably, it satisfies $n_H - n_s \leqq 0.4$. In a preferred embodiment, material of the low refractive index layer is silicon oxide or fluoride. The antireflection coating may be formed on a surface of the optical component for an optical pickup. Preferably, the optical component is made of material mainly composed of glass with a refractive index n_s of 1.49 to 1.70 and a thermal deformation temperature of 300° C. or below.

[0037] According to another aspect of the invention, there is provided a method of manufacturing an object lens for an optical pickup, used in an optical pickup device using at least three wavelengths of approximately 405 nm, 655 nm and 790 nm and having a surface where an antireflection coating composed of a high refractive index layer and a low refractive index layer is formed, the method comprising: selecting material for the high refractive index layer and the low refractive index layer that satisfy following conditions of $0.9 \leqq n_H/A \leqq 1.1$, $0.1 \leqq n_H - n_s$, where $A=(1.21*nS+0.84*nL*nL)/2$, when n_s is a refractive index of the objective lens, n_H is a refractive index of the high refractive index layer, and n_L is a refractive index of the low refractive index layer; forming the high refractive index layer with a refractive index of n_H on the objective lens; and forming the low refractive index layer with a refractive index of n_L on the high refractive index layer.

[0038] The step of selecting material preferably selects material so as to satisfy a condition of $n_H - n_s \leqq 0.4$. Further, the step of selecting material preferably selects material so as to satisfy a condition of: $1.30 \leqq n_L \leqq 1.55$

[0039] According to another aspect of the invention, there is provided an antireflection coating placed in a light transmitting surface of an optical component with a refractive index of n_s used in an optical pickup device using at least three wavelengths of approximately 405 nm, 655 nm and 790 nm, comprising two layers of: a high refractive index layer with a refractive index of n_H formed on the optical component; and a low refractive index layer with a refractive index of n_L formed on the high refractive index layer, wherein the antireflection coating satisfies following conditions of $0.9 \leqq n_H/A \leqq 1.1$, $0.1 \leqq n_H - n_s$, where $A=(1.21*n_s+0.84*n_L*n_L)/2$.

[0040] According to another aspect of the invention, there is provided an objective lens wherein the objective lens is made of material mainly composed of glass with a refractive index of 1.49 to 1.70 and a thermal deformation temperature of 300° C or below, and the objective lens has an antireflection coating composed of two layers of a high refractive index layer with a refractive index of n_H and an optical film thickness of $n_H d_H$ and a low refractive index layer with a refractive index of n_L and an optical film thickness of $n_L d_L$, and having lowest reflectance values only in two regions of approximately 405 nm and 655 nm and a highest reflectance value in one region between the two lowest reflectance values.

[0041] The present invention can provide an optical pickup system, an optical head, and an optical disk apparatus that can focus an optical beam on an information recording surface for each of a plurality of kinds of optical recording media having different use wavelengths with a passively lowest wavefront aberration and a high light use efficiency.

[0042] The present invention can provide an antireflection coating composed of two layers and having low reflectance in three kinds of wavelength regions and an optical pickup component.

[0043] The above and other objects, features and advantages of the present invention will become more fully understood from the detailed description given hereinbelow and the accompanying drawings which are given by way of illustration only, and thus are not to be considered as limiting the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0044] **FIG. 1** is a pattern diagram to describe an optical path length in an optical system composed of an objective lens and a transparent substrate of an optical disk;

[0045] **FIGS. 2A** to **2C** are graphs showing the wavefront aberration of HDDVD, DVD, and CD in a first embodiment;

[0046] **FIGS. 3A** to **3C** are pattern diagrams showing embodiments of an objective lens of the invention;

[0047] **FIGS. 4A and 4B** are pattern diagrams showing an example of the structure of a wavelength selective filter;

[0048] **FIG. 5** is a graph showing the spectral transmittance characteristics of a CD light shielding area or a wavelength selective filter;

[0049] **FIG. 6** is a pattern diagram showing a specific example of a lens surface shape of an embodiment of the invention;

[0050] **FIG. 7** is a table showing coefficients to calculate a distance Z_A;

[0051] **FIG. 8** is a table showing coefficients to calculate a distance Z_B;

[0052] **FIGS. 9A** to **9C** are tables showing the distance between and the arrangement of optical components of an optical system of a first embodiment;

[0053] **FIGS. 10A** to **10C** are graphs showing calculation results of an optical spot for different kinds of optical disks in the first embodiment;

[0054] **FIG. 11** is a table showing a difference in substantial optical path length between zone **1** and zones **2** to **9**;

[0055] FIG. 12 is a table showing the relationship between a distance Z_A and an optical height h;

[0056] FIG. 13 is a table showing the relationship between a distance Z_A and an optical height h;

[0057] FIG. 14 is a table showing the relationship between a distance Z_A and an optical height h;

[0058] FIG. 15 is a table showing the relationship between a distance Z_A and an optical height h;

[0059] FIG. 16 is a table showing the relationship between a distance Z_A and an optical height h;

[0060] FIGS. 17A to 17C are tables showing the distance between and the arrangement of optical components of an optical system of a first embodiment;

[0061] FIG. 18 is a table showing a difference in substantial optical path length between zone 1 and zones 2 to 22;

[0062] FIGS. 19A to 19C are graphs showing the wavefront aberration of Blu-ray, DVD, and CD of a second embodiment;

[0063] FIGS. 20A to 20C are graphs showing a difference and ratio of the wavefront aberration of Blu-ray, DVD, and CD of a second embodiment;

[0064] FIGS. 21A to 21C are graphs showing calculation results of an optical spot for different kinds of optical disks in the second embodiment;

[0065] FIG. 22 is a table showing the relationship between a distance Z_A and an optical height h;

[0066] FIGS. 23A to 23C are tables showing the arrangement in an optical system of a third embodiment;

[0067] FIG. 24 is a view showing the structure of a wavelength selective filter of the third embodiment;

[0068] FIGS. 25A to 25C are graphs showing the wavefront aberration of an objective lens of the third embodiment;

[0069] FIG. 26 is a table showing the amount of coma aberration generated in an objective lens of the third embodiment;

[0070] FIG. 27 is a table showing a difference in substantial optical path length between zone 1 and zones 2 to 7;

[0071] FIGS. 28A to 28C are graphs showing an optical spot in the third embodiment;

[0072] FIG. 29 is a table showing the relationship between a distance Z_A and an optical height h;

[0073] FIG. 30 is a table showing the relationship between a distance Z_A and an optical height h;

[0074] FIG. 31 is a table showing the relationship between a distance Z_A and an optical height h;

[0075] FIG. 32 is a table showing the relationship between a distance Z_A and an optical height h;

[0076] FIG. 33 is a table showing the relationship between a distance Z_A and an optical height h;

[0077] FIG. 34 is a table showing the relationship between a distance Z_A and an optical height h;

[0078] FIG. 35 is a table showing the relationship between a distance Z_A and an optical height h;

[0079] FIGS. 36A to 36C are tables showing the arrangement in an optical system of the third embodiment;

[0080] FIG. 37 is a table showing a difference in substantial optical path length between zone 1 and zones 2 to 31;

[0081] FIGS. 38A to 38C are graphs showing the wavefront aberration of an objective lens of a fourth embodiment;

[0082] FIG. 39 is a table showing the film structure of a wavelength selective filter of a fifth embodiment;

[0083] FIG. 40 is a graph showing the spectral characteristics of the wavelength selective filter of the fifth embodiment;

[0084] FIG. 41 is a table showing a film structure of the wavelength selective filter of the fifth embodiment;

[0085] FIG. 42 is a graph showing the spectral characteristics of the wavelength selective filter of the fifth embodiment;

[0086] FIG. 43 is a sectional view to describe the principle of an antireflection coating of a sixth embodiment;

[0087] FIGS. 44A to 44F are tables showing simulation results in the sixth embodiment;

[0088] FIG. 45 is a graph showing a change in reflectance depending on wavelength in the simulation result of the sixth embodiment;

[0089] FIG. 46 is a graph showing a change in reflectance depending on wavelength in the simulation result of the sixth embodiment;

[0090] FIG. 47 is a graph showing a change in reflectance depending on wavelength in the simulation result of the sixth embodiment;

[0091] FIGS. 48A to 48C are tables showing design examples of an AR coat;

[0092] FIGS. 49A to 49C are graphs showing the spectral transmittance characteristics per one lens surface by the AR coat;

[0093] FIG. 50 is a graph showing an example 4 of the invention;

[0094] FIG. 51 is a graph showing an example 5 of the invention;

[0095] FIG. 52 is a graph showing an example 6 of the invention;

[0096] FIG. 53 is a graph showing an example 7 of the invention;

[0097] FIG. 54 is a graph showing an example 8 of the invention;

[0098] FIG. 55 is a graph showing a comparative example 1 of the invention;

[0099] FIG. 56 is a graph showing a comparative example 2 of the invention;

[0100] FIG. 57 is a graph showing a comparative example 3 of the invention;

[0101] **FIGS. 58A and 58B** are tables showing analysis results in the fifth embodiment;

[0102] **FIG. 59** is a pattern diagram showing an example of the structure of an optical head of the invention;

[0103] **FIG. 60** is a pattern diagram showing another example of the structure of an optical head of the invention;

[0104] **FIG. 61** is a pattern diagram showing another example of the structure of an optical head of the invention;

[0105] **FIG. 62** is a pattern diagram showing an example of the structure of an optical disk apparatus of the invention; and

[0106] **FIGS. 63A and 63B** are a top view and a side view, respectively, showing an outer shape of an objective lens of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0107] A lens according to this invention is a multiwavelength lens using a plurality of kinds of monochromatic light. It is a general-purpose multiwavelength lens that can be used for a recording and reproducing apparatus compatible with different kinds of optical recording media such as CD including CD-R, DVD, Blu-ray disk, and Advanced Optical Disk (AOD). A multiwavelength optical system, optical head, and optical disk apparatus according to this invention use this multiwavelength optical lens.

[0108] The present invention is schematically described hereinafter.

[0109] It is assumed that for a first optical disk using a transparent substrate having a thickness t_1, the aberration of an objective lens placed in an optical disk apparatus to be used is corrected appropriately, and a laser beam with a wavelength λ_1 is appropriately focused an information recording surface of the substrate. In this optical disk apparatus, a laser beam with a wavelength λ_2 which is different from the wavelength λ_1 is now to be focused on a second optical disk using a transparent substrate having a thickness t_2.

[0110] In this case, the laser beam wavelength λ_1 and λ_2 and the transparent substrate thickness t_1 and t_1 respectively differ from each other, or, even if the thickness t_1 and t_1 are the same, the wavelength λ_1 and λ_2 differ from each other. Thus, spherical aberration due to a difference in transparent substrate thickness and chromatic aberration due to a difference in refractive index of the objective lens because of a difference in laser beam wavelength both occur, or only the chromatic aberration occurs, making it unable to focus the laser beam appropriately on the information recording surface.

[0111] The present invention sets the aspherical surface shape of an objective lens and the divergence of an incident light beam to an objective lens so that no or little aberration occurs in an optical path length at a given optical height for all different kinds of disks with difference wavelengths. It is thereby possible to reduce the aberration for all the optical disks. Further, since this invention achieves it only with refracted light, not using diffraction, no light loss of diffraction efficiency occurs.

[0112] As detailed later, a lens of an embodiment of the invention has a lens surface that is sectioned into a plurality of aspherical surfaces.

[0113] Referring first to **FIG. 1**, a case of focusing a laser beam on an information recording surface **2***a* of a substrate **2** by using an objective lens **1** is described hereinafter below. A surface A of the objective lens **1** is a light incident side, and a surface B is a light exit side. The information recording surface **2***a* is on the reverse of the side of the substrate **2** facing the objective lens **1**.

[0114] **FIG. 1** schematically shows an optical path of the objective lens **1**. In **FIG. 3**, a laser beam entering the objective lens **1** is parallel light. The optical system shown in **FIG. 1** is thus a so-called infinite optical system. **FIG. 1** schematically shows the optical path of a light beam that passes through a point Pi which is a vertical distance (optical height) h apart from an optical axis OA of the objective lens **1** to reach a point (focal point) P_5 where it crosses the optical axis OA.

[0115] An incident point to the objective lens **1** on the optical path is represented by P_2, an exit point from the objective lens **1** is by P_3, and an incident point to the transparent substrate **2** is by P_4. A spatial distance and the refractive index between the points are represented as follows:

[0116] Point P_1 to Incident point P_2: Distance=S_{1h}, Refractive index=n_1

[0117] Incident point P_2 to Exit point P_3: Distance=S_{2h}, Refractive index=n_2

[0118] Exit point P_3 to Incident point P_4: Distance=S_{3h}, Refractive index=n_3

[0119] Incident point P_4 to Focal point P_5: Distance=S_{4h}, Refractive index=n_4.

[0120] The optical path length L_h from the point P_1 to the focal point P_5 is expressed by the following expression:

$$L_h=n_1*S_{1h}+n_2*S_{2h}+n_3*S_{3h}+n_4*S_{4h} \quad \text{Expression 3:}$$

The optical path length L_h on the optical axis OA is when h=0 in Expression 3.

[0121] Expression 3 is applicable to any optical height h. When aberration is corrected, the focal point P_5 for each optical height h is on the information recording surface **2***a* within allowable ranges. Specifically, the present invention uses a laser beam having a different wavelength for each of a plurality of substrates having different thickness and therefore spherical aberration and chromatic aberration cancel each other out so that the focal point P_5 for a given optical height h is on the information recording surface **2***a* within each of the allowable ranges.

[0122] Though the case where the incident light to the objective lens **1** is parallel light, which is an infinite system, is described above, the incident light may be divergent light, which is a finite system. It is also possible to select the infinite or finite systems for use for different optical recording media and different wavelengths. Further, it is also possible to use the same finite system for different optical recording media while changing the divergence of an incident light beam. The incident light to the objective lens may be convergent light.

[0123] For example, a monochromatic light λ_1 of 405 nm wavelength for HDDVD (AOD) and a monochromatic light λ_2 of 655 nm wavelength for DVD are used. In this case, an area of a lens surface commonly used for the both wavelengths can be sectioned into a plurality of aspherical surface sections. In this technique, the optical path length of one aspherical section is different from that of another aspherical section by integral multiple of the wavelength λ_1 of each monochromatic light. Further, a difference between a maximum value and a minimum value of wavefront aberration of each monochromatic light in each aspherical section is $\Delta V_d(\lambda_1)$ and $\Delta V_d(\lambda_2)$ where d is an integral number of 1, 2 . . . , meaning each aspherical section.

[0124] In these conditions, if the ratio of the difference between the maximum value and the minimum value of the wavefront aberration of each monochromatic light is between 0.4 and 2.5, preferably between 0.5 and 2.0, in any aspherical section, Root Mean Square (RMS) wavefront aberration of the whole lens can fall within an allowable range for all the wavelengths. Further, the RMS wavefront aberration value in CD can be improved if the incident light beam is divergent light or incident light with higher divergence than in HDDVD and DVD. The spherical aberration due to a thick substrate and the chromatic aberration due to highly divergent incident light thereby cancel out each other, thereby correcting the spherical aberration that occurs in CD.

[0125] If the optical length when the optical height h=0 is L_0, and the optical path length at each optical height is L_h, the wavefront aberration V_h is expressed by the following expression:

$$V_h=(L_h-L_0)/\lambda_i \quad \text{Expression 4:}$$

[0126] **FIGS. 2A** to **2**C show the wavefront aberrations in HDDVD, DVD, and CD. In **FIG. 2**, the horizontal axis indicates optical height and the vertical axis indicates wavelength aberration. **FIG. 2A** shows the wavefront aberration in each aspherical section for HDDVD, **FIG. 2B** shows the wavefront aberration in each aspherical section for DVD, and **FIG. 2C** shows the wavefront aberration in each aspherical section for CD, which are calculated by the above expression.

[0127] For example, a difference between the maximum and minimum values of the wavefront aberration in a first aspherical section is defined as $\Delta V_d(\lambda_1)$ and $\Delta V_d(\lambda_2)$. As in the embodiments described later, the ratio of a difference between the maximum and minimum values of the wavefront aberration for each wavelength falls within the range of 0.4 to 2.5 in any aspherical section in this invention. Thus, each aspherical section has a uniform distribution of wavefront aberration for any wavelength. This is different from conventional techniques that design a lens surface based on one wavelength and corrects wavefront aberration in the other wavelength using phase lag.

[0128] In the multiwavelength lens of the present invention, a difference between the maximum and minimum values of the wavefront aberration of each wavelength can be 0.14 λ_i or lower, preferably 0.12 λ_i or lower, and more preferably 0.10 λ_i or lower. For example, when a difference between the maximum and minimum values is 0.14 λ_i or lower, if the wavelength is 790 nm, it is 110.6 nm or lower, if the wavelength is 655 nm, it is 91.7 nm or lower, and if the wavelength is 405 nm, it is 56.7 nm. The multiwavelength lens of this invention can thereby have suitable optical characteristics in each wavelength.

[0129] Further, if this invention is applied to a dual wavelength optical system, use of a multiwavelength lens in which the wavefront aberration for each wavelength is substantially symmetrical produces a suitable balance between the two wavelengths, thereby further reducing the RMS wavefront aberration.

[0130] As a result, the RMS wavefront aberration is 0.03152λ_1RMS in HDDVD, 0.023237λ_2RMS in DVD, and thus the RMS wavefront aberration is substantially equal in HDDVD and DVD. The RMS wavefront aberration in CD is 0.01764λ_3RMS, which is smaller than that of HDDVD and DVD.

[0131] For the recording and reproducing the CD (790 nm), it is possible to change the divergence of the incident light to the objective lens or a so-called object distance for the objective lens in a geometrical-optical sense. This is effective for correcting spherical aberration since the degree of spherical aberration changes by the divergence of the incident light. This is described in the embodiments below.

[0132] Further, in the embodiments of the invention described later, the incident light having the wavelengths of 405 nm and 655 nm are infinite and the incident light having the wavelength of 790 nm is finite. Specifically, the divergence of the incident light with 405 nm and 655 nm wavelengths are the same and the divergence of the incident light with 790 nm wavelength is different. Selection of a wavelength whose divergence is to be changed may be made each time according to use wavelength and substrate thickness so as to reduce aberration. Further, all the wavelengths may be incident as divergent light or as convergent light.

[0133] The embodiments of the invention described later allow formation of a suitable optical spot on an information recording surface for any optical disk having a substrate of a different thickness. This is applicable also when the thickness of a disk substrate is not different, that is, when the thickness is the same and the wavelength is different, by setting focal point P_5 shown in **FIG. 1** within each allowable range. Further, this invention is applicable not only to optical recording media but also to optical communication and so on where different wavelengths of laser beams pass through the same lens or optical system.

[0134] Preferred embodiment of the present invention is described hereinafter in detail.

First Embodiment

[0135] A first embodiment of the present invention is described below with reference to the drawings. It takes the case of using three kinds of optical disks, HDDVD (λ_1=405 nm), DVD(λ_2=655 nm), and CD(λ_3=790 nm), as an example. Though the lens used in the first embodiment has a refractive index that is equivalent to plastic resin, it may have a refractive index of a glass if it is desired to use a glass as a lens material.

[0136] **FIGS. 3A** to **3**B are pattern diagrams showing examples of the mechanism of an objective lens of this invention. **FIG. 3A** shows the case of HDDVD, **FIG. 3B** shows the case of DVD, and **FIG. 3C** shows the case of CD.

FIGS. 3A and 3C illustrates an objective lens **1** of the first embodiment, a transparent substrate **2** of HDDVD, a transparent substrate **3** of DVD, a transparent substrate **4** of CD, an aperture **5**, and a wavelength selective aperture **6**.

[0137] In **FIG. 3A**, the optical lens **1** is placed in an optical head of an optical disk apparatus, which are not shown. HDDVD is installed in the optical disk apparatus. The objective lens **1** focuses a laser beam that is incident as parallel light for recording or reproducing data. The HDDVD substrate **2** has the thickness t_1 of 0.6 mm. The laser beam used has a wavelength λ_1 of 405 nm, as a luminous flux with a numerical aperture (NA) of 0.650. Under these conditions, the laser beam is focused on the information recording surface **2***a* of the HDDVD substrate **2**, which is on the reverse of the side facing the objective lens **1**.

[0138] **FIG. 3B** shows a case where DVD is installed in the same optical disk apparatus, also not shown, and the same objective lens **1** is used to record and reproduce data. The DVD substrate **3** has the thickness t_2 of 0.6 mm. The laser beam used has a wavelength λ_2 of 655 nm, as a luminous flux with a numerical aperture (NA) of 0.628. In the above two cases using HDDVD and DVD, though the diameter of the aperture **5** is the same, NA is different. This is because the refractive index of the objective lens **1** differs since the wavelengths are different, which makes focal distances to differ from each other.

[0139] **FIG. 3C** shows a case where CD is installed in the same optical disk apparatus, also not shown, and the same objective lens **1** is used to record and reproduce data. The CD substrate **4** has the thickness t_3 of 1.2 mm. The laser beam used has a wavelength λ_3 of 790 nm, which is incident to the objective lens **1** as divergent light, used as a luminous flux with a numerical aperture (NA) of approximately 0.470.

[0140] The wavelength selective filter **6** shown in **FIGS. 3A** to **3**C is sectioned into an inner entire light transmitting area and an outer CD (790 nm) light shielding area, as shown in **FIG. 4**. It is formed by depositing a dichroic coating that reflects the light having 750 nm or higher wavelength after forming a mask in the inner part.

[0141] Specifically, a dichroic coating having the spectral transmittance characteristics as shown in **FIG. 5**, for example, is deposited on the CD light shielding area. It is thereby possible to obtain the wavelength selective filter **6** having the spectral transmittance characteristics of **FIG. 5** in the outer CD light shielding area. This achieves a purpose of shielding CD light only while letting DVD and HDDVD light pass through in the outer area. As a result, NA of HDDVD is 0.650, NA of DVD is 0.628, and NA of CD is 0.470.

[0142] Ideal spectral transmittance characteristics are that transmittance is 100% for a wavelength of 750 nm or lower and it is 0% for a wavelength of 750 nm or higher. The spectral transmittance characteristics shown in **FIG. 5** are close the ideal state, with 99% for the former and 0.2% for the latter. If it is impossible for actual filter characteristics to achieve these characteristics, the transmittance for a wavelength of 700 nm or lower may be 90% or higher and the transmittance for a wavelength of 770 nm or higher may be 5% or lower, for example. Though adverse effects such as decrease in the signal level of the optical disk apparatus or deterioration of CD jitter characteristics occur in this case also, they are not so significant to make it unusable, and thus it is available.

[0143] The first embodiment designs the lens surface shape of the objective lens **1** in such a way that the optical path length L_h expressed by Expression 3 for a given optical height h falls is a value that reduces aberration to fall within an allowable range in all the case of HDD, DVD, and CD. It is thereby possible to reduce aberration in HDDVD, DVD, and CD and produce an appropriate optical spot on the information recording surface of each medium.

[0144] In the first embodiment, the light incident surface A is radially sectioned from the optical axis into a plurality of zones, and the surface shape of each zone is designed so as to reduce aberration to an allowable range for HDDVD, DVD and CD.

[0145] The surface shape of the light incident surface A in the first embodiment is described hereinafter with reference to **FIG. 6**. A distance between the points a and b in the j-th zone from the optical axis OA in the direction of the optical height h (the radial direction) on the light incident surface A is expressed by the following function Z_{Aj}:

Expression 5

$$Z_{Aj} = B + \frac{Ch^2}{1+\sqrt{1-(K+1)C^2\cdot h^2}} + A_4\cdot h^4 + A_6\cdot h^6 + A_8\cdot h^8 + A_{10}\cdot h^{10} + A_{12}\cdot h^{12} + A_{14}\cdot h^{14} + A_{16}\cdot h^{16}$$

The optical height h in Expression 5 is that in the j-th zone.

[0146] In **FIG. 6**, on the light exit surface B of the objective lens **1**, the point at the optical height h is c, the point on the light exit surface B located apart from the point c in the direction parallel to the optical axis OA is d. The surface shape of the light exit surface B is designed to be expressed with a distance Z_B between the points a and b for a given optical height h by the following expression:

Expression 6

$$Z_{Bj} = \frac{Ch^2}{1+\sqrt{1-(K+1)C^2\cdot h^2}} + A_4\cdot h^4 + A_6\cdot h^6 + A_8\cdot h^8 + A_{10}\cdot h^{10}$$

[0147] Then, for each case of HDD, DVD, and CD, the range of h and constants B, C, K, A_4, A_6, A_8, A_{10}, A_{12}, A_{14}, A_{16} are calculated for each zone in Expression 5 to reduce aberration to an allowable range. **FIG. 7** shows the calculation results. Further, the values of the constants in Expression 6 are also calculated. **FIG. 8** shows the calculation results.

[0148] **FIGS. 9A** to **9**C show the distance between optical components and their arrangement based on the objective lens in an optical system equivalent to that of **FIG. 3** for HDDVD, DVD, and CD, respectively.

[0149] A distance between surface apexes f and e on the optical axis of the objective lens **1**, which is a center thickness t_0, is 1.94 mm. A refractive index n for a wavelength λ_1=405 nm (Blu-ray disk) is 1.54972, a refractive index n for a wavelength λ_2=655 nm (DVD) is 1.53, and a refractive index n for a wavelength λ_3=790 nm (CD) is 1.5263653.

[0150] The transparent substrate of Blu-ray disk (wavelength λ_1=405 nm) has a thickness of 0.6 mm and a refractive index of 1.6235. The transparent substrate of DVD (wavelength λ_2=655 nm) has a thickness of 0.6 mm and a refractive index of 1.58. The transparent substrate of CD (wavelength λ_3=790 nm) has a thickness of 1.2 mm and a refractive index of 1.57163.

[0151] In HDDVD with a wavelength of 405 nm, NA is 0.650 and a focal length is 3.1015 mm. In DVD with a wavelength of 655 nm, NA is 0.628 and a focal length is 3.2116 mm. The effective diameter of incident parallel light is ϕ4.032 in both HDDVD and DVD. Further, the entire lens surface in the side A is a HDDVD/DVD common use area. In CD with a wavelength of 790 nm, NA is 0.470 and a focal length is 3.2327 mm.

[0152] The tables of **FIGS. 9A** to **9**C show an aperture, objective lens, disk, and an object surface for the objective lens. As shown in **FIGS. 9A** to **9**C, in HDDVD and DVD, for example, the incident light to the objective lens is parallel light, that is, a distance between the object surface for the objective lens and the objective lens is ∞. An actual optical system places a HDDVD laser or a DVD laser in the focal position of a collimator lens and inputs the output light from the collimator lens to the objective lens as parallel light.

[0153] In CD, a distance from the object surface to the objective lens is 49.4 mm, and divergent light is input to the objective lens. In the case of CD as well, a distance from an emission point of a CD laser to a surface apex of the objective lens in the light source side may be 49.4 mm in an actual optical system. In this case, however, an optical pickup becomes large.

[0154] It is preferred in this case to place the collimator lens between the CD laser light source and the objective lens, and places the emission point of the CD laser in the position closer to the collimator lens than the focal position of the collimator lens. In this arrangement, the light emitted from the CD laser and having passed through the collimator lens becomes divergent light and enters the objective lens. The collimator lens and the CD laser are preferably arranged so that the incident light to the objective lens becomes the same as the light emitted from a distance of 49.4 mm without collimator lens.

[0155] **FIGS. 9A** to **9**C also show the effective diameter of the aperture surface. The wavelength selective filter as shown in **FIG. 4** is used. Thus, in **FIG. 4**, the outer diameter of the entire light transmitting area which is equal to the inner diameter of the CD light shielding area is ϕ3.15, and the outer diameter of the CD light shielding area is ϕ4.032 or larger, which is greater than the effective diameter of HDDVD and DVD. Specifically, the effective diameter of the aperture surface is set to ϕ4.8, for example, considering the size required for holding by a glass frame.

[0156] The thickness of the wavelength selective filter is determined so that the incident light enters at 0 degree. The incident light can enters obliquely due to positions of components such as a laser and mirrors, accuracy variation, displacement of an emission point of a two-wavelength laser or a three-wavelength laser in the direction perpendicular to the optical axis, and so on. For this reason, the thickness of the wavelength selective filter is preferably small, and it is 0.5 mm in the first embodiment.

[0157] In the first embodiment shown in **FIGS. 9A** to **9**C, the relationship of S_1, S_2, and S_3 expressed by Expressions 1 and 2 is as follows:

HDDVD:	λ_1 = 405 nm, S_1 = ∞,
DVD:	λ_2 = 655 nm, S_2 = ∞,
CD:	λ_3 = 790 nm, S_3 = 49.4 mm

Therefore,

$$405\ nm(\lambda_1)<790\ nm(\lambda_3).$$

Further,

$$(1/S_1)=(1/\infty)=0,$$

$$(1/S_3)=(1/49.4)=0.0202429$$

Therefore,

$$0<0.0202429;\ (1/S_1)<(1/S_3)$$

Hence, in HDDVD and CD, $\lambda_1<\lambda_3$ and $(1/S_1)<(1/S_3)$ are both satisfied.

Further, since

$$655\ nm(\lambda_2)<790\ nm(\lambda_3).$$

and

$$(1/S_2)=(1/\infty)=0,$$

$$(1/S_3)=(1/49.4)=0.0202429.$$

Therefore,

$$0<0.0202429;\ (1/S_2)<(1/S_3)$$

Hence, in DVD and CD, $\lambda_2<\lambda_3$ and $(1/S_2)<(1/S_3)$ are both satisfied.

[0158] The refractive index of this objective lens is close to the refractive index of a plastic resin. Thus, when using polyolefin resin or acrylic resin, the objective lens is designed by using the refractive index of the resin to determine each aspherical surface shape and a lens center thickness. Particularly, since the polyolefin resin does not substantially absorb water under the high-humidity environment as well, it is advantageous in that the refractive index does not change. On the other hand, the acrylic resin is advantageous in that a transmittance of Blu-ray is high and a transmittance in the vicinity of Blu-ray (405 nm) does not substantially change over time.

[0159] The objective lens is preferably made of material with low birefringence since it produces a suitable value of wavefront aberration when forming a lens by injection molding, cast molding, or the like. Further, use of acrylic material has a problem that water absorption changes under the high-humidity environment. Therefore, when using the acrylic material, it is preferred to perform humidity conditioning beforehand so as to make it absorb some water since it is effective when the objective lens is used under the environment of almost absolute dry or high-humidity. In this case, the lens is designed by using the refractive index of the resin after absorbing some water by the humidity conditioning.

[0160] Substitution of values into the coefficients C, K, A_4, A_6, A_8, and A_{10} in Expression 6 gives a value of the distance Z_B for a given optical height h ($\neq 0$) as negative. This means that the point d on the light exit side B is located closer to the light incident surface side (in the left side of **FIG. 6**) compared with the point c, which is, the surface apex e of the light output side B through which the optical axis OA passes. On the contrary, if the distance Z_B is a positive value, it means that the point d is located at the right side of the point e.

[0161] (i) An allowable value for the aberration to evaluate the aberration is an RMS wavefront aberration of 0.035λ and preferably 0.033λ for HDDVD (wavelength λ_1=405 nm), DVD (wavelength λ_2=655 nm) and CD (wavelength λ_3=790 nm) when an incident laser beam to the objective lens **1** has an incident angle of 0°, that is, when it is parallel light parallel with the optical axis OA. In the first embodiment, the light exit surface B and the light incident surface A are designed to have the above surface shapes in order that the wavefront aberrations for HDDVD, DVD, and CD do not exceed this allowable value.

[0162] Though the first embodiment describes the case of using three kinds of different wavelengths λ_1, λ_2, and λ_3, this is the same when using the n (n is an integral number of 2 and above) number of kinds of different wavelengths λ_i (i=1, 2, . . . , n).

[0163] (ii) In the case of using the n number of kinds of wavelengths λ_i, if the RMS wavefront aberrations when the incident laser beams with the wavelengths λ_i have the incident angle of 0° is $W_i \cdot \lambda_i$, the aberration satisfies the following expression:

Expression 7:

$$\sqrt{\frac{\sum W_i^2}{i}} \leqq W_0$$

The allowable value W_0 is 0.035 or below and preferably 0.033 or below.

[0164] In Expression 7, the wavelength of the i-th light beam is λ_i (i=1, 2, . . .), a sum of square of the RMS wavefront aberration for all the wavelengths is ΣW_i^2, and the RMS wavefront aberration of a light beam having wavelength λ_i is $W_i \cdot \lambda_i$.

[0165] (iii) In a case of using laser beams having the n number of kinds of different wavelengths λ_i, of the maximum RMS wavefront aberration is W_{max} and the minimum RMS wavefront aberration is W_{min}, the following expression are satisfied:

$$1 \leqq W_{max}/W_{min} < W_{th}$$

The allowable value W_{th} in this case is 1.8, preferably 1.6, and more preferably 1.4. In the case of the first embodiment, one of the RMS wavefront aberrations W_1 for DVD and the RMS wavefront aberration W_2 for CD is the maximum RMS wavefront aberration W_{max}, and the other is the minimum RMS wavefront aberration W_{min}.

[0166] **FIGS. 2A** to **2C** are graphs showing the wavefront aberration of the first embodiment. The RMS wavefront aberration in HDDVD is 0.03152 λRMS, the RMS wavefront aberration in DVD is 0.03237 λRMS, and the RMS wavefront aberration in CD is 0.01764 λRMS. The RMS wavefront aberration of 0.035 λRMS or below, and further 0.033 λRMS or below are achieved in HDDVD, DVD, and CD.

[0167] The value of Expression 7 is:

$$\sqrt{\frac{\sum W_i^2}{i}} = \sqrt{\frac{0.03152^2 + 0.03237^2 + 0.01764^2}{3}}$$
$$= 0.028003$$

It is 0.0 035 λRMS or below, and also 0.033 λRMS or below.

[0168] **FIGS. 10A** to **10C** are graphs showing the optical spot of the first embodiment. The diameter of the optical spot having a relative luminous intensity of $1/e^2$ (=0.135) is 0.5149 μm for Blu-ray with 405 nm, 0.8606 μm for DVD with 655 nm, and 1.3979 μm for CD with 790 nm.

[0169] The optical spot diameter is approximately 0.82*wavelength/NA in an ideal optical system having no aberration. In an actual lens, the optical spot diameter is generally preferably smaller. Since other adverse effects can occur if the optical spot diameter is too small, it is preferred that the optical spot is 0.9 to 1.03 times the value of 0.82*wavelength/NA. Further, if the optical spot diameter is too small, it causes an adverse effect such as Super-resolution. If the optical spot diameter is too large, it causes deteriorated focusing characteristics of the optical spot, affecting jitter characteristics or the like.

[0170] Evaluation of the first embodiment is as follows.

[0171] In HDDVD (wavelength 405 nm; NA 0.650), 0.82*wavelength/NA=0.5109 μm. Since an actual optical spot diameter is 0.5149 μm, it is 1.0078 times the value of 0.82*wavelength/NA, thus being within a preferable range of 0.9 to 1.02.

[0172] In DVD (wavelength 655 nm; NA 0.628), 0.82*wavelength/NA=0.8553 μm. Since an actual optical spot diameter is 0.8606 μm, it is 1.0062 times the value of 0.82*wavelength/NA, thus being within a preferable range of 0.9 to 1.02.

[0173] In CD (wavelength 790 nm; NA 0.470), 0.82*wavelength/NA=1.3783μm. Since an actual optical spot diameter is 1.3979 μm, it is 1.0142 times the value of 0.82*wavelength/NA, thus being within a preferable range of 0.9 to 1.02.

[0174] Further, this lens is designed so that the wavefront aberration appears on the positive (+) side in the wavelength of 655 nm (DVD), and on the negative (−) side in the wavelength of 405 nm (HDDVD). The wavefront aberration is thus substantially symmetrical.

[0175] **FIG. 11** shows a difference in substantial optical path length between zone **1** and zones **2** to **9**. The difference in optical path length between zone **1** and zones **2** to **8** is mλ (m is an integral number) for the wavelength of 655 nm (DVD), DVD and the wavelength of 790 nm (CD), and it is 2mλ (m is an integral number) for the wavelength of 405 nm (HDDVD).

[0176] As described in the foregoing, the first embodiment allows the aberration to fall within the above allowable range. This is achieved by designing the lens surface shape and setting the divergence of incident light to the objective lens that make the aberration within the allowable range, considering each wavelength and each substrate thickness.

[0177] The effect of the first embodiment to reduce the overall aberration is obvious from the graphs of the optical spot shown in **FIGS. 10A** to **10**C and the graphs of the wavefront aberration shown in **FIGS. 2A** to **2**C. Further, in the first embodiment, the surface shape of the light incident surface A of the objective lens **1** is given by Expression 5 and **FIG. 7**, and the surface shape of the light exit surface B is given by Expression 6 and **FIG. 8**. Therefore, the first embodiment does not use the diffraction lens structure employed in conventional lenses described earlier, such as the lenses in Japanese Patent Unexamined Publication No. 09-145995 and 2000-81566. Further, since the first embodiment can focus the substantially entire light flux for the aperture (NA) required for recording or reproducing, it is possible to obtain a high light use efficiency.

[0178] Though the first embodiment describes the case of using three kinds of optical disks, HDDVD, DVD, and CD, this invention is not limited thereto but is also applicable to the case of using other kinds of optical disks. Further, the first embodiment is applicable to the optical disk having the same or different substrate thickness. In this case, it changes the wavelength of the laser beam to be used for each disk and designs the lens surface shape so as to reduce the overall aberration according to it.

Second Embodiment

[0179] A second embodiment of the invention describes a case where the substrate thickness is different and the wavelength is also different (405 nm, 655 nm, and 790nm). Specifically, the second embodiment relates to the case of using Blu-ray or Blue laser with the wavelength of 405 nm and the substrate thickness of 0.1 mm, the case of using DVD with the wavelength of 655 nm and the substrate thickness of 0.6 mm, and the case of using CD with the wavelength of 790 nm and the substrate thickness of 1.2 mm.

[0180] In the second embodiment, the basic lens structure is the same as in the first embodiment shown in **FIG. 6**. Specifically, for Blu-ray and DVD, parallel light is incident to the side A to form a suitable optical spot on an information recording surface of a disk substrate (not shown) in the side B. For CD, divergent light is incident to the side A to form a suitable optical spot on an information recording surface of a disk substrate (not shown) in the side B.

[0181] On the side A in the light source side, the relationship between Z_A and h is expressed by Expression 5. The specific values are shown in the tables of FIGS. **12** to **15** for each zone **1** to **22**. On the other hand, on the side B in the disk side which is opposite to the light source, the relationship between Z_B and h is expressed by Expression 6. The specific values are shown in the table of **FIG. 16**. In FIGS. **12** to **16**, R represents curvature radius, "small" represents the optical axis side, and "large" represents the side apart from the optical axis.

[0182] The refractive index of the objective lens in the second embodiment is close to the refractive index of a glass with a high refractive index, which is the refractive index of VD89, for example.

[0183] A distance between the surface apexes f and e on the optical axis of the objective lens **1**, which is the center thickness t_0, is 2.076 mm. The refractive index n for a wavelength λ_1=405 nm (Blu-ray disk) is 1.83164, the refractive index n for a wavelength λ_2=655 nm (DVD) is 1.7911, and the refractive index n for a wavelength λ_3=790 nm (CD) is 1.783555.

[0184] The transparent substrate of Blu-ray disk (wavelength λ_1=405 nm) has a thickness of 0.6 mm and a refractive index of 1.6235. The transparent substrate of DVD (wavelength λ_2=655 nm) has a thickness of 0.6 mm and a refractive index of 1.58. The transparent substrate of CD (wavelength λ_3=790 nm) has a thickness of 1.2 mm and a refractive index of 1.573. Therefore, a difference in refractive index between Blu-ray disk (wavelength λ_1=405 nm) and DVD (wavelength λ_2=655 nm) is 0.03 or higher, and a difference in refractive index between Blu-ray disk (wavelength λ_1=405 nm) and CD (wavelength λ_3=790 nm) is also 0.03 or higher.

[0185] In Blu-ray disk with a wavelength of 405nm, NA is 0.850 and a focal length is 1.765 mm. In DVD with a wavelength of 655 nm, NA is 0.600 and a focal length is 1.8564 mm. In CD with a wavelength of 790 nm, NA is 0.469 and a focal length is 1.8745 mm. The aperture diameters are as shown in **FIGS. 17A** to **17**C. The wavelength selective filter is used for aperture just like in the first embodiment.

[0186] **FIGS. 17A** to **17**C show the distance between optical components and their arrangement based on the objective lens in an optical system equivalent to that of FIGS. **12** to **16** for Blu-ray, DVD, and CD, respectively. The tables of **FIGS. 17A** to **17**C show an aperture, objective lens, disk, and an object surface for the objective lens. As shown in **FIG. 17A** to **17**C, in Blu-ray and DVD, for example, the incident light to the objective lens is parallel light, that is, a distance between the object surface for the objective lens and the objective lens is ∞. An actual optical system places a Blue laser or a DVD laser in the focal position of a collimator lens and inputs the output light from the collimator lens to the objective lens as parallel light.

[0187] In CD, a distance from the object surface to the objective lens is 15.5 mm, and divergent light is input to the objective lens. In the case of CD as well, a distance from an emission point of a CD laser to a surface apex of the objective lens in the light source side may be 15.5 mm in an actual optical system. In this case, however, an optical pickup becomes large.

[0188] It is preferred in this case to place the collimator lens between the CD laser light source and the objective lens, and places the emission point of the CD laser in the position closer to the collimator lens than the focal position of the collimator lens. In this arrangement, the light emitted from the CD laser and having passed through the collimator lens becomes divergent light and enters the objective lens. The collimator lens and the CD laser are preferably arranged so that the incident light to the objective lens becomes the same as the light emitted from a distance of 15.5 mm without collimator lens.

[0189] In the second embodiment shown in **FIGS. 17A** to **17**C, the relationship of S_1, S_2, and S_3 expressed by Expressions 1 and 2 is as follows:

Blu-ray:	λ_1 = 405 nm, $S_1 = \infty$,
DVD:	λ_2 = 655 nm, $S_2 = \infty$,
CD:	λ_3 = 790 nm, S_3 = 15.5 mm

Therefore,

$405\ nm(\lambda_1) < 790\ nm(\lambda_3)$.

Further,

$(1/S_1) = (1/\infty) = 0$,

$(1/S_3) = (1/15.5) = 0.064516129$

Therefore,

$0 < 0.064516129;\ (1/S_1) < (1/S_3)$

Hence, in Blu-ray and CD, $\lambda_1 < \lambda_3$ and $(1/S_1) < (1/S_3)$ are both satisfied.

Further, since

$655\ nm(\lambda_2) < 790\ nm(\lambda_3)$.

and

$(1/S_2) = (1/\infty) = 0$,

$(1/S_3) = (1/15.5) = 0.064516129$.

Therefore,

$0 < 0.064516129;\ (1/S_2) < (1/S_3)$

Hence, in DVD and CD, $\lambda_2 < \lambda_3$ and $(1/S_2) < (1/S_3)$ are both satisfied.

[0190] As shown in **FIG. 18**, the area in the side A up to the effective diameter ϕ2.228 where the range h is from 0 to 1.114, which is the zones **1** to **21** shown in **FIG. 18** is a common use area of DVD and Blu-ray. On the other hand, the outer area of the effective diameter ϕp2.228 where the range h exceeds 1.114, which is the zone **22** shown in **FIG. 18** is an exclusive use area of Blu-ray.

[0191] However, the light with the wavelength of 655 nm (DVD) passes though the Blu-ray exclusive use area with the wavelength selective filter. Therefore, the incident laser beam enters DVD and it becomes flare light having extremely high aberration on the information recording surface of DVD, which does not have any harmful effect.

[0192] This is obvious also from the optical spot graphs of **FIGS. 21A** to **21**C.

[0193] **FIGS. 19A** to **19**C are graphs showing the wavefront aberration of the second embodiment. The RMS wavefront aberration in Blu-ray is 0.02410 λRMS, the RMS wavefront aberration in DVD is 0.02753 λRMS, and the RMS wavefront aberration in CD is 0.02127 λRMS. The RMS wavefront aberration of 0.035 λRMS or below, and further 0.033 λRMS or below are achieved in Blu-ray, DVD, and CD.

[0194] The value of Expression 7 is:

$$\sqrt{\frac{\sum W_i^2}{i}} = \sqrt{\frac{0.02410^2 + 0.02753^2 + 0.02127^2}{3}} = 0.02443$$

It is 0.0 035 λRMS or below, and also 0.033 λRMS or below.

[0195] **FIG. 18** also shows the substantial optical path length in the Blu-ray/DVD common use area zones **2** to **21** is displaced about how many times the wavelength λ in each aspherical surface section shown in **FIGS. 17A** to **17**C when the substantial optical path length in zone **1** is a reference length.

[0196] **FIG. 18** shows that, in zones **2** to **21**, the difference in optical path length is 2mλ for the wavelength of 405 nm (Blu-ray), and it is mλ (m is an integral number) for the wavelength of 655 nm (DVD) and the wavelength of 790 nm (CD). Since the shorter wavelength λ_1 is between 380 nm and 430 nm, the longer wavelength λ_2 is between 630 nm and 680 nm, and λ_3 is about 790 nm, it is likely to satisfy the relationship of the difference in substantial optical path length described above and to obtain the suitable wavelength aberration shown in **FIGS. 19A** to **19**C.

[0197] Further, since the refractive index of the lens is the value described above, it is likely to obtain an appropriate difference in substantial optical path length and suitable wavelength aberration. Specifically, a different in refractive index between wavelengths 405 nm and 655 nm is 0.04054, and a difference in refractive index between wavelengths 405 nm and 790 nm is 0.048085. Since the both values are larger than 0.03, it is likely to produce an appropriate difference in substantial optical path length and suitable wavelength aberration.

[0198] **FIGS. 20A** to **20**C show a difference and a ratio of wavefront aberration between the wavelengths of 405 nm (Blu-ray) and 655 nm (DVD) in each aspherical surface section shown in **FIGS. 17A** to **17**C.

[0199] As shown in **FIGS. 20A** to **20**C, the ratio of difference in wavefront aberration ΔVd(λ655)/ΔVd(λ405) in the common use are of 655 nm and 405 nm is within the range of 0.90 to 1.65. Further, the ratio ΔVd(λ405)/ΔVd(λ655) is within the range of 0.60 to 1.11. The wavefront aberration in each section is 0.14 λ or below in the both wavelengths.

[0200] **FIGS. 21A** to **21**C are graphs showing the optical spot of the second embodiment. The diameter of the optical spot having a relative luminous intensity of $1/e^2$ (=0.135) is 0.3836 μm for Blu-ray with 405 nm, 0.8570 μm for DVD with 655 nm, and 1.4112 μm for CD with 790 nm.

[0201] Evaluation of the optical spot diameter in comparison with 0.82*wavelength/NA which is described in the first embodiment is as follows.

[0202] In Blu-ray (wavelength 405 nm; NA 0.850), 0.82*wavelength/NA=0.3907 μm. Since an actual optical spot diameter is 0.3836 μm, it is 0.9818 times the value of 0.82*wavelength/NA, thus being within a preferable range of 0.9 to 1.02.

[0203] In DVD (wavelength 655 nm; NA 0.600), 0.82*wavelength/NA=0. 8952 μm. Since an actual optical spot diameter is 0.8570 μm, it is 0.9574 times the value of 0.82*wavelength/NA, thus being within a preferable range of 0.9 to 1.02. In DVD, the optical spot diameter is smaller than in the ideal lens by about as much as 4% (0.04 times). This is because the DVD light passes through the Blu-ray exclusive use area also, and the optical spot diameter becomes smaller due to this effect.

[0204] In CD (wavelength 790 nm; NA 0.469), 0.82*wavelength/NA=1.3812 μm. Since an actual optical spot diameter is 1.4084 μm, it is 1.0197 times the value of 0.82*wavelength/NA, thus being within a preferable range of 0.9 to 1.02.

[0205] Though the wavelength of one monochromatic light is 405 nm and the wavelengths of the other monochromatic light are 655 nm and 790 nm in the second embodiment, the one may be 380 to 430 nm and the other may be 630 to 680 nm and 770 to 820 nm. While the refractive index differs in this case, it is designed in accordance with the value.

Third Embodiment

[0206] The configuration of a third embodiment of the invention (convergent light incidence in HDDVD) describes the case where an object length to CD is longer than in the first embodiment (parallel light incidence in HDDVD). In the first embodiment, the incident light to the objective lens is parallel light in HDDVD and DVD, and it is divergent light in CD. In the third embodiment, the incident light to the objective lens is convergent light in HDDVD, parallel light in DVD, and divergent light in CD. The configuration of the third embodiment (convergent light incidence in HDDVD) can increase the object distance to CD compared to the first embodiment the first embodiment (parallel light incidence in HDDVD). The coma aberration occurring off-axis is higher when divergent light is incident to the objective lens compared to when parallel light is incident to the objective lens. Therefore, when the objective lens is horizontally shifted (objective lens shift) in the plane substantially perpendicular to the optical axis for tracking, high comma aberration can occur. The degree of comma aberration is largely affected by the divergence of light. Smaller divergence or longer object distance can reduce comma aberration in the objective lens shift. Therefore, the configuration of the optical system of the third embodiment is advantageous in CD objective lens shift compared to the configuration of the first embodiment. However, since convergent light is incident to HDDVD, comma aberration occurs in HDDVD also during the objective lens shift. Thus, it is preferred to consider the balance of object distance (magnification) in HDDVD and CD. If the magnification in HDDVD is m**1** and magnification in CD is m**3**, it is preferable to satisfy:

$$0<m1\leqq 1/10,\ -1/10\leqq m3<0$$

[0207] If m**1** and m**3** are out of the above range, comma aberration in the objective lens shift increases. The following range is more preferable:

$$0<m1\leqq 1/20,\ -1/20\leqq m3<0$$

[0208] Though the lens in the third embodiment has a refractive index equivalent to plastic resin, it may be designed to have a refractive index of glass if a lens material is glass.

[0209] The basic lens structure of the third embodiment is described with reference to **FIG. 6** showing the first embodiment In the third embodiment, for HDDVD, convergent light is incident to the side A to form a suitable optical spot on an information recording surface of a disk substrate (not shown) in the side B. For CD, divergent light is incident to the side A to form a suitable optical spot on an information recording surface of a disk substrate (not shown) in the side B. For DVD, parallel light is incident to the side A to form a suitable optical spot on an information recording surface of a disk substrate (not shown) in the side B.

[0210] On the side A in the light source side, the relationship between Z_A and h is expressed by Expression 5. The specific values are shown by the table of **FIG. 22** for each zone **1** to **7**.

[0211] A distance between the surface apexes f and e on the optical axis of the objective lens **1**, which is the center thickness t_0, is 1.92 mm. The refractive index n for a wavelength λ_1=408 nm (HDDVD) is 1.5229, the refractive index n for a wavelength λ_2=658 nm (DVD) is 1.5048, and the refractive index n for a wavelength λ_3=785 nm (CD) is 1.5018.

[0212] The transparent substrate of HDDVD (wavelength λ_1=408 nm) has a thickness of 0.6 mm and a refractive index of 1.622. The transparent substrate of DVD (wavelength λ_2=658 nm) has a thickness of 0.6 mm and a refractive index of 1.577. The transparent substrate of CD (wavelength λ_3=785 nm) has a thickness of 1.2 mm and a refractive index of 1.5720.

[0213] In HDDVD with a wavelength of 408 nm, NA is 0.650 and a focal length is 3.101 mm. In DVD with a wavelength of 658 nm, NA is 0.650 and a focal length is 3.2059 mm. In CD with a wavelength of 785 nm, NA is 0.470 and a focal length is 3.2246 mm. The aperture diameters are as shown in **FIGS. 23A** to **23**C. The wavelength selective filter is used for aperture just like in the first embodiment.

[0214] The tables of **FIGS. 23A** to **23**C show the distance between optical components and their arrangement based on the objective lens in an optical system equivalent to that of FIGS. **1** for HDDVD, DVD, and CD, respectively. **FIGS. 23A** to **23**C show an aperture, objective lens, disk, and an object surface for the objective lens. As shown in **FIG. 23A** to **23**C, in HDDVD, for example, the incident light to the objective lens is convergent light. Thus a distance between the object surface for the objective lens and the objective lens is negative, −93.9 mm. An actual optical system places a collimator lens between a HDDVD laser light source and an objective lens, and places an emission point of the HDDVD laser in the position apart from the collimator lens compared with the focal position of the collimator lens. In this arrangement, the light emitted from the HDDVD laser and having passed through the collimator lens becomes convergent light and enters the objective lens. In DVD, the incident light to the objective lens is parallel light, that is, a distance between the object surface for the objective lens and the objective lens is ∞. An actual optical system places a DVD laser in the focal position of a collimator lens and inputs the output light from the collimator lens to the objective lens as parallel light.

[0215] In CD, a distance from the object surface to the objective lens is 98.9113.0 mm, and divergent light is input to the objective lens. In an actual optical system, a distance from an emission point of a CD laser to a surface apex of the objective lens in the light source side may be 98.9113 mm. In this case, however, an optical pickup becomes large. It is thus preferred to place the collimator lens between the CD laser light source and the objective lens, and places the emission point of the CD laser in the position closer to the collimator lens than the focal position of the collimator lens. In this arrangement, the light emitted from the CD laser and having passed through the collimator lens becomes divergent light and enters the objective lens. The collimator lens and the CD laser are preferably arranged so that the incident light to the objective lens becomes the same as the light emitted from a distance of 98.9113 mm without collimator lens.

[0216] In the third embodiment shown in **FIGS. 23A** to **23**C, the relationship of S_1, S_2, and S_3 expressed by Expressions 1 and 2 is as follows:

HDDVD:	λ_1 = 408 nm, S_1 = −93.9,
DVD:	λ_2 = 658 nm, S_2 = ∞,
CD:	λ_3 = 785 nm, S_3 = 113.0 mm

Therefore,

$408\ nm(\lambda_1)<785\ nm(\lambda_3)$.

Further,

$(1/S_1)=(1/-93.9)=-0.010649627$,

$(1/S_3)=(1/113.0)=0.008849557$

Therefore,

$-0.010649627<0.008849557;\ (1/S_1)<(1/S_3)$

[0217] Hence, in HDDVD and CD, $\lambda_1<\lambda_3$ and $(1/S_1)<(1/S_3)$ are both satisfied.

[0218] Further, since magnification ml of HDDVD is 1/31.2, and magnification m**3** of CD is −1/34.1, 0<m**1**≦1/20 and −1/20≦m**3**<0 are both satisfied.

[0219] Further,

$658\ nm(\lambda_2)<785\ nm(\lambda_3)$

and

$(1/S_2)=(1/\infty)=0$,

$(1/S_3)=(1/113.0)=0.008849557$.

Therefore,

$0<0.008849557;\ (1/S_2)<(1/S_3)$

[0220] Hence, in DVD and CD, $\lambda_2<\lambda_3$ and $(1/S_2)<(1/S_3)$ are both satisfied.

[0221] As shown in **FIG. 22**, the area in the side A up to the effective diameter ϕ3.8932 mm where the range h is from 0 to 1.94658, which is the zones **1** to **6** shown in **FIG. 22** is a common use area of DVD and HDDVD. On the other hand, the outer area of the effective diameter ϕ3.8932 where the range h exceeds 1.94658, which is the zone **7** shown in **FIG. 22** is an exclusive use area of DVD.

[0222] However, the light with the wavelength of 408 nm (HDDVD) also passes though the DVD exclusive use area with the wavelength selective filter. Therefore, the laser beam emitted from the laser enters HDDVD after passing through the objective lens. Since the incident light becomes flare light having extremely high aberration on the information recording surface of HDDVD, it does not have any harmful effect.

[0223] The wavelength selective filter as shown in **FIG. 24** may be used. The wavelength selective filter is sectioned into an inner entire light transmitting area **61**, an intermediate CD (785 nm) light shielding area **62**, and an outer HDDVD (408 nm) and CD (785 nm) light shielding area **63** as shown in **FIG. 24**. For example, a dichroic coating that reflects the light having a 750 nm or higher wavelength may be deposited on the intermediate CD light shielding area **62**, and a dichroic coating that allows only the light having a 600 to 700 nm wavelength to pass through is deposited on the outer HDDVD and CD light shielding area **63**. Thereby, the numerical aperture (NA) of HDDVD is 0.650, NA of DVD is 0.650, and NA of CD is 0.470.

[0224] **FIGS. 25A** to **25**C are graphs showing the wavefront aberration of the third embodiment.

[0225] The RMS wavefront aberration in HDDVD is 0.03253 λRMS, the RMS wavefront aberration in DVD is 0.03178 λRMS, and the RMS wavefront aberration in CD is 0.02091 λRMS. Thus, the RMS wavefront aberration of 0.035 λRMS or below, and further 0.033 λRMS or below are achieved in HDDVD, DVD, and CD.

[0226] The value of Expression 7 is:

$$\sqrt{\frac{\sum W_i^2}{i}} = \sqrt{\frac{0.03253^2 + 0.03178^2 + 0.02091^2}{3}} = 0.02890$$

It is 0.0 035 λRMS or below, and also 0.033 λRMS or below.

[0227] **FIG. 26** shows the comma aberration (third order) that occurs in CD (NA=0.470) objective lens shift of 0.3 mm in the objective lens of the first embodiment and the objective lens of the third embodiment. In the first embodiment, the incident light to the objective lens is parallel light in HDDVD and DVD while it is divergent light in CD, and an object distance in CD is 49.4 mm. In the third embodiment, the incident light to the objective lens is convergent light in HDDVD, parallel light in DVD, and divergent light in CD, and an object distance in CD is thereby 113.0 mm, which is longer than in the first embodiment. As a result, as shown in **FIG. 26**, the comma aberration during the CD objective lens shift, which is 0.0469 λRMW in the objective lens of the first embodiment, is reduced to 0.0177 λRMW in the objective lens of the third embodiment.

[0228] **FIG. 27** also shows the substantial optical path length in the HDDVD/DVD common use area zones **2** to **6** is displaced about how many times the wavelength λ in each aspherical surface section shown in **FIGS. 22A** to **22**C when the substantial optical path length in zone **1** is a reference length.

[0229] **FIG. 27** shows that, in zones **2** to **6**, the difference in optical path length is 2 mλ for the wavelength of 408 nm (HDDVD), and it is mλ (m is an integral number) for the wavelength of 658 nm (DVD) and the wavelength of 785 nm (CD). Since the shorter wavelength λ_1 is between 380 nm and 430 nm, the longer wavelength λ_2 is between 630 nm and 680 nm, and λ_3 is about 790 nm, it is likely to satisfy the relationship of the difference in substantial optical path length described above and to obtain the suitable wavelength aberration shown in **FIGS. 25A** to **25**C.

[0230] **FIGS. 28A** to **28**C are graphs showing the optical spot of the third embodiment. The diameter of the optical spot having a relative luminous intensity of $1/e^2$ (=0.135) is

0.5029 μm for HDDVD with 408 nm, 0.8236 μm for DVD with 658 nm, and 1.3811 μm for CD with 785 nm, which are within an allowable range.

[0231] Evaluation of the optical spot diameter in comparison with 0.82*wavelength/NA which is described in the first embodiment is as follows.

[0232] In HDDVD (wavelength 408 nm; NA 0.650), 0.82*wavelength/NA=0.5147 μm. Since an actual optical spot diameter is 0.5029 μm, it is 0.9771 times the value of 0.82*wavelength/NA, thus being within a preferable range of 0.9 to 1.02. In HDDVD, the optical spot diameter is smaller than that of the ideal lens by about as much as 2.3% (0.023 times). This is because the HDDVD light passes through the DVD exclusive use area also, and the optical spot diameter becomes smaller due to this effect.

[0233] In DVD (wavelength 658 nm; NA 0.65), 0.82*wavelength/NA=0.8301 μm. Since an actual optical spot diameter is 0.8236 μm, it is 0.9922 times the value of 0.82*wavelength/NA, thus being within a preferable range of 0.9 to 1.02.

[0234] In CD (wavelength 785 nm; NA 0.470), 0.82*wavelength/NA=1.3696 μm. Since an actual optical spot diameter is 1.3811 μm, it is 1.0084 times the value of 0.82*wavelength/NA, thus being within a preferable range of 0.9 to 1.02.

[0235] Though the wavelengths of monochromatic light are 408 nm, 658 nm, and 785 nm in the third embodiment, they may be 380 to 430 nm, 630 to 680 nm, and 770 to 820 nm, respectively. While the refractive index differs in this case, it may be designed in accordance with these values. Further, the incident light to the objective lens is parallel light in HDDVD and DVD, and it is divergent light in CD in the first embodiment, and the incident light to the objective lens is convergent light in HDDVD, parallel light in DVD, and divergent light in CD in the third embodiment. However, it is not limited to these combinations. For example, it is possible to use convergent light in HDDVD and DVD and divergent light in CD. If the object distance is the same in HDDVD and DVD, it is possible to use the same optical detector for both HDDVD and DVD.

Fourth Embodiment

[0236] A fourth embodiment of the invention describes the case where the substrate thickness is different and the wavelength is also different (408 nm, 655 nm, and 790 nm), which is similar to the second embodiment. In this embodiment, the objective lens is made of different material from the objective lens in the second embodiment.

[0237] In the second embodiment, it is expected that an objective lens is made of glass having a high melting point and a high thermal deformation temperature (Tg=528° C.), such as VC89, for example. On the other hand, in the fourth embodiment, it is expected that an objective lens is made of glass having a low melting point and a low thermal deformation temperature (Tg=228° C.), such as K-PG325 manufactured by SUMITA optical glass, inc., for example. A difference in objective lens material between the second and fourth embodiments is comparatively described below.

[0238] Since the glass with a high refractive index such as VC89 has a high melting point of 600° C. or above, it requires a carbide die in which it is difficult to provide a microstructure on its surface as a lens molding die that is endurable for the temperature. Further, since it takes a long time to reduce the temperature to a normal temperature after lens molding, it causes low productivity per hour. On the other hand, the glass with a low refractive index such as K-PG325 has a low melting point of about 300° C., it is possible to use an equivalent lens molding die to the one used for plastic material, in which it is easy to provide a microstructure such as orbicular zones. Further, since it takes only a short time to reduce the temperature to a normal temperature, it achieves high productivity per hour. In the following, the material that is mainly composed of glass with a refractive index of 1.49 to 1.70 and a thermal deformation temperature of 300° C. or below is called "low-melting glass".

[0239] The refractive index of the low-melting glass is 1.49 to 1.70 for light of 408 nm, for example, which is lower than normal glass such as VC89. Therefore, optical design of a high NA lens is difficult to make since the low-melting glass has a low refractive index. This embodiment secures the characteristics when using the low-melting glass as material of the objective lens by increasing the center thickness of the lens to 2.642 mm. Though the low-melting glass has substantially the same refractive index as plastic material, it is more advantageous as objective lens material in having higher temperature/humidity characteristics than the plastic material.

[0240] Specifically, the fourth embodiment relates to the case of using Blu-ray or light emitted from Blue laser with the wavelength of 408 nm and the substrate thickness of 0.0875 mm, the case of using DVD with the wavelength of 655 nm and the substrate thickness of 0.6 mm, and the case of using CD with the wavelength of 790 nm and the substrate thickness of 1.2 mm. It uses the low-melting glass as lens material.

[0241] In the fourth embodiment, the basic lens structure is the same as in the first embodiment shown in **FIG. 6**. Specifically, for Blu-ray and DVD, parallel light is incident to the side A to form a suitable optical spot on an information recording surface of a disk substrate (not shown) in the side B. For CD, divergent light is incident to the side A to form a suitable optical spot on an information recording surface of a disk substrate (not shown) in the side B.

[0242] On the side A in the light source side, the relationship between Z_A and h is expressed by Expression 5. The specific values are shown in the tables of FIGS. **29** to **34** for each zone. On the other hand, on the side B in the disk side which is opposite to the light source, the relationship between Z_B and h is expressed by Expression 6. The specific values are shown in the table of **FIG. 35**. In FIGS. **29** to **35**, R represents curvature radius, "small" represents the optical axis side, and "large" represents the side apart from the optical axis.

[0243] A distance between the surface apexes f and e on the optical axis of the objective lens **1**, which is the center thickness t_0, is 2.642 mm. The refractive index n for a wavelength λ_1=408 nm (Blu-ray disk) is 1.5126, the refractive index n for a wavelength λ_2=655 nm (DVD) is 1.4987, and the refractive index n for a wavelength λ_3=790 nm (CD) is 1.4958.

[0244] The transparent substrate of Blu-ray disk (wavelength λ_1=408 nm) has a thickness of 0.0875 mm and a refractive index of 1.6205. The transparent substrate of DVD (wavelength λ_2=655 nm) has a thickness of 0.6 mm and a refractive index of 1.5794. The transparent substrate of CD (wavelength λ_3=790 nm) has a thickness of 1.2 mm and a refractive index of 1.5725. Therefore, a difference in refractive index between Blu-ray disk (wavelength λ_1=408 nm) and DVD (wavelength λ_2=655 nm) is 0.03 or higher, and a difference in refractive index between Blu-ray disk (wavelength λ_1=408 nm) and CD (wavelength λ_3=790 nm) is also 0.03 or higher.

[0245] In Blu-ray disk with a wavelength of 408 nm, NA is 0.850 and a focal length is 2.3721 mm. In DVD with a wavelength of 655 nm, NA is 0.650 and a focal length is 2.4262 mm. In CD with a wavelength of 790 nm, NA is 0.510 and a focal length is 2.4378 mm. The aperture diameters are as shown in **FIGS. 36A** to **36**C. The wavelength selective filter is used for aperture just like in the first embodiment.

[0246] **FIGS. 36A** to **36**C show the distance between optical components and their arrangement based on the objective lens in an optical system equivalent to that of FIGS. **29** to **35** for Blu-ray, DVD, and CD, respectively. The tables of **FIGS. 36A** to **36**C show an aperture, objective lens, disk, and an object surface for the objective lens. As shown in **FIG. 36A** to **36**C, in Blu-ray and DVD, for example, the incident light to the objective lens is parallel light, that is, a distance between the object surface for the objective lens and the objective lens is ∞. An actual optical system places a Blue laser or a DVD laser in the focal position of a collimator lens and inputs the output light from the collimator lens to the objective lens as parallel light.

[0247] In CD, a distance from the object surface to the objective lens is 19.35 mm, and divergent light is input to the objective lens. In the case of CD as well, a distance from an emission point of a CD laser to a surface apex of the objective lens in the light source side may be 19.35 mm in an actual optical system. In this case, however, an optical pickup becomes large.

[0248] It is preferred in this case to place the collimator lens between the CD laser light source and the objective lens, and places the emission point of the CD laser in the position closer to the collimator lens than the focal position of the collimator lens. In this arrangement, the light emitted from the CD laser and having passed through the collimator lens becomes divergent light and enters the objective lens. The collimator lens and the CD laser are preferably arranged so that the incident light to the objective lens becomes the same as the light emitted from a distance of 19.35 mm without collimator lens.

[0249] In the fourth embodiment shown in **FIGS. 36A** to **36**C, the relationship of S_1, S_2, and S_3 expressed by Expressions 1 and 2 is as follows:

Blu-ray:	λ_1 = 408 nm, S_1 = ∞,
DVD:	λ_2 = 655 nm, S_2 = ∞,
CD:	λ_3 = 790 nm, S_3 = 19.35 mm

Therefore,

$$408\ nm(\lambda_1)<790\ nm(\lambda_3).$$

Further,

$$(1/S_1)=(1/\infty)=0,$$

$$(1/S_3)=(1/19.35)=0.05168$$

Therefore,

$$0<0.05168;\ (1/S_1)<(1/S_3)$$

Hence, in Blu-ray and CD, $\lambda_1<\lambda_3$ and $(1/S_1)<(1/S_3)$ are both satisfied.

Further, since

$$655\ nm(\lambda_2)<790\ nm(\lambda_3)$$

and

$$(1/S_2)=(1/\infty)=0,$$

$$(1/S_3)=(1/19.35)=0.05168.$$

Therefore,

$$0<0.05168;\ (1/S_2)<(1/S_3).$$

Hence, in DVD and CD, $\lambda_2<\lambda_3$ and $(1/S_2)<(1/S_3)$ are both satisfied.

[0250] As shown in **FIG. 37**, the area in the side A up to the effective diameter ϕ3.153 where the range h is from 0 to 1.5765, which is the zones **1** to **29** shown in **FIG. 37** is a common use area of DVD and Blu-ray. On the other hand, the outer area of the effective diameter ϕ3.153 where the range h exceeds 1.5765, which is the zones **30** and **31** shown in **FIG. 37** is an exclusive use area of Blu-ray.

[0251] However, the light with the wavelength of 655 nm (DVD) passes though the Blu-ray exclusive use area with the wavelength selective filter. Therefore, the incident laser beam enters DVD and it becomes flare light having extremely high aberration on the information recording surface of DVD, which does not have any harmful effect.

[0252] **FIGS. 38A** to **38**C are graphs showing the wavefront aberration of the fourth embodiment. The RMS wavefront aberration in Blu-ray is 0.03210 λRMS, the RMS wavefront aberration in DVD is 0.03740 λRMS, and the RMS wavefront aberration in CD is 0.04320 λRMS. Thus, the RMS wavefront aberration is 0.045 λRMS or below in Blu-ray, DVD, and CD.

[0253] **FIG. 37** also shows the substantial optical path length in the Blu-ray/DVD common use area zones **2** to **29** is displaced about how many times the wavelength λ in each aspherical surface section shown in **FIGS. 36A** to **36**C when the substantial optical path length in zone **1** is a reference length.

[0254] **FIG. 37** shows that, in zones **2** to **21**, the difference in optical path length is 2 mλ for the wavelength of 408 nm (Blu-ray), and it is mλ (m is an integral number) for the wavelength of 655 nm (DVD) and the wavelength of 790 nm (CD). Since the shorter wavelength λ_1 is between 380 nm and 430 nm, the longer wavelength λ_2 is between 630 nm and 680 nm, and λ_3 is about 790 nm, it is likely to satisfy the relationship of the difference in substantial optical path length described above and to obtain the suitable wavelength aberration shown in **FIGS. 38A** to **38**C.

[0255] Though the wavelengths of one monochromatic light are 408 nm, 655 nm and 790 nm in the fourth embodiment, they may be 380 to 430 nm, 630 to 680 nm and

770 to 820 nm, respectively. While the refractive index differs in this case, it may be designed in accordance with the value.

[0256] As described in the foregoing, the fourth embodiment forms the objective lens of NA=0.85 with the material mainly composed of glass with the refractive index of 1.49 to 1.70 for the light of 408 nm. Since material with a low melting point of about 300° C., for example, can be used as the low-refractive index material, it is possible to produce the lens with a normal die and thereby increase productivity.

Fifth Embodiment

[0257] **FIG. 39** shows the film structure of a wavelength selective filter (sharp-cut filter) by 16-layer coating. The wavelength selective filter is composed of SiO_2 layers and Ta_2O_5 layers that are laminated on one another on a glass substrate made of BK7. The refractive index shown in **FIG. 39** is a value for the light of 780 nm. **FIG. 40** shows the spectral transmittance characteristics of the wavelength selective filter having the structure of **FIG. 39**. The transmittance of the CD wavelength 780 nm to 790 nm is as low as 1%, thus being suitable. The spectral transmittance characteristics shown in the graph of **FIG. 40** remain the same even if the refractive index or the thickness of the film structure shown in **FIG. 39** are deviated by about 0.5% to 1% due to manufacturing error.

[0258] On the other hand, the 16-layer coating causes high costs due to a large number of coats. **FIG. 41** shows the film structure of the wavelength selective filter by 10-layer coating. The refractive index shown in **FIG. 41** is a value for the light of 810 nm. **FIG. 42** shows the spectral transmittance characteristics of the wavelength selective filter having the structure of **FIG. 41**. The transmittance of the CD wavelength 780 nm to 790 nm is about 7% to 8%. Though the transmittance characteristics are deteriorated compared to the 16-layer coating wavelength selective filter, it is not too significant to affect the CD recording and reproducing characteristics, and thus sufficient for practical use. The 10-layer coating wavelength selective filter can reduce costs compared to the 16-layer coating wavelength selective filter. The spectral transmittance characteristics shown in the graph of **FIG. 42** remain the same even if the refractive index or the thickness of the film structure shown in **FIG. 41** are deviated by about 0.5% to 1% due to manufacturing error.

[0259] The wavelength selective filter preferably has a transmittance of 10% or lower for a CD wavelength (770 to 800 nm). A more preferable transmittance is 5% or lower, and the most preferable transmittance is 2% or lower.

[0260] Further, the wavelength selective filter preferably has a transmittance of 85% or higher for Blu-ray and DVD wavelength (380 to 700 nm). A more preferable transmittance is 90% or higher, and the most preferable transmittance is 95% or lower.

[0261] Though the wavelength selective filter shown in FIGS. **39** to **42** is formed on a glass substrate, separated from an objective lens, it may be coated on one side of the objective lens. In this case, it is preferably coated on an almost flat surface of the objective lens facing to the disk. This allows easy formation of a uniform film. Further, if the refractive index of the wavelength selective filter and the refractive index of the objective lens are substantially equal, it is possible to achieve the similar design to the coating design in the embodiment shown in FIGS. **39** to **42**, which facilitates manufacturing. In this embodiment, the refractive index of the objective lens such as plastic is 1.54 to 1.55, and the refractive index of BK7 is 1.51; therefore, the both refractive indexes are substantially the same. The refractive index of the wavelength selective filter is preferably within the range of 0.9 to 1.1 with respect to the refractive index of the objective lens.

Sixth Embodiment

[0262] A sixth embodiment of the invention is described hereinafter with reference to the drawings. This embodiment describes an objective lens that focuses laser light on an optical recording medium as an optical component included in an optical pickup device. The optical pickup device is compatible with CD, DVD, and Blu-ray disk. The optical component is not limited to the objective lens, and it is possible to achieve an effect of the invention if it is an optical member through which light with three kinds of wavelength regions pass.

[0263] An antireflection coating used in this invention is composed of layers with a high refractive index and layers with a low refractive index laminated on one another on an optical component. Material of the layer with a high refractive index is at least one selected from oxides such as aluminum oxide, zirconium oxide, titanium oxide, tantalum oxide, niobium oxide, antimonyoxide, cerium oxide, yttrium oxide, hafnium oxide and magnesium oxide, nitrides such as silicon nitride and germanium nitride, carbides such as silicon carbide, sulfides such as zinc sulfide, and mixed material of these. Material of the layer with a low refractive index is at least one selected from silicon oxide, fluorides such as magnesium fluoride, aluminum fluoride, barium fluoride, calcium fluoride, lithium fluoride, sodium fluoride, strontium fluoride, yttrium fluoride, chiolite and cryorite, and mixed material of these. It is preferred to use oxide, nitride, carbide and fluoride to obtain high retention characteristics under a high temperature and high humidity environment.

[0264] The antireflection coating of this invention is formed by vacuum deposition, for example. In the vacuum deposition process, various deposition techniques such as vacuum evaporation, sputtering, chemical vapor deposition, reservation, and so on. When performing the vacuum evaporation, it is effective to ionize part of vapor flow in order to improve the film property and use ion plating that applies bias to a substrate, cluster ion beam, and ion assisted deposition that applies ion to a substrate with ion gun. The sputtering involves DC reactive sputtering, RF sputtering, ion beam sputtering, and so on. The chemical vapor deposition involves plasma polymerization, light assisted deposition, thermal decomposition, organic metal chemical vapor deposition, and so on. It is possible to create a desired film thickness by adjusting a deposition time during film formation and so on.

[0265] The optical component may be composed of any optical material that is transparent in a use band, including plastic such as polyolefin resin, cycloolefin resin, methacrylic resin and polycarbonate resin, optical glass such as quartz glass and borosilicate glass, oxide single crystal or polycrystal substrate such as Al_2O_3 and MgO, fluoride single crystal or polycrystal substrate such as CaF_2, MgF_2, BaF_2 and LiF, chlorides such as NaCl, KBr and KCl, and bromide single crystal or polycrystal substrate. The principle of the effect of the antireflection coating is described hereinafter with reference to **FIG. 43**. **FIG. 43** is a sectional view schematically illustrating the objective lens **1** having a two-layer antireflection coating on its surface. The antireflection coating has a high refractive index layer **8** and a low refractive index layer **7**.

[**0266**] Reflected light R when light O is incident on the objective lens **1** is described below. Though **FIG. 43** expediently illustrates the light O incident on the objective lens obliquely, the light O is incident on the lens parallel to the optical axis of the objective lens **1**. The light O first enters the low refractive index layer **7**. The light O is divided into transmission light P and reflected light R1 at the surface of the low refractive index layer **7**. Then, the transmission light P enters the high refractive index layer **8** through the low refractive index layer **7**. At the boundary between the low refractive index layer **7** and the high refractive index layer **8**, the transmission light P is divided into transmission light Q and reflected light R2. Then, the transmission light Q reaches the objective lens **1** through the high refractive index layer **8** and is reflected at the boundary between the high refractive index layer **8** and the objective lens **1** to become reflected light R3.

[**0267**] Though some light enters the objective lens **1** without becoming the reflected light R3 at the boundary between the high refractive index layer **8** and the objective lens **1**, the description is omitted since it is not necessary to describe the reflected light R. Further, though the reflected light R2 includes component that is multiply reflected at a reflectance of about 5% on the upper and lower boundaries of the low refractive index layer **7**, and the reflected light R3 includes component that is multiply reflected at a reflectance of about 5% on the upper and lower boundaries of the high refractive index layer. However, the intensity of the light of these components becomes as low as 0.25% or below after being reflected twice or more, and the description is also omitted here.

[**0268**] The reflected light R is synthesized light of the reflected light R1 to R3 shown in **FIG. 43**. Thus, the state of the reflected light R changes by a phase difference in the reflected light R1 to R3. The phase difference in the reflected light R1 and R2 is defined by the relationship of the objective lens **1**, the refractive index n_H of the high refractive index layer **8** and the refractive index n_L of the low refractive index layer **7**, and optical film thickness of the high refractive index layer **8** and the low refractive index layer **7**, and the wavelength of the light O.

[**0269**] The basic principal is as follows. For example, the optical film thickness of the low refractive index layer **7** is one-fourth of the wavelength of the light O. In this case, the phase difference between the reflected light R1 and R2 corresponds to one-half the wavelength of the light O, and therefore the reflected light R1 and R2 cancel out each other. As a result, only the reflected light R3 becomes reflected light R. Thus, the light intensity ratio of the reflected light R3 with respect to the light O is reflectance in this wavelength region. On the other hand, if the wavelength of the light O is changed while keeping the conditions of the objective lens **1**, the high refractive index layer **8** and the low refractive index layer **7**, the reflected light R1 to R3 cancel out each other in some cases. The reflectance is low in this wavelength region.

[**0270**] Using this principle, if an antireflection coating that minimizes a reflectance in the vicinity of the wavelength region corresponding to the wavelength used for Blu-ray disk (about 405 nm) and in the vicinity of the wavelength region corresponding to the wavelength used for DVD (about 655 nm) while reducing a reflectance in the wavelength region corresponding to the wavelength used for CD (790 nm) is formed on the surface of the objective lens **1**, it is possible to produce a high performance optical pickup apparatus compatible with the three kinds of optical media.

[**0271**] An example of simulation by setting the conditions for the objective lens **1**, the high refractive index layer **8** and the low refractive index layer **7** based on the above principle is as follows. In the simulation and example described below, the film thickness d_H of the high refractive index layer **8** and the film thickness d_L of the low refractive index layer **7** are determined on the basis of one-fourth of a given wavelength (QW). The given wavelength corresponds to the wavelength of the light O shown in **FIG. 43**, and it is 500 nm in this embodiment. The value of n_Hd_H (optical film thickness of the high refractive index layer **8**) is about 1 QW in this embodiment as in the description of **FIG. 43**, and the value of n_Ld_L (optical film thickness of the low refractive index layer **7**) is about 2 QW. Thus, 225 nm$\leqq n_Hd_H \leqq$275 nm and 100 nm$\leqq n_Ld_L \leqq$150 nm.

[**0272**] **FIGS. 44A** to **44F** show simulations of a change in the reflectance in the three kinds of wavelength regions accompanying a change in the refractive index of the high refractive index layer **8** with respect to the objective lens **1** and the low refractive index layer **7**. The values of the reflectance in each wavelength region show a maximum reflectance in the wavelength 405±5 nm (hereinafter as λ_1), a maximum reflectance in the wavelength 655±20 nm (hereinafter as λ_2), and a minimum reflectance in the wavelength 790±20 nm (hereinafter as λ_3). n_5 represents a refractive index of an objective lens, n_L represents a refractive index of a low refractive index layer, and n_H represents a refractive index of a high refractive index layer.

[**0273**] The table of **FIG. 44A** shows an example that uses APEL, which is a registered trademark of and manufactured by Mitsui Chemicals, Inc., as an objective lens and uses SiO_2 as a low refractive index layer. In the table, the data in the heavy lines indicates the most suitable simulation result. **FIG. 45** shows the graph of the reflectance for each wavelength when n_H is 1.75, 1.85, and 1.95 and in a single low refractive index layer under the conditions shown in the table of **FIG. 44A**. The reflectance value for the wavelength creates a curving line with two nodes having the minimum values in the vicinity of λ_1 and λ_2. The reflectance is low also in the vicinity of λ_3. Since the reflectance of a single APEL is 4.5%, the reflectance is reduced in a desired wavelength region by use of the antireflection coating. Further, a comparative example of the single low refractive index layer also shows that the reflectance is reduced for the three kinds of wavelength regions.

[**0274**] **FIG. 44B** shows a simulation where n_s=1.70 and the other conditions are the same as in **FIG. 44A**. Similarly, **FIG. 44C** shows a simulation where n_s=1.85. Since n_H

needs to be higher than n_s, an available lower limit of n_H is higher than the case of n_s=1.54 and the amount of data decreases.

[0275] **FIG. 46** shows the graph of reflectance for each wavelength under the conditions of **FIG. 4C** when n_H is 1.95, 2.05, and 2.15 and in a single low refractive index layer. The reflectance for the wavelength has its minimum value in the vicinity of λ_1 and λ_2. However, compared to the curving line of **FIG. 45**, a change in reflectance in the wavelength region from λ_2 and λ_3 or higher is steep, and the reflectance is very high for λ_3. Since the reflectance of the objective lens **1** is 8.9% in **FIG. 46**, the reflectance is reduced by placing the antireflection coating.

[0276] **FIGS. 44D** to **44**F show the cases that uses MgF_2 for a low refractive index layer and n_L=1.38. The tables of **FIGS. 44D** to **44**F show the simulations where n_s is 1.54, 1.70, and 1.85. **FIG. 46** shows the graph of the reflectance for each wavelength when n_H is 1.65, 1.75, and 1.85 and in a single low refractive index layer under the conditions shown in the table of **FIG. 44D**. Just like in **FIG. 45**, the reflectance values for the wavelength are minimum in the vicinity of λ_1 and λ_2. However, compared to the curving line of **FIG. 45**, a change in reflectance in the wavelength region from λ_2 and λ_3 or higher is steep, and the reflectance is very high for λ_3. Since the reflectance of the objective lens **1** is 4.5% in **FIG. 47**, the reflectance is reduced by placing the antireflection coating.

[0277] In **FIGS. 44A** to **44**F, the data in which the reflectance is higher than the case where the low refractive index layer is a single layer is indicated by gray color. Further, the cell containing the data in which the reflectance is higher than that of the single object lens is inverted. Thus, the value of n_H including the gray-colored cell or the inverted cell is not suitable in terms of optical characteristics. **FIGS. 44A** to **44**C has a gray cell where n_H=2.15, and **FIGS. 44D** to **44**F has a gray cell where n_H=1.95.

[0278] The inventers of the present invention have found the relationship between the values of n_s, n_H, and n_L by analyzing n_H where a gray cell appears in the tables of **FIG. 44A** to **44**F and an optimal n_H. Since the value of n_H where a gray cell appears is close to the value of square of n_L, the upper limit of the optimal value of n_H is expected to at least satisfy the condition of $n_H \leqq n_L*n_L$. Further, since the value of n_H needs to be higher than the value of n_s, it is expected to at least satisfy the condition of $n_s < n_H$.

[0279] Therefore, a minimum condition of optimal value of n_H is: $n_s < n_H \leqq n_L*n_L$. The value of optimal n_H existing in this range can be given by $(a*n_s+b*n_L*n_L)/2$, where a and b are given constants. As a result of the simulations as shown in **FIGS. 44A** to **44**F, the values of a and b are preferably in the range of: $1.00 \leqq a \leqq 1.4$ and $0.65 \leqq b \leqq 1.00$. The most suitable combination is a=1.21 and b=0.84, for example. If the optimal value of n_H with respect to n_s and n_L is parameter A, $A=(1.21*n_s+0.84*n_L*n_L)/2$.

[0280] Further, as shown in the table of **FIG. 51**, if the value of n_s increases, an effective range of n_H decreases, making the reflectance in the vicinity of the wavelength 790 nm higher as shown in **FIG. 53**. Further, if the value of n_s decreases, ausable object is limited. Therefore, the value of n_s preferably satisfies: $1.46 \leqq n_s \leqq 1.65$. Similarly, if the value of n_L increases, the maximum value of the reflectance between λ_1 and λ_2 becomes higher, which narrows down the bandwidth with a low reflectance. If the value of n_L becomes less than 1.3, it is difficult to obtain a stable film formation material. Therefore, the value of n_L preferably satisfies: $1.3 \leqq n_L \leqq 1.55$.

[0281] Specific examples are shown in consideration of these conditions. By depositing one of the three kinds of AR coats shown in the following examples 1, 2 and 3, it is possible to obtain relatively high transmittance characteristics in the three wavelengths described above. In addition, since the number of layers is as small as two, it is possible to provide the AR coating with relatively low costs. **FIGS. 48A** to **48**C show design examples of these AR coats.

EXAMPLE 1

[0282] On a lens having a refractive index of 1.53, a mixed material of Al_2O_3 (n=1.68) and ZrO_2 (n=2.07) having a refractive index of 1.85 with the thickness of 135.1 nm (optical film thickness $\lambda/2$) and SiO_2 having a refractive index of 1.46 with the thickness of 85.5 nm (optical film thickness $\lambda/4$) are coated. A reference wavelength of an AR coat optical film thickness is 500 nm.

EXAMPLE 2

[0283] On a lens having a refractive index of 1.53, Y_2O_3 having a refractive index of 1.80 with the thickness of 139 nm (optical film thickness $\lambda/2$) and SiO_2 having a refractive index of 1.46 with the thickness of 85.5 nm (optical film thickness $\lambda/4$) are coated. A reference wavelength of an AR coat optical film thickness is 500 nm.

EXAMPLE 3

[0284] On a lens having a refractive index of 1.53, SiN having a refractive index of 2.04 with the thickness of 122.5 nm (optical film thickness $\lambda/2$) and SiO_2 having a refractive index of 1.46 with the thickness of 85.5 nm (optical film thickness $\lambda/4$) are coated. A reference wavelength of an AR coat optical film thickness is 500 nm.

[0285] **FIGS. 49A** to **49**C show the spectral reflectance characteristics per one lens surface by the AR coating of Examples 1 to 3. The tables of **FIGS. 49A** to **49**C correspond to Examples 1, 2, and 3, respectively. As shown in the graphs, the reflectance decreases in the wavelength regions of around 405 nm and from 650 nm to 790 nm in any of **FIGS. 49A** to **49**C.

[0286] Examples shown in **FIGS. 48A and 48B** satisfy the conditions of $0.9 \leqq n_H/A \leqq 1.1$ and $0.1 \leqq n_H-n_s$ and the condition of $n_H-n_s \leqq 0.4$. Specifically, in **FIG. 48A**, n_L is 1.46, n_H is 1.85, n_s is 1.53, A is 1.82, n_Ld_L is 125 nm, n_Hd_H is 250 nm, n_H/A is 1.0, n_H-n_s is 0.32. In **FIG. 48B**, n_L is 1.46, n_H is 1.80, n_s is 1.53, A is 1.821, n_Ld_L is 125 nm, n_Hd_H is 250 nm, n_H/A is 1.0, n_H-n_s is 0.27. In **FIG. 48C**, n_L is 1.46, n_H is 2.04, n_s is 1.53, A is 1.82, n_Ld_L is 125 nm, n_Hd_H is 250 nm, n_H/A is 1.1, n_H-n_s is 0.51.

[0287] **FIG. 50** shows Example 4 that uses ZEONEX, which is a registered trademark of and manufactured by ZEON CORPORATION, for the objective lens **1**, a mixed film of Al_2O_3 and ZrO_2 for the high refractive index layer **8**, and SiO_2 for the low refractive index layer **7**. In this case, n_s is 1.525, n_H is 1.83, n_L is 1.46, and A is 1.818. Further, n_Hd_H is 256.3 nm and n_Ld_L is 129.3 nm. As shown in **FIG. 50**, the reflectance for each wavelength is lowest in the vicinity of λ_1 and λ_2. Further, it is also as low as 3% or lower at λ_3. Thus, this example produces a suitable antireflection coating.

[0288] **FIG. 51** shows Example 5 that uses APEL for the objective lens **1**, MgO for the high refractive index layer **8**, and MgF_2 for the low refractive index layer **7**. In this case, n_s is 1.54, n_H is 1.74, n_L is 1.38, and A is 1.732. Further, n_Hd_H is 260.1 nm and n_Ld_L is 126.3 nm. As shown in **FIG. 51**, the reflectance for each wavelength is lowest in the vicinity of λ_1 and λ_2. Further, it is also as low as 3% or lower at λ_3. Thus, this example produces a suitable antireflection coating.

[0289] **FIG. 52** shows Example 6 that uses polymethyl methacrylate (PMMA) for the objective lens **1**, Y_2O_3 for the high refractive index layer **8**, and MgF_2 for the low refractive index layer **7**. In this case, n_s is 1.49, n_H is 1.78, n_L is 1.38, and A is 1.701. Further, n_Hd_H is 253.8 nm and n_Ld_L is 129.8 nm. As shown in **FIG. 52**, the reflectance for each wavelength is lowest in the vicinity of λ_1 and λ_2. Further, it is also as low as 3% or lower at λ_3. Thus, this example produces a suitable antireflection coating.

[0290] **FIG. 53** shows Example 7 that uses ARTON, which is a registered trademark of and manufactured by Japan Synthetic Rubber Co., Ltd., for the objective lens **1**, Y_2O_3 for the high refractive index layer **8**, and SiO_2 for the low refractive index layer **7**. In this case, n_s is 1.51, n_H is 1.78, n_L is 1.46, and A is 1.809. Further, n_Hd_H is 258.1 nm and n_Ld_L is 123.9 nm. As shown in **FIG. 53**, the reflectance for each wavelength is lowest in the vicinity of λ_1 and λ_2. Further, it is also as low as 3% or lower at λ_3. Thus, this example produces a suitable antireflection coating. In this example, the value of the parameter A is greater than the value of n_H. The minimum values of reflectance in the vicinity of λ_1 and λ is also higher, which shows a change due to a difference between the value of n_H and the value of the parameter A becomes large.

[0291] **FIG. 54** shows Example 8 that uses PMMA for the objective lens **1**, a mixed film of Al_2O_3 and ZrO_2 for the high refractive index layer **8**, and MgF_2 for the low refractive index layer **7**. In this case, n_s is 1.49, n_H is 1.83, n_L is 1.38 and A is 1.756. Further, n_Hd_H is 250.3 nm and n_Ld_L is 132.6 nm. As shown in **FIG. 54**, the reflectance for each wavelength is lowest in the vicinity of λ_1 and λ_2. Further, it is also as low as 3% or lower at λ_3. Thus, this example produces a suitable antireflection coating. In this example, the value of the parameter A is smaller than the value of n_H. Though a difference between the value of n_H and the value of the parameter A is larger than in Examples 4 to 7, it shows that this difference still allows formation of a suitable antireflection coating.

[0292] As a comparative example, a case that is to be eliminated if n_H is defined by a parameter A of this embodiment within a range defined as a two-layer antireflection coating. **FIG. 55** is Comparative Example 1 that uses PC for the objective lens **1** and ZrO_2 for the high refractive index layer **8**, and SiO_2 for the low refractive index layer **7**. In this case, n_s is 1.58, n_H is 2.05, n_L is 1.46 and A is 1.851. Further, n_Hd_H is 248.8 nm and n_Ld_L is 132.8 nm. As shown in **FIG. 55**, the reflectance for each wavelength is lowest in the vicinity of λ_1 and λ_2. However, the reflectance is high at λ_3, exceeding 3%. Thus, though it may be used as an antireflection coating, it is not suitable.

[0293] **FIG. 56** is Comparative Example 2 that uses ZEONEX for the objective lens **1** and Ta_2O_5 for the high refractive index layer **8**, and SiO_2 for the low refractive index layer **7**. In this case, n_s is 1.525, n_H is 2.14, n_L is 1.46 and A is 1.818. Further, n_Hd_H is 242.2 nm and n_Ld_L is 137.0 nm. As shown in **FIG. 56**, the reflectance for each wavelength is lowest in the vicinity of λ_1 and λ_2. However, the reflectance is high at λ_3, exceeding 5%. Thus, the optical characteristics for λ_3, is unfavorable and it is not suitable as an antireflection coating compatible with three wavelengths.

[0294] **FIG. 57** is Comparative Example 3 that uses BK7 for the objective lens **1** and TIO_2 for the high refractive index layer **8**, and SiO_2 for the low refractive index layer **7**. In this case, n_s is 1.52, n_H is 2.30, n_L is 1.46 and A is 1.815. Further, n_Hd_H is 226.0 nm and n_Ld_L is 136.0 nm. As shown in **FIG. 57**, the reflectance for each wavelength is lowest in the vicinity of λ_1 and λ_2. However, the lowest value at λ_2 is 2.5% or more, and the value corresponding to λ_2 exceeds 3%. Further, the reflectance exceeds 10% at λ_3. Thus, it is not suitable not only as an antireflection coating compatible with three wavelengths but also as an antireflection coating compatible with two wavelengths.

[0295] **FIGS. 58A and 58B** show the table on the characteristics in Examples and Comparative Examples. **FIGS. 58A and 58B** show the values of n_s, n_H, and n_L in Examples 4 to 8 and Comparative Examples 1 to 3, the value of parameter A, the ratio of n_H and parameter A, the reflectance value in λ_1, λ_2, and λ_3 and each analysis value of the optical characteristics. The reflectance for each λ indicates the average value of the reflectance in each region of λ. If the reflectance exceeds 3%, the cell is gray-colored.

[0296] As shown in **FIG. 58A**, the reflectance for each λ in Examples 4 to 8 is 2.5% at the highest, which is a generally suitable value. In Comparative Examples 1 to 3, on the other hand, data shown by gray cell appears mainly for λ_3, and the optical characteristics are not suitable in terms of antireflection coating compatible with three wavelengths.

[0297] The optical characteristics of Examples and Comparative Examples are analyzed in further detail below. **FIG. 58B** shows analytic values calculated from n_s, n_H, and n_L in each Example and Comparative Example. While the value of n_H/A is within the range of 1±0.1 in Examples 4 to 8, it is 1.11 or higher in Comparative Examples 1 to 3. Thus, the condition of $0.9 \leqq n_H/A \leqq 1.1$ can be defined. Further, the value of n_H-n_s is higher in Comparative Examples 1 to 3 than in Examples 4 to 8. Thus, the relationship of n_H and n_s satisfies preferably $0.1 \leqq n_H - n_s \leqq 0.4$ and more preferably $0.1 \leqq n_H - n_s \leqq 0.35$.

[0298] **FIG. 58B** also shows reflectance average values and standard deviations of the wavelengths λ_1, λ_2, and λ_3. The lower the average value is, the lower the reflectance in each λ. The lower the standard deviation is, the smaller the variation in reflectance in each λ. Therefore, if both the reflectance average and standard deviation are low, it means that the reflectance in each λ is low and stable, which is a suitable example. **FIG. 58B** further shows an average of square sum of reflectance as a determination value. The determination value is 2.11 at the highest in Examples 4 to 8, and it is thus as low as 3.0 or below. On the other hand, the determination value is as high as 4.5 or greater in

Comparative Examples 1 to 3. Therefore, the determination value is preferably 3.0 or below and more preferably 2.5 or below.

[0299] The reflectance in λ_3 mainly affects the standard deviation. As shown in the graphs of the reflectance corresponding to each wavelength in Examples 4 to 8 and Comparative Examples 1 to 3, the reflectance in λ_1, and λ_2 is relatively low in Comparative Example 1 and 2 as well. Thus, no problem occurs if it is used as an antireflection coating for two wavelengths. However, a change in reflectance is steep in the wavelength region of λ_2 and λ_3 in Comparative Examples 1 to 3, a reflectance in λ_3 is high. Thus, analysis of standard deviation of reflectance in λ_1 to λ_3 allows verification of suitability. Further, use of a square sum as a determination value enables to reflect the effect of λ_3 accurately.

[0300] The analytical result shown in **FIG. 58B** tells that, when forming a three-wavelength antireflection coating of two layers composed of the high refractive index layer **8** and the low refractive index layer **7** in the objective lens **1**, it is possible to form a suitable a three-wavelength antireflection coating by defining a parameter A of $A=(1.21*n_s+0.84*n_L*n_L)/2$ and selecting each member so as to satisfy the condition of $0.1n_H-n_s \leqq 0.4$.

[0301] As described in the foregoing, the present invention can provide an antireflection coating which is composed of two layers and which makes reflectance low in three kinds of wavelength regions, and an optical pickup component.

[0302] Since the antireflection coating of this invention has a two-layer structure, it is possible to reduce a film coating deposition time compared to a film coating having a three of more layer structure, thereby reducing harmful effects such as thermal deformation of a deposition surface.

[0303] Particularly, it is effective to use a low malting glass with a low melting point and thermal deformation temperature (Tg=288° C. such as K-PG325 manufactured by SUMITA optical glass for the antireflection coating of this invention in order to prevent deformation of a lens surface when depositing a filmcoating. Further, the antireflection coating exerts its maximum effect when it is coated on both surfaces or one surface of a lens compatible with three wavelengths used in the first and the second embodiments of the invention.

[0304] By using the parameter A described in the above embodiments, it is possible to form a selection system of each member in a three wavelength antireflection coating compose of two layers. This system at least includes a condition input section, a calculation section, a result display section, a material storage section, and a control section. If the condition input section inputs one or two of n_s, n_H, n_L, the calculation section calculates a suitable value for the rest of values based on the parameter A and the condition of n_H-n_s, and selects a suitable material from the materials stored in the material storage section. The control section executes these processing.

[0305] It is normally difficult to calculate suitable values for the rest of variables by specifying only one of three variables. However, with addition of the condition of selecting one from the material stored in the material storage section, it is possible to select suitable values for the remaining two variables by specifying one of thee variables.

[0306] As described above, the present invention can focus all light beams on a desired position with possibly lowest aberration, with NA necessary for recording or reproducing by refraction without using a diffraction lens structure, for three or more kinds of optical disks that record or reproduce data with different wavelengths.

[0307] Further, the lens of this invention is applicable to a multiwavelength optical system using a plurality of monochromatic light and an optical system using different wavelengths in optical communication or the like.

Optical Head Structure 1

[0308] **FIG. 59** shows an example of the structure of an optical head using the objective lens according to the present invention. **FIG. 59** corresponds to the optical system for HDDVD (405 nm) disk shown in the first embodiment. As shown in **FIG. 59**, an optical head **10** of this embodiment has a Blue laser **11**, a DVD laser **12**, a CD laser **13**, a linear diffraction grating **14** for 3 spots, a half prism **15**, a collimator lens **16**, a half prism **17**, and actuators **181** and **182**. In **FIG. 59**, the same elements as in **FIG. 3** are denoted by the same reference symbols.

[0309] In **FIG. 59**, when recording or reproducing the DVD disk **2**, the DVD laser **12** is driven. A laser beam of the 655 nm wavelength generated in the DVD laser **12** is reflected by the half-prism **15** and enters the collimator lens **16**. The laser beam becomes parallel light after passing through the collimator lens **16**. The laser beam transmits through the half prism **17**, and then transmits through the wavelength selective filter **6**. The transmitted light then enters the objective lens **1** and is focused at NA 0.63 to form an optical spot on an information recording surface of the DVD disk **3**. Then, the light reflected by the DVD disk **3** becomes parallel light at the objective lens **1** and enters the collimator lens **16**.

[0310] The parallel light becomes convergent light in the collimator lens **16** and then reaches a light detector (not shown). A detection output signal from the light detector is supplied to a signal processing circuit (not shown), thereby creating an information recording and reproducing signal, focus error signal, and tracking error signal. After that, a system control circuit (not shown) controls an actuator drive circuit (not shown) to drive the actuators **181** and **182** so as to place the objective lens **1** in an appropriate focus position and tracking position based on the obtained focus error signal and tracking error signal.

[0311] When recording or reproducing the HDDVD disk **1**, the Blue laser **11** is driven. A laser beam of the 405 nm wavelength generated in the Blue laser **11** transmits through the half prism **15**. The transmitted laser beam enters the collimator lens **16** and becomes parallel light after transmitting through the collimator lens **16**. The parallel light is then focused on an information recording surface of the HDDVD disk **1** at NA 0.65 to form an optical spot as is the case with the DVD described above.

[0312] The focused light reaches a light detector (not shown) A detection output signal from the light detector is supplied to a signal processing circuit (not shown), thereby creating an information recording and reproducing signal, focus error signal, and tracking error signal. After that, a system control circuit (not shown) controls an actuator drive circuit (not shown) to drive the actuators **181** and **182** so as to place the objective lens **1** in an appropriate focus position and tracking position based on the obtained focus error signal and tracking error signal.

[**0313**] When recording or reproducing the CD disk **4**, the CD laser **13** is driven. A laser beam of the 795 nm wavelength generated in the CD laser **13** transmits through the linear diffraction grating **14**, is reflected by the half prism **17** and enters the wavelength selective filter **6**. The inner side of the wavelength selective filter **6** is the entire light transmitting area **61**, and the outer side lets the light passing through the inner side of the light shielding area **62** transmit through as shown in **FIG. 4**. The transmission light enters the objective lens **1** and is focused with NA0.47 to form an optical spot on the information recording surface of the CD disk **4**.

[**0314**] The light reflected by the CD disk **4** becomes convergent light by the objective lens **1** and reaches a light detector (not shown). A detection output signal from the light detector is supplied to a signal processing circuit (not shown), thereby creating an information recording and reproducing signal, focus error signal, and tracking error signal. To obtain the tracking error signal for the CD disk **3**, the laser beam from the CD laser **12** is separated into 0^{th} order light and $\pm 1^{st}$ order light by the diffraction grating **18**, thus obtaining the tracking error signal from the $\pm 1^{st}$ order light

[**0315**] Then, based on the focus error signal and tracking error signal thus obtained, the actuators **181** and **182** are driven so as to place the objective lens **1** in an appropriate focus position and tracking position.

[**0316**] Though the optical detector is not shown in **FIG. 59**, a laser and an optical detector may be placed in one package of a laser, for example. Alternatively, another half prism or the like may be placed so that the reflected light from the disc enters the optical detector placed in a different position from the laser. Further, since parallel light, which is infinite, is incident on the objective lens in HDDVD (405 nm) and DVD (655 nm) and the reflected light from the disk is both parallel light, it is possible to use the same optical detector, for example.

[**0317**] Further, since the CD light is finite, it is difficult to use the same detector as HDDVD and DVD in a normal optical arrangement and an optical detector for CD is required. Therefore, it is possible to place a diffraction grating that functions as a diffraction grating only for the wavelength of about 790 nm and allows the reflected light from the CD disk to enter the same optical detector as HDDVD and DVD, for example.

[**0318**] The collimator lens **16** is not always necessary, and the present invention is also applicable to an optical system of a so-called finite system. Further, it is possible to place a laser in a position farther away from a focal position of parallel light of the collimator lens **16** so as to makes incident light to the objective lens convergent light.

Optical Head Structure 2

[**0319**] **FIG. 60** shows an example of the structure of an optical head using the objective lens according to the present invention. **FIG. 60** corresponds to the optical pickup system for Blu-ray shown in the second embodiment. The structure of the optical head shown in **FIG. 60** is similar to the optical system arrangement of HDDVD shown in **FIG. 59**.

[**0320**] In **FIG. 60**, when recording or reproducing the DVD disk **3**, the DVD laser **12** is driven. A laser beam of the 655 nm wavelength generated in the DVD laser **12** is reflected by the half-prism **15** and enters the collimator lens **16**. The laser beam becomes parallel light after passing through the collimator lens **16**. The laser beam transmits through the half prism **17**, and then transmits through the wavelength selective filter **6**. The transmitted light then enters the objective lens **1** and is focused at NA 0.60 to form an optical spot on an information recording surface of the DVD disk **3**.

[**0321**] The parallel light entering the objective lens **1** is the light with NA0.8 or higher. As shown in the second embodiment, the Blu-ray exclusive area exists in the outer area of the objective lens **1** in the light source side. Therefore, if DVD light of 655 nm is incident, the light transmitting through the Blu-ray exclusive use area becomes DVD flare, which does not contribute to image formation nor optical spot formation on the DVD disk. Therefore, the optical spot substantially equal to NA 0.60 is formed on the DVD disk **3**.

[**0322**] The light reflected by the DVD disk 3 becomes parallel light by the objective lens **1** and enters the collimator lens **16**. The collimator lens **16** changes the parallel light into convergent light and the light reaches an optical detector (not shown). A detection output signal from the light detector is supplied to a signal processing circuit (not shown), thereby creating an information recording and reproducing signal, focus error signal, and tracking error signal. After that, a system control circuit (not shown) controls an actuator drive circuit (not shown) to drive the actuators **181** and **182** so as to place the objective lens **1** in an appropriate focus position and tracking position based on the obtained focus error signal and tracking error signal.

[**0323**] When recording or reproducing the Blu-ray disk **1**, the Blue laser **11** is driven. A laser beam of the 405 nm wavelength generated in the Blue laser **11** transmits through the half prism **15**. The transmitted laser beam enters the collimator lens **16** and becomes parallel light after transmitting through the collimator lens **16**. The parallel light is then focused on an information recording surface of the Blu-ray disk **1** at NA 0.65 to form an optical spot as is the case with the DVD described above.

[**0324**] The focused light reaches a light detector (not shown) A detection output signal from the light detector is supplied to a signal processing circuit (not shown), thereby creating an information recording and reproducing signal, focus error signal, and tracking error signal. After that, a system control circuit (not shown) controls an actuator drive circuit (not shown) to drive the actuators **181** and **182** so as to place the objective lens **1** in an appropriate focus position and tracking position based on the obtained focus error signal and tracking error signal.

[**0325**] When recording or reproducing the CD disk **4**, the CD laser **13** is driven. A laser beam of the 790 nm wavelength generated in the CD laser **13** transmits through the linear diffraction grating **14**, is reflected by the half prism **17** and enters the wavelength selective filter **6**. The inner side of the wavelength selective filter **6** is the entire light transmitting area **61**, and the outer side lets the light passing through the inner side of the light shielding area **62** transmit through as shown in **FIG. 4**. The transmission light enters the objective lens **1** and is focused with NA0.47 to form an optical spot on the information recording surface of the CD disk **4**.

[**0326**] The light reflected by the CD disk **4** becomes convergent light by the objective lens **1** and reaches a light detector (not shown). A detection output signal from the light detector is supplied to a signal processing circuit (not shown), thereby creating an information recording and reproducing signal, focus error signal, and tracking error signal. To obtain the tracking error signal for the CD disk **3**, the laser beam from the CD laser **12** is separated into 0^{th} order light and $\pm 1^{st}$ order light by the diffraction grating **18**, thus obtaining the tracking error signal from the $\pm 1^{st}$ order light

[**0327**] Then, based on the focus error signal and tracking error signal thus obtained, the actuators **181** and **182** are driven so as to place the objective lens **1** in an appropriate focus position and tracking position.

[**0328**] Though the optical detector is not shown in **FIG. 60**, a laser and an optical detector may be placed in one package of a laser, for example. Alternatively, another half prism or the like may be placed so that the reflected light from the disk enters the optical detector placed in a different position from the laser. Further, since parallel light, which is infinite, is incident on the objective lens in HDDVD (405 nm) and DVD (655 nm) and the reflected light from the disk is both parallel light, it is possible to use the same optical detector, for example.

[**0329**] Further, since the CD light is finite, it is difficult to use the same detector as HDDVD and DVD in a normal optical arrangement, and thus an optical detector for CD is required. It is possible to place a diffraction grating that functions as a diffraction grating only for the wavelength of about 790 nm and allows the reflected light from the CD disk to enter the same optical detector as HDDVD and DVD, for example.

[**0330**] The collimator lens **16** is not always necessary, and the present invention is also applicable to an optical system of a so-called finite system. Further, it is possible to place a laser in a position farther away from a focal position of parallel light of the collimator lens **16** so as to makes incident light to the objective lens convergent light.

Optical Head Structure 3

[**0331**] **FIG. 61** shows an example of the structure of an optical head according to the present invention. **FIG. 61** corresponds to the optical pickup system described in the third embodiment.

[**0332**] In **FIG. 61**, when recording or reproducing the HDDVD disk **2**, the HDDVD laser **11** is driven. The laser beam of 408 nm wavelength generated by the HDDVD laser **11** is reflected by the half prism **15** and enters the collimator lens **16**. The laser beam becomes convergent light after transmitting through the collimator lens **16**, transmits through the half prism **17**, and then transmits the wavelength selective filter **6**. The transmitted light enters the objective lens **1** and is focused with NA0.65 to form an optical spot on the information recording surface of the HDDVD disk **2**.

[**0333**] The light with NA=0.65 or higher is incident on the objective lens **1**. As shown in the third embodiment, the DVD exclusive area exists in the outer area of the objective lens **1** in the light source side. Therefore, if HDDVD light of 408 nm is incident, the light transmitting through the DVD exclusive use area becomes flare, which does not contribute to image formation nor optical spot formation on the HDDVD disk. Therefore, the optical spot substantially equal to NA 0.65 is formed on the HDDVD disk **2**.

[**0334**] The light reflected by the HDDVD disk **2** becomes divergent light by the objective lens **1** and enters the collimator lens **16**. The collimator lens **16** changes the divergent light into convergent light and output it to an optical detector (not shown). A detection output signal from the light detector is supplied to a signal processing circuit (not shown), thereby creating an information recording and reproducing signal, focus error signal, and tracking error signal. After that, a system control circuit (not shown) controls an actuator drive circuit (not shown) to drive the actuators **181** and **182** so as to place the objective lens **1** in an appropriate focus position and tracking position based on the obtained focus error signal and tracking error signal.

[**0335**] When recording or reproducing the DVD disk **3**, the DVD laser **12** is driven. A laser beam of the 658 nm wavelength generated in the DVD laser **12** transmits through the half prism **15**. The transmitted laser beam then enters the collimator lens **16**. The laser beam becomes parallel light after passing through the collimator lens **16**. After that, the light is focused at NA 0.65 on the information recording surface of the DVD disk **3** to form an optical spot as is the case with HDDVD.

[**0336**] The light reflected by the DVD disk **3** becomes parallel light by the objective lens **1** and enters the collimator lens **16**. The collimator lens **16** changes the parallel light into convergent light and outputs it to an optical detector (not shown). A detection output signal from the light detector is supplied to a signal processing circuit. (not shown), thereby creating an information recording and reproducing signal, focus error signal, and tracking error signal. After that, a system control circuit (not shown) controls an actuator drive circuit (not shown) to drive the actuators **181** and **182** so as to place the objective lens **1** in an appropriate focus position and tracking position based on the obtained focus error signal and tracking error signal.

[**0337**] When recording or reproducing the CD disk **4**, the CD laser **13** is driven. A laser beam of the 785 nm wavelength generated in the CD laser **13** transmits through the linear diffraction grating **14**, is reflected by the half prism **17** and enters the wavelength selective filter **6**. The inner side of the wavelength selective filter **6** is the entire light transmitting area **61**. Thus, the outer side lets the light passing through the inner side of the light shielding area **62** transmit through as shown in **FIG. 4**. The transmission light enters the objective lens **1** and is focused with NA0.47 to form an optical spot on the information recording surface of the CD disk **4**.

[**0338**] The light reflected by the CD disk **4** becomes convergent light by the objective lens **1** and reaches a light detector (not shown). A detection output signal from the light detector is supplied to a signal processing circuit (not shown), thereby creating an information recording and reproducing signal, focus error signal, and tracking error signal. To obtain the tracking error signal for the CD disk **3**, the laser beam from the CD laser **12** is separated into 0^{th} order light and $\pm 1^{st}$ order light by the diffraction grating **18**, thus obtaining the tracking error signal from the $\pm 1^{st}$ order light

[**0339**] Then, based on the focus error signal and tracking error signal thus obtained, the actuators **181** and **182** are driven so as to place the objective lens **1** in an appropriate focus position and tracking position, as is the case with the DVD disk **3**.

[**0340**] Though the optical detector is not shown in **FIG. 61**, a laser and an optical detector may be placed in one package of a laser, for example. Alternatively, another half prism or the like may be placed so that the reflected light from the disk enters the optical detector placed in a different position from the laser.

[**0341**] Further, the present invention is applicable to the lens structure where convergent light for HDDVD, convergent light for DVD, and divergent light for CD, are respectively incident. If the object distance of HDDVD and DVD is the same, it is possible to use the same optical detector for HDDVD and DVD.

Optical Disk Apparatus Structure

[**0342**] **FIG. 62** shows an embodiment of an optical disk apparatus using the objective lens according to the present invention. It includes an actuator drive circuit **20**, a signal processing circuit **21**, a laser drive circuit **22**, a system control circuit, **23** and disk distinguishing means **24**. The elements corresponding to those in **FIGS. 59 and 60** have the same structure and thus omitted.

[**0343**] First, the disk distinguishing means **24** distinguishes a type of a disk loaded. Among methods for distinguishing the disk are a method detecting the thickness of the disk substrate optically or mechanically and a method detecting a reference mark preciously stored in the disk or a disk cartridge. Or, there is also a method reproducing disk signals with tentative disk thickness and type, and judging that it is a disk of another thickness and type if normal signals are not obtained. The disk distinguishing means **24** then transmits the result to the system control circuit **23**.

[**0344**] When the result shows that the disk is a DVD disk, the system control circuit **23** transmits a signal for lighting the DVD laser **11** to the laser drive circuit **22**, and the DVD laser **11** lights by the laser drive circuit **22**. Thus, in an optical head, the laser beam having the 655 nm wavelength reaches the light detector **17**, as is the embodiment shown in **FIG. 59**. The light detector **17** then transmits a detection signal to the signal processing circuit **21**. and thereby an information recording and reproducing signal, focus error signal, and tracking error signal are generated and transmitted to the system control circuit **23**.

[**0345**] The system control circuit **23** controls the actuator drive circuit **20** based on the focus error signal and tracking error signal. The actuator drive circuit **20** drives the actuator **19** by this control to move the objective lens **1** in the focus direction and tracking direction, which is called a servo circuit operation. By this operation, the focus control and tracking control are regularly processed, and the above circuits and the actuators **181** and **182** operate to arrange the object lens **1** in a right position to the DVD disk **3**, thus suitably obtaining the information recording and reproducing signals.

[**0346**] On the other hand, when the result shows that the disk loaded is the CD disk **4**, the system control circuit **23** transmits a signal for lighting the CD laser **13** to the laser drive circuit **22**. The CD laser **13** thus generates the laser beam having a 790 nm wavelength. The subsequent operations are the same as the case of the optical head shown in **FIGS. 59 and 60**. The laser beam reaches the light detector **17**, and the circuits and the actuator **19** process the servo operation to obtain the information recording and reproducing signal suitably, as is the case with the DVD disk **2**.

[**0347**] When the result shows that the disk loaded is a Blue-ray or HDDVD disk, the system control circuit **23** transmits a signal for lighting the Blue laser **11** to the laser drive circuit **22**. The Blue laser **11** thus generates the laser beam having a 405 nm wavelength. The subsequent operations are the same as the case of the optical head shown in **FIGS. 59 and 60**. The laser beam reaches the light detector **17**, and the circuits and the actuator **19** process the servo operation to obtain the information recording and reproducing signal suitably, as is the case with the DVD disk **2**.

[**0348**] **FIG. 63A** is a top view when manufacturing an objective lens of the present invention industrially. **FIG. 63B** is a side view of the lens, and the left half shows the cross section. As shown in **FIGS. 63A and 63B**, a flange **101** is formed on the outer periphery of the lens **1**. The flange **101** is formed so that a flange surface **102** comes an optical recording medium side when the lens **1** is mounted to the optical disk apparatus to read information from the optical recording medium. In the followings, the side to the optical recording medium is referred to as a upper side **102** and the other side is referred to as an under side **103**. The flange **101** is placed in the periphery of an optical functional part of the lens **1** to surround the entire circumference. The flange **101** is not necessarily continuous in the circumference, and it may have a notch in a part of the circumference.

[**0349**] As shown in **FIG. 63B**, the flange surface **102** is partly higher than a top surface of the optical functional part when viewed along the optical axis. Thus, if the lens **1** is placed on a desk or the like with the flange surface **102** facing down, the flange surface **102**, not the optical functional part, contacts the desk. It is thereby possible to prevent the optical functional part from being damaged due to contact with the disk or the like. It is also possible to avoid damage that occurs when an optical recording medium directly contacts the optical functional part after mounting the lens **1** to the optical disk apparatus.

[**0350**] From the invention thus described, it will be obvious that the embodiments of the invention may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended for inclusion within the scope of the following claims.

What is claimed is:

1. An antireflection coating formed on a light transmitting surface of an optical component with a refractive index of n_s used in an optical pickup device using at least two wavelengths of approximately 405 nm and 655 nm, the antireflection coating comprising two layers of:

a high refractive index layer with a refractive index of n_H and an optical coating thickness of $n_H d_H$ formed on the optical component; and

a low refractive index layer with a refractive index of n_L, and an optical coating thickness of $n_L d_L$ formed on the high refractive index layer,

wherein a reflectance is lowest only in two regions of approximately 405 nm and 655 nm and highest in one region between the two lowest regions.

2. The antireflection coating of claim 1, wherein following conditions are satisfied:

$0.9 \leqq n_H/A \leqq 1.1$,

$0.1 \leqq n_H - n_s$,

$225 \leqq n_H d_H \leqq 275$ nm,

100 nm $\leqq n_L d_L \leqq 150$ nm,

where $A=(1.21 * n_s + 0.84 * n_L * n_L)/2$.

3. The antireflection coating of claim 2, wherein a following condition is satisfied:

$n_H - n_s \leqq 0.4$.

4. The antireflection coating of claim 2, wherein a following condition is satisfied:

$1.30 \leqq n_L \leqq 1.55$.

5. An antireflection coating formed on a light transmitting surface of an optical component with a refractive index of n_s used in an optical pickup device using at least three wavelengths of approximately 405 nm, 655 nm, and 790 nm, the antireflection coating comprising two layers of:

a high refractive index layer with a refractive index of n_H and an optical coating thickness of $n_H d_H$ formed on the optical component; and

a low refractive index layer with a refractive index of n_L, and an optical coating thickness of $n_L d_L$ formed on the high refractive index layer,

wherein a reflectance is lowest only in two regions of approximately 405 nm and 655 nm and highest in one region between the two lowest regions.

6. The antireflection coating of claim 5, wherein following conditions are satisfied:

$0.9 \leqq n_H/A \leqq 1.1$,

$0.1 \leqq n_H - n_s$,

225 nm $\leqq n_H d_H \leqq 275$ nm,

100 nm $\leqq n_L d_L \leqq 150$ nm,

where $A=(1.21 * n_s + 0.84 * n_L * n_L)/2$.

7. The antireflection coating of claim 6, wherein a following condition is satisfied:

$n_H - n_s \leqq 0.4$.

8. The antireflection coating of claim 6, wherein a following condition is satisfied:

$1.30 \leqq n_L \leqq 1.55$.

9. The antireflection coating of claim 5, wherein material of the low refractive index layer is silicon oxide or fluoride.

10. An optical component for an optical pickup, on which surface the antireflection coating of claim 5 is formed.

11. The optical component for an optical pickup of claim 10, wherein the optical component is made of material mainly composed of glass with a refractive index n_s of 1.49 to 1.70 and a thermal deformation temperature of 300° C. or below.

12. An objective lens receiving light beams with wavelengths of approximately 405 nm, 655 nm and 790 nm for at least three kinds of optical recording media and having a positive power to focus each light beam on an information recording surface of a transparent substrate of each optical recording medium by refraction,

wherein, if distances between points P_1, P_2, P_3 where incident light beams or extension lines of incident light beams with wavelengths of approximately 405 nm, 655 nm and 790 nm to the objective lens cross an optical axis and a point Q where a lens surface of the objective lens located farther from each optical recording medium than another lens surface crosses the optical axis are expressed as S_1, S_2, S_3, and signs of the distances S_1, S_2, S_3, are defined as positive if positions of the points P_1, P_2, P_3 are located in a different side from the optical recording medium with respect to the point Q, and defined as negative if the positions of the points P_1, P_2, P_3 are located in the same side as the optical recording medium with respect to the point Q, an incident light beam satisfying following expressions enters the objective lens:

$(1/S_1)<(1/S_3)$,

$(1/S_2)<(1/S_3)$,

each light beam is focused on the information recording surface with RMS wavefront aberration of 0.050 λRMS or below, and

an antireflection coating having lowest reflectance values only in two regions of approximately 405 nm and 655 nm and a highest reflectance value in one region between the two lowest reflectance values is formed on at least one surface of two lens surfaces.

13. The objective lens of claim 12, wherein the antireflection coating comprises two layers of:

a high refractive index layer with a refractive index of n_H and an optical coating thickness of $n_H d_H$ formed on an optical component; and

a low refractive index layer with a refractive index of n_L, and an optical coating thickness of $n_L d_L$ formed on the high refractive index layer.

14. The objective lens of claim 13, wherein the antireflection coating satisfies following conditions:

$0.9 \leqq n_H/A \leqq 1.1$,

$0.1 \leqq n_H - n_s$,

225 nm $\leqq n_H d_H \leqq 275$ nm,

100 nm $\leqq n_L d_L \leqq 150$ nm,

where $A=(1.21 * n_s + 0.84 * n_L * n_L)/2$.

15. An antireflection coating formed on a light transmitting surface of an optical component with a refractive index of n_s used in an optical pickup device using at least three wavelengths of approximately 405 nm, 655 nm and 790 nm, comprising two layers of:

a high refractive index layer with a refractive index of n_H formed on the optical component; and a low refractive index layer with a refractive index of n_L formed on the high refractive index layer,

wherein following conditions are satisfied:

$0.9 \leqq n_H/A \leqq 1.1,$

$0.1 \leqq n_H - n_s,$

where $A=(1.21*n_s+0.84*n_L*n_L)/2.$

16. An optical component for an optical pickup, wherein the optical component is made of material mainly composed of glass with a refractive index of 1.49 to 1.70 and a thermal deformation temperature of 300° C. or below, and the optical component has an antireflection coating composed of two layers of a high refractive index layer with a refractive index of n_H and an optical coating thickness of $n_H d_H$ and a low refractive index layer with a refractive index of n_L and an optical coating thickness of $n_L d_L$, and having lowest reflectance values only in two regions of approximately 405 nm and 655 nm and a highest reflectance value in one region between the two lowest reflectance values.

17. A method of manufacturing an optical component for an optical pickup, used in an optical pickup device using at least three wavelengths of approximately 405 nm, 655 nm and 790 nm and having a surface where an antireflection coating composed of a high refractive index layer and a low refractive index layer is formed, the method comprising:

selecting material for the high refractive index layer and the low refractive index layer that satisfy following conditions:

$0.9 \leqq n_H/A \leqq 1.1,$

$0.1 \leqq n_H - n_s,$

where $A=(1.21*nS+0.84*nL*nL)/2$

when n_s is a refractive index of the optical component, n_H is a refractive index of the high refractive index layer, and n_L is a refractive index of the low refractive index layer;

forming the high refractive index layer with a refractive index of n_H on the optical component; and

forming the low refractive index layer with a refractive index of n_L on the high refractive index layer.

18. The method of manufacturing an optical component for an optical pickup of claim 17, wherein the step of selecting material selects material so as to satisfy a condition of: $n_H - nS \leqq 0.4$.

19. The method of manufacturing an optical component for an optical pickup of claim 17, wherein the step of selecting material selects material so as to satisfy a condition of: $1.30 \leqq n_L \leqq 1.55$.

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