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(72) Inventor(s):
John Brian Hoyes
Anatoly Verenchikov

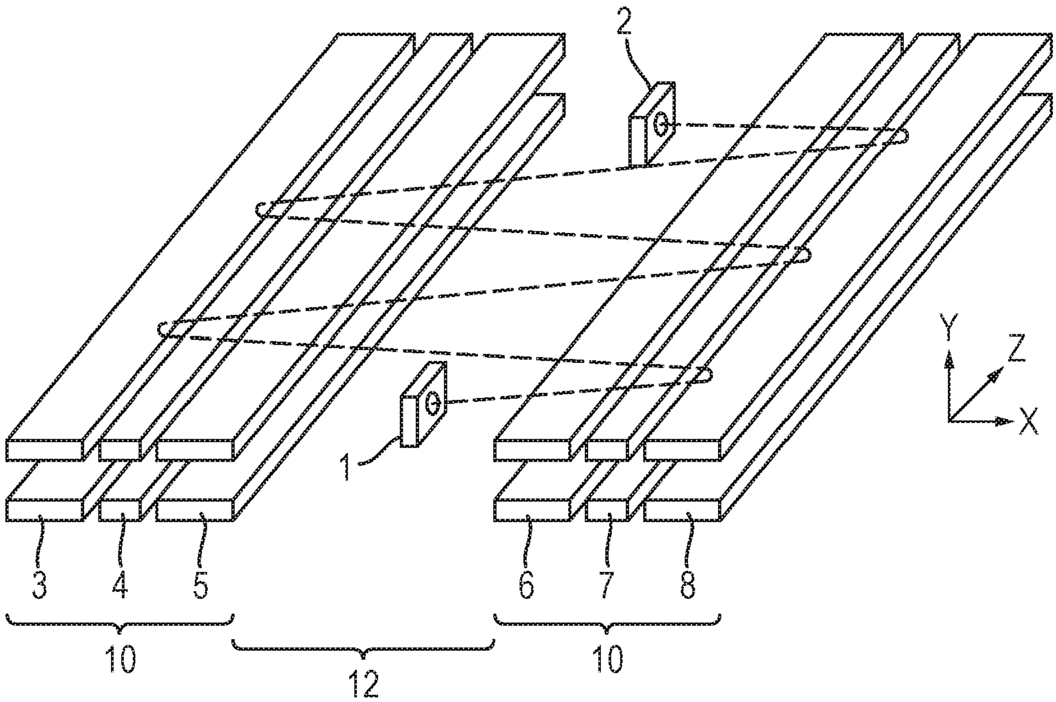
(73) Proprietor(s):
Micromass UK Limited
Stamford Avenue, Altrincham Road, WILMSLOW, SK9 4AX, United Kingdom

LECO Corporation
3000 Lakeview Avenue, St. Joseph 49085-2396, Michigan, United States of America

(74) Agent and/or Address for Service:
Dehns
St. Bride's House, 10 Salisbury Square, LONDON, EC4Y 8JD, United Kingdom

GB 2567794 B

Fig. 1



04 05 18

Fig. 2

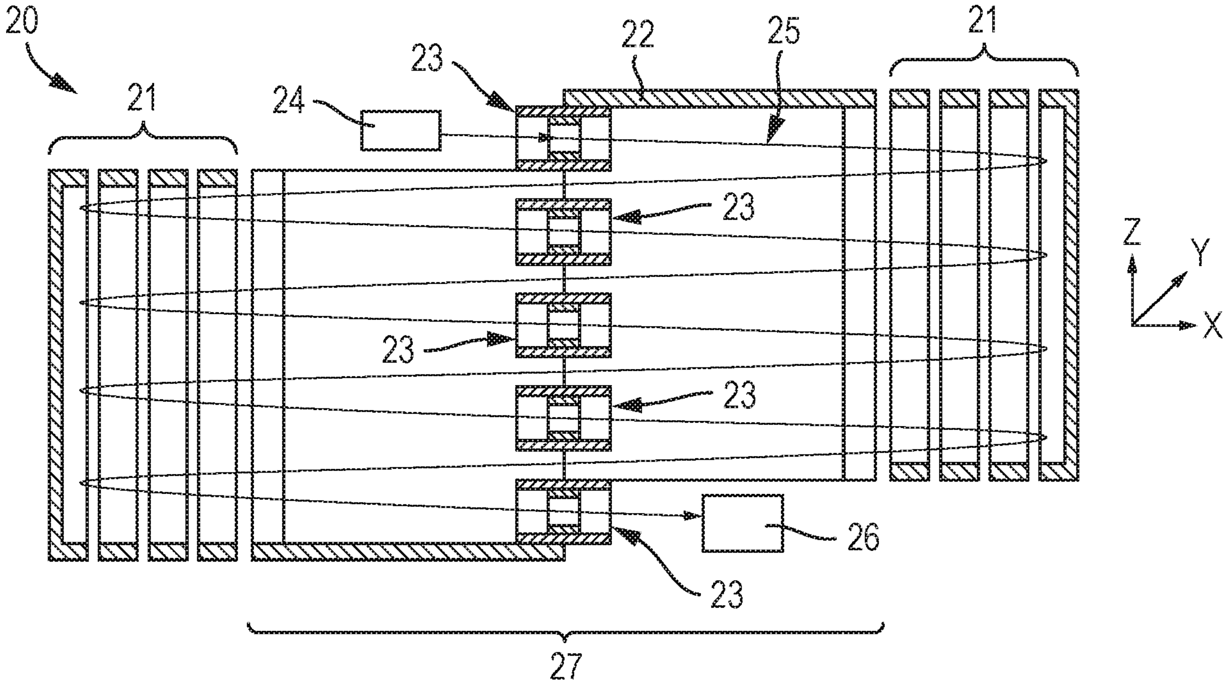
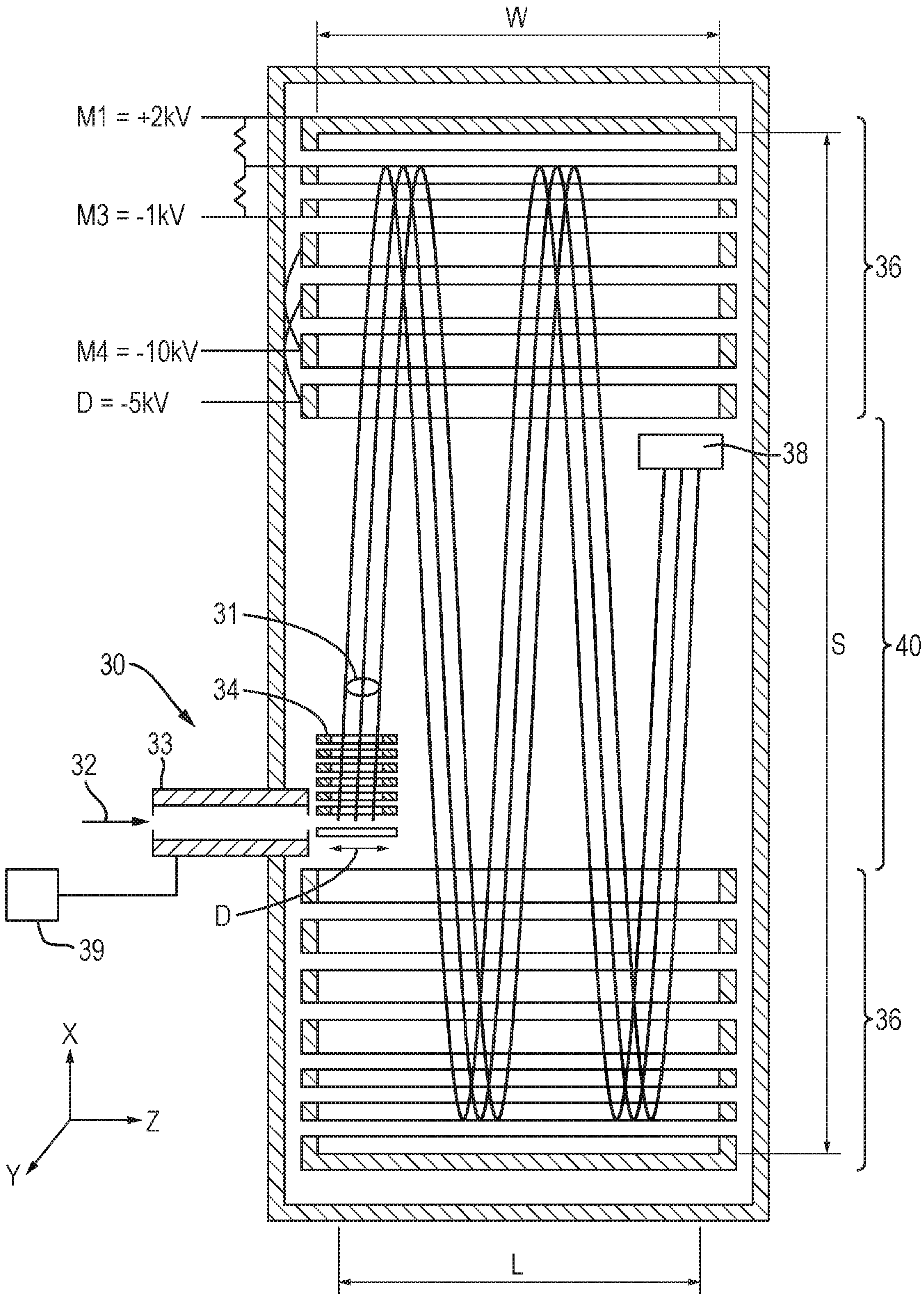
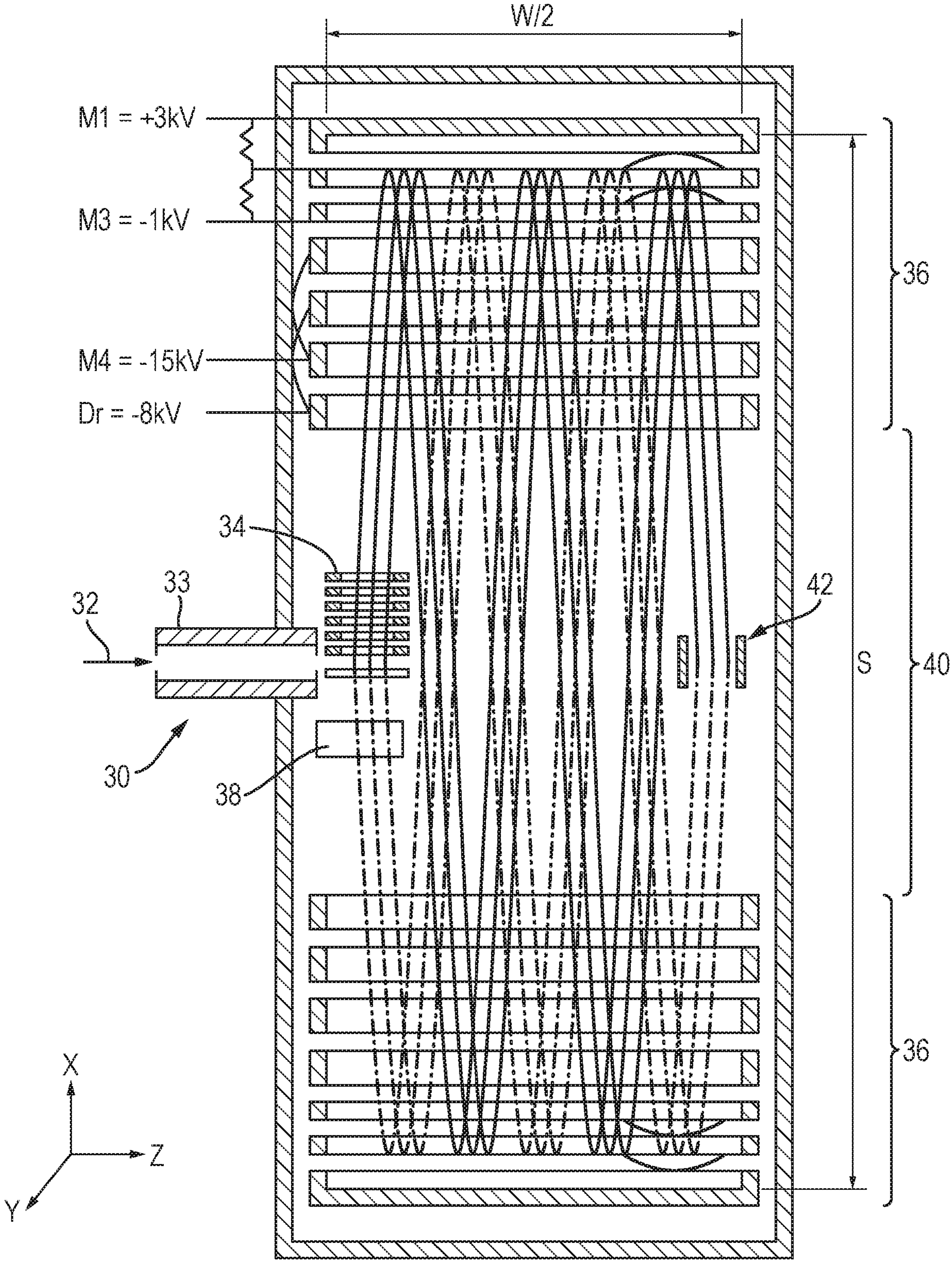


Fig. 3



04 05 18

Fig. 4



04 05 18

Fig. 5A

(Rk=250K)

	Varient #	1	2	3	4	5	6	7	8
	System size (mm)	200x500							
Param	Resolution, K	10	14	20	27		10	13	15
	Duty Cycle	21.3%	14.9%	9.8%	5.7%		21.3%	16.0%	12.8%
Size	# of reflections	2	3	4	5		2	3	4
	Length L, mm	400	400	400	400		400	400	400
	Width W, mm	150	150	150	150		200	200	200
TOF	Energy in TOF, eV	9200	9200	9200	9200		9200	9200	9200
	V tof, mm/us	42.90	42.90	42.90	42.90		42.90	42.90	42.90
	Leff, mm	1200	1600	2000	2400		1200	1600	2000
	TOF, us	28	37	47	56		28	37	47
Beam	Z energy, eV	100	80	50	30		100	100	100
	V beam, mm/us	4.47	4.00	3.16	2.45		4.47	4.47	4.47
Trajectory	Z step, mm	42	37	29	23		42	42	42
	Inclination, mrad	104	93	74	57		104	104	104
	Inclination, deg	6.1	5.5	4.3	3.4		6.1	6.1	6.1
	Mirr Z edge, mm	33	19	16	18		58	37	17
OA	beam d, mm	1.2	1.2	1.2	1.2		1.2	1.2	1.2
	beam ang, mrad	17	17	17	17		17	17	17
	OA length	27	22	14	8		27	27	27
	OA time, us	5.97	5.58	4.58	3.20		5.97	5.97	5.97
	Duty Cycle	0.213	0.149	0.098	0.057		0.213	0.160	0.128
dK	Accelerator field, V/mm	600	600	600	600		600	600	580
	dK, eV	720	720	720	720		720	720	696
R(6%)	dK/K	7.83%	7.83%	7.83%	7.83%		7.83%	7.83%	7.57%
250000	Res(dK)	86371	86371	86371	86371		86371	86371	98914
	dT(dK)	0.16	0.22	0.27	0.32		0.16	0.22	0.24
Packets	Vx, m/s	76.03	68.00	53.76	41.64		76.03	76.03	76.03
	Turn Around, ns	1.27	1.13	0.90	0.69		1.27	1.27	1.31
	DAS and Det, ns	0.7	0.7	0.7	0.7		0.7	0.7	0.7
Resolution	FWHM, ns	1.46	1.35	1.17	1.04		1.46	1.46	1.50
	Resolution	9603	13820	19949	26962		9603	12742	15495
Mesh	angle, mrad	6.52	6.52	6.52	6.52		6.52	6.52	6.30
	Y spread, mm	1.83	1.83	1.83	1.83		1.83	1.83	1.77
	Leff	1.2	1.6	2	2.4		1.2	1.6	2
	Square	0.1	0.1	0.1	0.1		0.125	0.125	0.125
	Resolution	9603	13820	19949	26962		9603	12742	15495
	Duty Cycle	0.213	0.149	0.098	0.057		0.213	0.160	0.128
	Transm OA	1	1	1	0.6		1	1	1
	Res*DC*Transm	2050	2066	1960	925.6		2050	2040	1984

04 05 18

Fig. 5A (Cont. I)

9	10	11	12	#	14	15	16	17	18		20	21
250x500						250x700						
22	29	35	42		13	20	29	40	49		22	28
8.9%	6.2%	4.3%	2.2%		28.5%	19.5%	13.4%	8.2%	5.7%		16.3%	13.1%
5	6	7	8		2	3	4	5	6		4	5
400	400	400	400		600	600	600	600	600		600	600
200	200	200	200		200	200	200	200	200		350	350
9200	9200	9200	9200		9200	9200	9200	9200	9200		9200	9200
42.90	42.90	42.90	42.90		42.90	42.90	42.90	42.90	42.90		42.90	42.90
2400	2800	3200	3600		1600	2200	2800	3400	4000		2800	3400
56	65	75	84		37	51	65	79	93		65	79
60	40	30	20		100	70	41	20	15		100	85
3.46	2.83	2.45	2.00		4.47	3.74	2.86	2.00	1.73		4.47	4.12
32	26	23	19		63	52	40	28	24		63	58
81	66	57	47		104	87	67	47	40		104	96
4.8	3.9	3.4	2.7		6.1	5.1	3.9	2.7	2.4		6.1	5.7
19	21	20	25		37	21	20	30	27		50	31
1.2	1.2	1.2	1.2		1.2	1.2	1.2	1.2	1.2		1.2	1.2
17	17	17	17		17	17	17	17	17		17	17
17	11	8	4		48	37	25	13	9		48	43
4.99	4.02	3.20	1.83		10.63	9.98	8.75	6.49	5.33		10.63	10.35
0.089	0.062	0.043	0.022		0.285	0.195	0.134	0.082	0.057		0.163	0.131
580	580	580	560		600	600	600	550	530		600	600
696	696	696	672		720	720	720	660	636		720	720
7.57%	7.57%	7.57%	7.30%		7.83%	7.83%	7.83%	7.17%	6.91%		7.83%	7.83%
98914	98914	98914	113820		86371	86371	86371	122327	141863		86371	86371
0.28	0.33	0.38	0.37		0.22	0.30	0.38	0.32	0.33		0.38	0.46
58.89	48.08	41.64	34.00		76.03	63.61	48.68	34.00	29.44		76.03	70.09
1.02	0.83	0.72	0.61		1.27	1.06	0.81	0.62	0.56		1.27	1.17
0.7	0.7	0.7	0.7		0.7	0.7	0.7	0.7	0.7		0.7	0.7
1.27	1.13	1.07	1.00		1.46	1.30	1.14	0.99	0.95		1.50	1.44
22110	28779	34818	42078		12742	19656	28724	40093	48966		21815	27577
6.30	6.30	6.30	6.09		6.52	6.52	6.52	5.98	5.76		6.52	6.52
1.77	1.77	1.77	1.70		2.74	2.74	2.74	2.51	2.42		2.74	2.74
2.4	2.8	3.2	3.6		1.6	2.2	2.8	3.4	4		2.8	3.4
0.125	0.125	0.125	0.125		0.175	0.175	0.175	0.175	0.175		0.28	0.28
22110	28779	34818	42078		12742	19656	28724	40093	48966		21815	27577
0.089	0.062	0.043	0.022		0.285	0.195	0.134	0.082	0.057		0.163	0.131
1	0.8	0.6	0.4		1	1	0.82	0.4	0.3		1	1
1974	1418	896.5	366.009		3633	3824	3157	1313	839.2183		3554	3601

04 05 18

Fig. 5A (Cont. II)

22	23	24	25	26	28	29	30	31	32	33
400x700					400x1000					
35	44	53	61	70	35	48	61	75	90	105
10.4%	8.2%	6.6%	5.4%	4.3%	17.9%	13.5%	10.6%	8.4%	6.6%	5.2%
6	7	8	9	10	4	5	6	7	8	9
600	600	600	600	600	900	900	900	900	900	900
350	350	350	350	350	350	350	350	350	350	350
9200	9200	9200	9200	9200	9200	9200	9200	9200	9200	9200
42.90	42.90	42.90	42.90	42.90	42.90	42.90	42.90	42.90	42.90	42.90
4000	4600	5200	5800	6400	4000	4900	5800	6700	7600	8500
93	107	121	135	149	93	114	135	156	177	198
60	42	32	25	20	60	36	25	18	13	10
3.46	2.90	2.53	2.24	2.00	3.46	2.68	2.24	1.90	1.61	1.41
48	41	35	31	28	73	56	47	40	34	30
81	68	59	52	47	81	63	52	44	38	33
4.8	4.0	3.5	3.1	2.7	4.8	3.7	3.1	2.6	2.2	1.9
30	33	33	34	35	30	34	34	36	40	41
1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
17	17	17	17	17	17	17	17	17	17	17
33	26	20	16	13	58	41	32	25	19	15
9.66	8.81	8.06	7.28	6.49	16.65	15.39	14.27	13.08	11.68	10.37
0.104	0.082	0.066	0.054	0.043	0.179	0.135	0.106	0.084	0.066	0.052
600	540	520	500	440	600	580	500	480	440	420
720	648	624	600	528	720	696	600	576	528	504
7.83%	7.04%	6.78%	6.52%	5.74%	7.83%	7.57%	6.52%	6.26%	5.74%	5.48%
86371	131643	153094	179098	298649	86371	98914	179098	210866	298649	359728
0.54	0.41	0.40	0.38	0.25	0.54	0.58	0.38	0.37	0.30	0.28
58.89	49.27	43.01	38.01	34.00	58.89	45.62	38.01	32.26	27.41	24.04
0.98	0.91	0.83	0.76	0.77	0.98	0.79	0.76	0.67	0.62	0.57
0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
1.32	1.22	1.15	1.10	1.07	1.32	1.20	1.10	1.04	0.98	0.95
35298	43950	52543	61448	69580	35298	47564	61448	75193	90128	104816
6.52	5.87	5.65	5.43	4.78	6.52	6.30	5.43	5.22	4.78	4.57
2.74	2.47	2.37	2.28	2.01	4.11	3.97	3.42	3.29	3.01	2.88
4	4.6	5.2	5.8	6.4	4	4.9	5.8	6.7	7.6	8.5
0.28	0.28	0.28	0.28	0.28	0.4	0.4	0.4	0.4	0.4	0.4
35298	43950	52543	61448	69580	35298	47564	61448	75193	90128	104816
0.104	0.082	0.066	0.054	0.043	0.179	0.135	0.106	0.084	0.066	0.052
1	0.84	0.64	0.5	0.4	1	0.72	0.5	0.36	0.26	0.2
3656	3034	2235.33	1654.06	1210.2	6303	4614	3243.24	2266.1	1544.638	1097.551

04 05 18

Fig. 5B

04 05 18

(Rk=80K)

	Varient #	1	2	3	4	5	6	7
	System size (mm)	200x500						
Param	Resn, K	9	13	17	23	9	12	14
	Duty Cycle	21.3%	14.9%	9.8%	5.7%	21.3%	16.0%	12.8%
Size	N refl	2	3	4	5	2	3	4
	Length L, mm	400	400	400	400	400	400	400
	Width W, mm	150	150	150	150	200	200	200
TOF	K, eV	9200	9200	9200	9200	9200	9200	9200
	V tof, mm/us	42.9	42.9	42.9	42.9	42.9	42.9	42.9
	Leff, mm	1200	1600	2000	2400	1200	1600	2000
	TOF, us	27.98	37.3	46.63	55.95	27.98	37.3	46.63
Beam	Beam, eV	100	80	50	30	100	100	100
	V beam, mm/us	4.472	4	3.162	2.449	4.472	4.472	4.472
Trajectory	Z step, mm	41.7	37.3	29.49	22.84	41.7	41.7	41.7
	Inclination, mrad	104.3	93.25	73.72	57.1	104.3	104.3	104.3
	Inclination, deg	6.133	5.485	4.337	3.359	6.133	6.133	6.133
	Mirr Z edge, mm	33.3	19.05	16.02	17.9	58.3	37.45	16.59
OA	beam d, mm	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	beam ang, mrad	17	17	17	17	17	17	17
	OA length	26.7	22.3	14.49	7.842	26.7	26.7	26.7
	OA time, us	5.971	5.575	4.582	3.201	5.971	5.971	5.971
	Duty Cycle	0.213	0.149	0.098	0.057	0.213	0.16	0.128
dK	E, V/mm	600	580	540	460	600	600	580
	dK, eV	720	696	648	552	720	720	696
R(6%)	dK/K	0.078	0.076	0.07	0.06	0.078	0.078	0.076
80000	Res(dK)	27639	31653	42126	80000	27639	27639	31653
	dT(dK)	0.506	0.589	0.553	0.35	0.506	0.675	0.737
Packets	Vx, m/s	76.03	68	53.76	41.64	76.03	76.03	76.03
	Turn Around, ns	1.267	1.172	0.996	0.905	1.267	1.267	1.311
	DAS and Det, ns	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Resolution	FWHM, ns	1.534	1.487	1.337	1.197	1.534	1.597	1.659
	Resolution	9121	12541	17438	23380	9121	11677	14056
Mesh	angle, mrad	6.522	6.304	5.87	5	6.522	6.522	6.304
	Y spread, mm	1.826	1.765	1.643	1.4	1.826	1.826	1.765
	Leff	1.2	1.6	2	2.4	1.2	1.6	2
	Square	0.1	0.1	0.1	0.1	0.125	0.125	0.125
	Resolution	9121	12541	17438	23380	9121	11677	14056
	Duty Cycle	0.213	0.149	0.098	0.057	0.213	0.16	0.128
	Transm OA	1	1	1	0.6	1	1	1
	Res*DC*Transm	1947	1874	1714	802.6	1947	1869	1800

Fig. 5B (Cont. I)

8	9	10	11	12	13	14	15	16	17	18	19
250x500				250x700							
19	25	30	36	12	17	25	34	43	19	23	29
8.9%	6.2%	4.3%	2.6%	28.5%	19.5%	13.4%	9.0%	6.0%	16.3%	13.2%	10.5%
5	6	7	8	2	3	4	5	6	4	5	6
400	400	400	400	600	600	600	600	600	600	600	600
200	200	200	200	200	200	200	200	200	350	350	350
9200	9200	9200	9200	9200	9200	9200	9200	9200	9200	9200	9200
42.9	42.9	42.9	42.8952	42.9	42.9	42.9	42.9	42.89522	42.9	42.9	42.9
2400	2800	3200	3600	1600	2200	2800	3400	4000	2800	3400	4000
55.95	65.28	74.6	83.9254	37.3	51.29	65.28	79.26	93.25048	65.28	79.26	93.25
60	40	30	22	100	70	41	24	16	100	90	65
3.464	2.828	2.449	2.09762	4.472	3.742	2.864	2.191	1.788854	4.472	4.243	3.606
32.3	26.38	22.84	19.5604	62.55	52.34	40.05	30.65	25.02173	62.55	59.34	50.43
80.76	65.94	57.1	48.901	104.3	87.23	66.76	51.08	41.70288	104.3	98.91	84.05
4.75	3.879	3.359	2.87653	6.133	5.131	3.927	3.004	2.453111	6.133	5.818	4.944
19.24	20.87	20.05	21.7585	37.45	21.49	19.89	23.39	24.93481	49.89	26.64	23.7
1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
17	17	17	17	17	17	17	17	17	17	17	17
17.3	11.38	7.842	4.56039	47.55	37.34	25.05	15.65	10.02173	47.55	44.34	35.43
4.995	4.022	3.201	2.17408	10.63	9.979	8.749	7.141	5.602317	10.63	10.45	9.827
0.089	0.062	0.043	0.0259	0.285	0.195	0.134	0.09	0.060078	0.163	0.132	0.105
530	480	450	420	600	540	500	450	420	530	510	480
636	576	540	504	720	648	600	540	504	636	612	576
0.069	0.063	0.059	0.05478	0.078	0.07	0.065	0.059	0.054783	0.069	0.067	0.063
45396	67477	87352	115113	27639	42126	57311	87352	115112.9	45396	52947	67477
0.616	0.484	0.427	0.36454	0.675	0.609	0.569	0.454	0.405039	0.719	0.749	0.691
58.89	48.08	41.64	35.6595	76.03	63.61	48.68	37.25	30.41052	76.03	72.12	61.29
1.111	1.002	0.925	0.84904	1.267	1.178	0.974	0.828	0.72406	1.434	1.414	1.277
0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
1.451	1.314	1.236	1.1592	1.597	1.499	1.327	1.175	1.085504	1.751	1.747	1.612
19285	24832	30169	36199.7	11677	17103	24586	33726	42952.61	18644	22692	28926
5.761	5.217	4.891	4.56522	6.522	5.87	5.435	4.891	4.565217	5.761	5.543	5.217
1.613	1.461	1.37	1.27826	2.739	2.465	2.283	2.054	1.917391	2.42	2.328	2.191
2.4	2.8	3.2	3.6	1.6	2.2	2.8	3.4	4	2.8	3.4	4
0.125	0.125	0.125	0.125	0.175	0.175	0.175	0.175	0.175	0.28	0.28	0.28
19285	24832	30169	36199.7	11677	17103	24586	33726	42952.61	18644	22692	28926
0.089	0.062	0.043	0.0259	0.285	0.195	0.134	0.09	0.060078	0.163	0.132	0.105
1	0.8	0.6	0.44	1	1	0.82	0.48	0.32	1	1	1
1722	1224	776.8	412.609	3329	3328	2702	1458	825.7643	3037	2992	3048

04 05 18

Fig. 5B (Cont. II)

20	21	22	23	24	25	26	27	28	29
400x700				400x1000					
36	43	51	60	29	40	52	65	78	91
8.5%	6.9%	5.7%	4.6%	18.0%	13.7%	10.7%	8.5%	6.8%	5.5%
7	8	9	10	4	5	6	7	8	9
600	600	600	600	900	900	900	900	900	900
350	350	350	350	350	350	350	350	350	350
9200	9200	9200	9200	9200	9200	9200	9200	9200	9200
42.9	42.8952	42.8952	42.8952	42.895	42.9	42.8952	42.8952	42.89522	42.89522
4600	5200	5800	6400	4000	4900	5800	6700	7600	8500
107.2	121.226	135.213	149.201	93.25	114.2	135.213	156.195	177.1759	198.1573
48	36	28	22	65	40	27	19	14	11
3.098	2.68328	2.36643	2.09762	3.6056	2.828	2.32379	1.94936	1.67332	1.48324
43.34	37.5326	33.1006	29.3406	75.649	59.34	48.7563	40.9002	35.10853	31.12038
72.23	62.5543	55.1677	48.901	84.055	65.94	54.1736	45.4447	39.00947	34.5782
4.249	3.67967	3.24516	2.87653	4.9444	3.879	3.18668	2.67322	2.294675	2.034012
23.31	24.8696	26.0471	28.2971	23.701	26.64	28.7312	31.8493	34.56589	34.95827
1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
17	17	17	17	17	17	17	17	17	17
28.34	22.5326	18.1006	14.3406	60.649	44.34	33.7563	25.9002	20.10853	16.12038
9.146	8.3974	7.64892	6.8366	16.821	15.68	14.5264	13.2865	12.01714	10.86836
0.085	0.06927	0.05657	0.04582	0.1804	0.137	0.10743	0.08506	0.067826	0.054847
450	430	420	380	480	440	410	380	360	350
540	516	504	456	576	528	492	456	432	420
0.059	0.05609	0.05478	0.04957	0.0626	0.057	0.05348	0.04957	0.046957	0.045652
87352	104773	115113	171786	67477	95568	126761	171786	213260.9	238698.2
0.614	0.57852	0.58731	0.43426	0.691	0.598	0.53334	0.45462	0.415397	0.415079
52.67	45.6158	40.2293	35.6595	61.294	48.08	39.5044	33.1391	28.44644	25.21507
1.171	1.06083	0.95784	0.93841	1.277	1.093	0.96352	0.87208	0.790179	0.720431
0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
1.496	1.39644	1.32378	1.24868	1.6119	1.429	1.30492	1.20715	1.134433	1.086881
35851	43405.2	51070.9	59743.5	28926	39975	51808.8	64695.7	78090.1	91158.65
4.891	4.67391	4.56522	4.13043	5.2174	4.783	4.45652	4.13043	3.913043	3.804348
2.054	1.96304	1.91739	1.73478	3.287	3.013	2.80761	2.60217	2.465217	2.396739
4.6	5.2	5.8	6.4	4	4.9	5.8	6.7	7.6	8.5
0.28	0.28	0.28	0.28	0.4	0.4	0.4	0.4	0.4	0.4
35851	43405.2	51070.9	59743.5	28926	39975	51808.8	64695.7	78090.1	91158.65
0.085	0.06927	0.05657	0.04582	0.1804	0.137	0.10743	0.08506	0.067826	0.054847
0.96	0.72	0.56	0.44	1	0.8	0.54	0.38	0.28	0.22
2935	2164.83	1617.87	1204.52	5217.9	4389	3005.63	2091.24	1483.032	1099.954

04 05 18

Fig. 6A

(Rk=250K)

	Varient #	1	2	3	4	6	7	8	9
	System size (mm)	200x500				250x500			
Param	Resn, K	10	16	22	30	10	13	18	24
	Duty Cycle	23.7%	14.7%	9.4%	5.6%	23.7%	17.7%	12.5%	9.0%
Size	# of reflections	2	3	4	5	2	3	4	5
	Length L, mm	400	400	400	400	400	400	400	400
	Width W, mm	150	150	150	150	200	200	200	200
TOF	K, eV	6000	6000	6000	6000	6000	6000	6000	6000
	V tof, mm/us	34.64	34.64	34.64	34.64	34.64	34.64	34.64	34.64
	Leff, mm	1200	1600	2000	2400	1200	1600	2000	2400
	TOF, us	35	46	58	69	35	46	58	69
Beam	Beam, eV	100	50	30	19	100	100	60	40
	V beam, mm/us	4.47	3.16	2.45	1.95	4.47	4.47	3.46	2.83
Trajectory	Z step, mm	52	37	28	23	52	52	40	33
	Inclination, mrad	129	91	71	56	129	129	100	82
	Inclination, deg	7.6	5.4	4.2	3.3	7.6	7.6	5.9	4.8
	Mirr Z edge, mm	23	20	18	19	48	23	20	18
OA	beam d, mm	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	beam ang, mrad	17	17	17	17	17	17	17	17
	OA length	37	22	13	8	37	37	25	18
	OA time, us	8.19	6.80	5.42	3.85	8.19	8.19	7.22	6.24
	Duty Cycle	0.237	0.147	0.094	0.056	0.237	0.177	0.125	0.090
dK	E, V/mm	500	450	420	400	550	500	450	420
	dK, eV	600	540	504	480	660	600	540	504
R(6%)	dK/K	10.0%	9.0%	8.4%	8.0%	11.0%	10.0%	9.0%	8.4%
250000	Res(dK)	32400	49383	65077	79102	22130	32400	49383	65077
	dT(dK)	0.53	0.47	0.44	0.44	0.78	0.71	0.58	0.53
Packets	Vx, m/s	76.03	53.76	41.64	33.14	76.03	76.03	58.89	48.08
	Turn Around, ns	1.52	1.19	0.99	0.83	1.38	1.52	1.31	1.14
	DAS and Det, ns	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Resolution	FWHM, ns	1.76	1.46	1.29	1.17	1.74	1.82	1.60	1.44
	Resolution	9857	15802	22340	29616	9978	12694	18098	23996
Mesh	angle, mrad	8.33	7.50	7.00	6.67	9.17	8.33	7.50	7.00
	Y spread, mm	2.33	2.10	1.96	1.87	2.57	2.33	2.10	1.96
	Leff	1.2	1.6	2	2.4	1.2	1.6	2	2.4
	Square	0.1	0.1	0.1	0.1	0.125	0.125	0.125	0.125
	Resolution	9857	15802	22340	29616	9978	12694	18098	23996
	Duty Cycle	0.237	0.147	0.094	0.056	0.237	0.177	0.125	0.090
	Transm OA	1	1	0.6	0.38	1	1	1	0.8
	Res*DC*Transm	2331	2328	1259	625.7	2360	2252	2262	1730

04 05 18

Fig. 6A (Cont. I)

10	11	12	14	15	16	17	18	20	21	22
					250x700					
31	38	45	12	21	31	42	54	20	28	36
6.0%	4.2%	2.8%	30.2%	19.4%	13.1%	9.1%	5.8%	17.3%	13.3%	10.5%
6	7	8	2	3	4	5	6	4	5	6
400	400	400	600	600	600	600	600	600	600	600
200	200	200	200	200	200	200	200	350	350	350
6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000
34.64	34.64	34.64	34.64	34.64	34.64	34.64	34.64	34.64	34.64	34.64
2800	3200	3600	1600	2200	2800	3400	4000	2800	3400	4000
81	92	104	46	64	81	98	115	81	98	115
25	19	15	100	45	25	16	10	100	62	42
2.24	1.95	1.73	4.47	3.00	2.24	1.79	1.41	4.47	3.52	2.90
26	23	20	77	52	39	31	24	77	61	50
65	56	50	129	87	65	52	41	129	102	84
3.8	3.3	2.9	7.6	5.1	3.8	3.0	2.4	7.6	6.0	4.9
23	21	20	23	22	23	23	27	20	23	24
1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
17	17	17	17	17	17	17	17	17	17	17
11	8	5	62	37	24	16	9	62	46	35
4.84	3.85	2.89	13.97	12.32	10.61	8.94	6.71	13.97	13.06	12.15
0.060	0.042	0.028	0.302	0.194	0.131	0.091	0.058	0.173	0.133	0.105
420	380	360	460	420	380	350	310	430	410	390
504	456	432	552	504	456	420	372	516	492	468
8.4%	7.6%	7.2%	9.2%	8.4%	7.6%	7.0%	6.2%	8.6%	8.2%	7.8%
65077	97116	120563	45227	65077	97116	134944	219270	59231	71662	87532
0.62	0.48	0.43	0.51	0.49	0.42	0.36	0.26	0.68	0.68	0.66
38.01	33.14	29.44	76.03	51.00	38.01	30.41	24.04	76.03	59.86	49.27
0.91	0.87	0.82	1.65	1.21	1.00	0.87	0.78	1.77	1.46	1.26
0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
1.30	1.22	1.16	1.87	1.48	1.29	1.17	1.08	2.02	1.76	1.59
31044	38008	44809	12376	21396	31331	41818	53587	20004	27914	36362
7.00	6.33	6.00	7.67	7.00	6.33	5.83	5.17	7.17	6.83	6.50
1.96	1.77	1.68	3.22	2.94	2.66	2.45	2.17	3.01	2.87	2.73
2.8	3.2	3.6	1.6	2.2	2.8	3.4	4	2.8	3.4	4
0.125	0.125	0.125	0.175	0.175	0.175	0.175	0.175	0.28	0.28	0.28
31044	38008	44809	12376	21396	31331	41818	53587	20004	27914	36362
0.060	0.042	0.028	0.302	0.194	0.131	0.091	0.058	0.173	0.133	0.105
0.5	0.38	0.3	1	0.9	0.5	0.32	0.2	1	1	0.84
929.2	602.3	373.4	3742	3736	2057	1218	623.2	3457	3715	3213

04 05 18

Fig. 6A (Cont. II)

23	24	25	26	28	29	30	31	32	33
400x700				400x1000					
45	55	64	75	36	51	66	82	96	113
8.4%	6.9%	5.6%	4.5%	18.0%	13.6%	10.7%	8.4%	6.9%	5.6%
7	8	9	10	4	5	6	7	8	9
600	600	600	600	900	900	900	900	900	900
350	350	350	350	350	350	350	350	350	350
6000	6000	6000	6000	6000	6000	6000	6000	6000	6000
34.64	34.64	34.64	34.64	34.64	34.64	34.64	34.64	34.64	34.64
4600	5200	5800	6400	4000	4900	5800	6700	7600	8500
133	150	167	185	115	141	167	193	219	245
30	23	18	14	42	25	17	12	9.5	7.5
2.45	2.14	1.90	1.67	2.90	2.24	1.84	1.55	1.38	1.22
42	37	33	29	75	58	48	40	36	32
71	62	55	48	84	65	53	45	40	35
4.2	3.6	3.2	2.8	4.9	3.8	3.1	2.6	2.3	2.1
27	26	27	30	24	30	31	34	32	32
1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
17	17	17	17	17	17	17	17	17	17
27	22	18	14	60	43	33	25	21	17
11.20	10.33	9.41	8.36	20.81	19.27	17.85	16.30	15.10	13.73
0.084	0.069	0.056	0.045	0.180	0.136	0.107	0.084	0.069	0.056
370	350	330	310	390	360	330	310	300	270
444	420	396	372	468	432	396	372	360	324
7.4%	7.0%	6.6%	6.2%	7.8%	7.2%	6.6%	6.2%	6.0%	5.4%
108048	134944	170753	219270	87532	120563	170753	219270	250000	381039
0.61	0.56	0.49	0.42	0.66	0.59	0.49	0.44	0.44	0.32
41.64	36.46	32.26	28.45	49.27	38.01	31.35	26.34	23.43	20.82
1.13	1.04	0.98	0.92	1.26	1.06	0.95	0.85	0.78	0.77
0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
1.46	1.37	1.30	1.23	1.59	1.40	1.28	1.19	1.14	1.09
45448	54673	64478	75186	36362	50659	65518	81549	96484	112546
6.17	5.83	5.50	5.17	6.50	6.00	5.50	5.17	5.00	4.50
2.59	2.45	2.31	2.17	4.10	3.78	3.47	3.26	3.15	2.84
4.6	5.2	5.8	6.4	4	4.9	5.8	6.7	7.6	8.5
0.28	0.28	0.28	0.28	0.4	0.4	0.4	0.4	0.4	0.4
45448	54673	64478	75186	36362	50659	65518	81549	96484	112546
0.084	0.069	0.056	0.045	0.180	0.136	0.107	0.084	0.069	0.056
0.6	0.46	0.36	0.28	0.84	0.5	0.34	0.24	0.19	0.15
2299	1730	1305	952.2	5503	3451	2374	1649	1262	944.9

04 05 18

Fig. 6B

04 05 18

(Rk=80K)

	Varient #	1	2	3	4	5	6	7	8
	System size (mm)	200x500				250x500			
Param	Resn, K	8	13	19	25	8	10	15	20
	Duty Cycle	23.7%	14.7%	9.4%	5.6%	23.7%	17.7%	12.5%	9.0%
Size	# of reflections	2	3	4	5	2	3	4	5
	Length L, mm	400	400	400	400	400	400	400	400
	Width W, mm	150	150	150	150	200	200	200	200
TOF	K, eV	6000	6000	6000	6000	6000	6000	6000	6000
	V tof, mm/us	34.64	34.64	34.64	34.64	34.64	34.64	34.64	34.64
	Leff, mm	1200	1600	2000	2400	1200	1600	2000	2400
	TOF, us	35	46	58	69	35	46	58	69
Beam	Beam, eV	100	50	30	19	100	100	60	40
	V beam, mm/us	4.47	3.16	2.45	1.95	4.47	4.47	3.46	2.83
Trajectory	Z step, mm	52	37	28	23	52	52	40	33
	Inclination, mrad	129	91	71	56	129	129	100	82
	Inclination, deg	7.6	5.4	4.2	3.3	7.6	7.6	5.9	4.8
	Mirr Z edge, mm	23	20	18	19	48	23	20	18
OA	beam d, mm	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	beam ang, mrad	17	17	17	17	17	17	17	17
	OA length	37	22	13	8	37	37	25	18
	OA time, us	8.19	6.80	5.42	3.85	8.19	8.19	7.22	6.24
	Duty Cycle	0.237	0.147	0.094	0.056	0.237	0.177	0.125	0.090
dK	E, V/mm	420	410	340	310	430	410	370	340
	dK, eV	504	492	408	372	516	492	444	408
R(6%)	dK/K	8.40%	8.20%	6.80%	6.20%	8.60%	8.20%	7.40%	6.80%
80000	Res(dK)	20825	22932	48491	70166	18954	22932	34575	48491
	dT(dK)	0.83	1.01	0.60	0.49	0.91	1.01	0.83	0.71
Packets	Vx, m/s	76.03	53.76	41.64	33.14	76.03	76.03	58.89	48.08
	Turn Around, ns	1.81	1.31	1.22	1.07	1.77	1.85	1.59	1.41
	DAS and Det, ns	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Resolution	FWHM, ns	2.11	1.80	1.53	1.37	2.11	2.22	1.93	1.73
	Resolution	8203	12863	18854	25288	8210	10388	14966	19999
Mesh	angle, mrad	7.00	6.83	5.67	5.17	7.17	6.83	6.17	5.67
	Y spread, mm	1.96	1.91	1.59	1.45	2.01	1.91	1.73	1.59
	Leff	1.2	1.6	2	2.4	1.2	1.6	2	2.4
	Square	0.1	0.1	0.1	0.1	0.125	0.125	0.125	0.125
	Resolution	8203	12863	18854	25288	8210	10388	14966	19999
	Duty Cycle	0.237	0.147	0.094	0.056	0.237	0.177	0.125	0.090
	Transm OA	1	1	0.6	0.38	1	1	1	0.8
	Res*DC*Transm	1940	1895	1063	534.3	1942	1843	1871	1442

Fig. 6B (Cont. I)

9	10	11	12	13	14	15	16	17	18	19
			250x700							
27	32	38	10	18	27	36	47	16	23	30
6.0%	4.2%	2.8%	30.2%	19.4%	13.1%	9.1%	5.8%	17.3%	13.3%	10.5%
6	7	8	2	3	4	5	6	4	5	6
400	400	400	600	600	600	600	600	600	600	600
200	200	200	200	200	200	200	200	350	350	350
6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000
34.64	34.64	34.64	34.64	34.64	34.64	34.64	34.64	34.64	34.64	34.64
2800	3200	3600	1600	2200	2800	3400	4000	2800	3400	4000
81	92	104	46	64	81	98	115	81	98	115
25	19	15	100	45	25	16	10	100	62	42
2.24	1.95	1.73	4.47	3.00	2.24	1.79	1.41	4.47	3.52	2.90
26	23	20	77	52	39	31	24	77	61	50
65	56	50	129	87	65	52	41	129	102	84
3.8	3.3	2.9	7.6	5.1	3.8	3.0	2.4	7.6	6.0	4.9
23	21	20	23	22	23	23	27	20	23	24
1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
17	17	17	17	17	17	17	17	17	17	17
11	8	5	62	37	24	16	9	62	46	35
4.84	3.85	2.89	13.97	12.32	10.61	8.94	6.71	13.97	13.06	12.15
0.060	0.042	0.028	0.302	0.194	0.131	0.091	0.058	0.173	0.133	0.105
310	290	280	400	330	310	280	260	330	310	290
372	348	336	480	396	372	336	312	396	372	348
6.20%	5.80%	5.60%	8.00%	6.60%	6.20%	5.60%	5.20%	6.60%	6.20%	5.80%
70166	91618	105425	25313	54641	70166	105425	141802	54641	70166	91618
0.58	0.50	0.49	0.91	0.58	0.58	0.47	0.41	0.74	0.70	0.63
38.01	33.14	29.44	76.03	51.00	38.01	30.41	24.04	76.03	59.86	49.27
1.23	1.14	1.05	1.90	1.55	1.23	1.09	0.92	2.30	1.93	1.70
0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
1.52	1.43	1.36	2.22	1.79	1.52	1.37	1.23	2.52	2.17	1.94
26503	32259	38319	10396	17707	26503	35732	46972	16045	22617	29721
5.17	4.83	4.67	6.67	5.50	5.17	4.67	4.33	5.50	5.17	4.83
1.45	1.35	1.31	2.80	2.31	2.17	1.96	1.82	2.31	2.17	2.03
2.8	3.2	3.6	1.6	2.2	2.8	3.4	4	2.8	3.4	4
0.125	0.125	0.125	0.175	0.175	0.175	0.175	0.175	0.28	0.28	0.28
26503	32259	38319	10396	17707	26503	35732	46972	16045	22617	29721
0.060	0.042	0.028	0.302	0.194	0.131	0.091	0.058	0.173	0.133	0.105
0.5	0.38	0.3	1	0.9	0.5	0.32	0.2	1	1	0.84
793.3	511.2	319.3	3144	3092	1740	1041	546.2	2772	3010	2626

04 05 18

Fig. 6B (Cont. II)

20	21	22	23	24	25	26	27	28	29
400x700				400x1000					
38	46	54	64	30	42	54	69	83	98
8.4%	6.9%	5.6%	4.5%	18.0%	13.6%	10.7%	8.4%	6.9%	5.6%
7	8	9	10	4	5	6	7	8	9
600	600	600	600	900	900	900	900	900	900
350	350	350	350	350	350	350	350	350	350
6000	6000	6000	6000	6000	6000	6000	6000	6000	6000
34.64	34.64	34.64	34.64	34.64	34.64	34.64	34.64	34.64	34.64
4600	5200	5800	6400	4000	4900	5800	6700	7600	8500
133	150	167	185	115	141	167	193	219	245
30	23	18	14	42	25	17	12	9.5	7.5
2.45	2.14	1.90	1.67	2.90	2.24	1.84	1.55	1.38	1.22
42	37	33	29	75	58	48	40	36	32
71	62	55	48	84	65	53	45	40	35
4.2	3.6	3.2	2.8	4.9	3.8	3.1	2.6	2.3	2.1
27	26	27	30	24	30	31	34	32	32
1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
17	17	17	17	17	17	17	17	17	17
27	22	18	14	60	43	33	25	21	17
11.20	10.33	9.41	8.36	20.81	19.27	17.85	16.30	15.10	13.73
0.084	0.069	0.056	0.045	0.180	0.136	0.107	0.084	0.069	0.056
280	270	260	250	300	290	280	250	240	220
336	324	312	300	360	348	336	300	288	264
5.60%	5.40%	5.20%	5.00%	6.00%	5.80%	5.60%	5.00%	4.80%	4.40%
105425	121933	141802	165888	80000	91618	105425	165888	195313	276620
0.63	0.62	0.59	0.56	0.72	0.77	0.79	0.58	0.56	0.44
41.64	36.46	32.26	28.45	49.27	38.01	31.35	26.34	23.43	20.82
1.49	1.35	1.24	1.14	1.64	1.31	1.12	1.05	0.98	0.95
0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
1.76	1.64	1.54	1.45	1.93	1.67	1.54	1.39	1.33	1.26
37720	45741	54292	63824	29982	42236	54335	69438	82716	97531
4.67	4.50	4.33	4.17	5.00	4.83	4.67	4.17	4.00	3.67
1.96	1.89	1.82	1.75	3.15	3.05	2.94	2.63	2.52	2.31
4.6	5.2	5.8	6.4	4	4.9	5.8	6.7	7.6	8.5
0.28	0.28	0.28	0.28	0.4	0.4	0.4	0.4	0.4	0.4
37720	45741	54292	63824	29982	42236	54335	69438	82716	97531
0.084	0.069	0.056	0.045	0.180	0.136	0.107	0.084	0.069	0.056
0.6	0.46	0.36	0.28	0.84	0.5	0.34	0.24	0.19	0.15
1908	1447	1099	808.3	4538	2877	1969	1404	1082	818.8

04 05 18

Fig. 7

Rk=100K, K=5keV

	Varient #	1	2	3	4	5	6	7	8	9	10
	System size (mm)	150x300				200x300					
Param	Resn, K	4	7	11	15	4	6	8	12	15	7
	Duty Cycle	26.9%	14.4%	7.3%	2.8%	24.8%	17.7%	12.1%	7.5%	4.4%	26.0%
Size	# of reflections	2	3	4	5	2	3	4	5	6	2
	Length L, mm	250	250	250	250	250	250	250	250	250	350
	Width W, mm	110	110	110	110	160	160	160	160	160	110
TOF	K, eV	3000	3000	3000	3000	4000	4000	4000	4000	4000	5000
	V tof, mm/us	24.49	24.49	24.49	24.49	28.28	28.28	28.28	28.28	28.28	31.62
	Leff, mm	625	875	1125	1375	625	875	1125	1375	1625	875
	TOF, us	26	36	46	56	22	31	40	49	57	28
Beam	Beam, eV	100	44	24	15	100	100	70	42	28	75
	V beam, mm/us	4.47	2.97	2.19	1.73	4.47	4.47	3.74	2.90	2.37	3.87
Trajectory	Z step, mm	46	30	22	18	40	40	33	26	21	43
	Inclination, mrad	183	121	89	71	158	158	132	102	84	122
	Inclination, deg	10.7	7.1	5.3	4.2	9.3	9.3	7.8	6.0	4.9	7.2
	Mirr Z edge, mm	9	10	10	11	40	21	14	16	17	12
OA	beam d, mm	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	beam ang, mrad	17	17	17	17	17	17	17	17	17	17
	OA length	31	15	7	3	25	25	18	11	6	28
	OA time, us	6.85	5.15	3.36	1.55	5.48	5.48	4.83	3.66	2.50	7.19
	Duty Cycle	0.269	0.144	0.073	0.028	0.248	0.177	0.121	0.075	0.044	0.260
dK	E, V/mm	280	230	210	190	360	330	300	280	260	380
	dK, eV	336	276	252	228	432	396	360	336	312	456
R(6%)	dK/K	11.2%	9.2%	8.4%	7.6%	10.8%	9.9%	9.0%	8.4%	7.8%	9.1%
100000	Res(dK)	8236	18091	26031	38846	9526	13492	19753	26031	35013	18734
	dT(dK)	1.55	0.99	0.88	0.72	1.16	1.15	1.01	0.93	0.82	0.74
Packets	Vx, m/s	76.03	50.43	37.25	29.44	76.03	76.03	63.61	49.27	40.23	65.84
	Turn Around, ns	2.72	2.19	1.77	1.55	2.11	2.30	2.12	1.76	1.55	1.73
	DAS and Det, ns	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Resolution	FWHM, ns	3.20	2.50	2.10	1.85	2.51	2.67	2.45	2.11	1.89	2.01
	Resolution	3983	7132	10930	15191	4404	5600	8120	11512	15231	6885
Mesh	angle, mrad	9.33	7.67	7.00	6.33	9.00	8.25	7.50	7.00	6.50	7.60
	Y spread, mm	1.63	1.34	1.23	1.11	1.58	1.44	1.31	1.23	1.14	1.86
	Leff	0.625	0.875	1.125	1.375	0.625	0.875	1.125	1.375	1.625	0.875
	Square	0.045	0.045	0.045	0.045	0.06	0.06	0.06	0.06	0.06	0.06
	Resolution	3983	7132	10930	15191	4404	5600	8120	11512	15231	6885
	Duty Cycle	0.269	0.144	0.073	0.028	0.248	0.177	0.121	0.075	0.044	0.260
	Transm OA	2	0.88	0.48	0.3	2	2	1.4	0.84	0.56	1.5
	Res*DC*Transm	2139	904.7	383.8	125.5	2186	2057	1380	728.7	371.2	2686

04 05 18

Fig. 7 (Cont. I)

11	12	13	15	16	17	18	19	20	21	22	23	24	25
150x400			200x400					250x400					
12	18	24	6	9	14	19	24	6	8	11	15	19	25
13.9%	6.8%	2.3%	27.9%	18.9%	12.1%	7.8%	5.0%	27.9%	19.9%	14.9%	10.7%	7.7%	5.4%
3	4	5	2	3	4	5	6	2	3	4	5	6	7
350	350	350	350	350	350	350	350	350	350	350	350	350	350
110	110	110	160	160	160	160	160	210	210	210	210	210	210
5000	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000
31.62	31.62	31.62	31.62	31.62	31.62	31.62	31.62	31.62	31.62	31.62	31.62	31.62	31.62
1225	1575	1925	875	1225	1575	1925	2275	875	1225	1575	1925	2275	2625
39	50	61	28	39	50	61	72	28	39	50	61	72	83
35	19	12	100	80	44	28	20	100	100	85	54	37	26
2.65	1.95	1.55	4.47	4.00	2.97	2.37	2.00	4.47	4.47	4.12	3.29	2.72	2.28
29	22	17	49	44	33	26	22	49	49	46	36	30	25
84	62	49	141	126	94	75	63	141	141	130	104	86	72
4.9	3.6	2.9	8.3	7.4	5.5	4.4	3.7	8.3	8.3	7.7	6.1	5.1	4.2
11	12	12	31	14	14	15	14	56	31	14	14	15	17
1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
17	17	17	17	17	17	17	17	17	17	17	17	17	17
14	7	2	34	29	18	11	7	34	34	31	21	15	10
5.40	3.37	1.39	7.71	7.32	6.01	4.73	3.57	7.71	7.71	7.43	6.50	5.55	4.49
0.139	0.068	0.023	0.279	0.189	0.121	0.078	0.050	0.279	0.199	0.149	0.107	0.077	0.054
340	300	280	390	370	330	300	280	410	400	350	330	300	280
408	360	336	468	444	396	360	336	492	480	420	396	360	336
8.2%	7.2%	6.7%	9.4%	8.9%	7.9%	7.2%	6.7%	9.8%	9.6%	8.4%	7.9%	7.2%	6.7%
29231	48225	63552	16885	20843	32939	48225	63552	13824	15259	26031	32939	48225	63552
0.66	0.52	0.48	0.82	0.93	0.76	0.63	0.57	1.00	1.27	0.96	0.92	0.75	0.65
44.98	33.14	26.34	76.03	68.00	50.43	40.23	34.00	76.03	76.03	70.09	55.87	46.24	38.77
1.32	1.10	0.94	1.95	1.84	1.53	1.34	1.21	1.85	1.90	2.00	1.69	1.54	1.38
0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
1.64	1.41	1.27	2.23	2.18	1.84	1.64	1.51	2.22	2.39	2.33	2.05	1.85	1.68
11834	17712	24032	6211	8905	13512	18570	23797	6231	8103	10701	14834	19444	24657
6.80	6.00	5.60	7.80	7.40	6.60	6.00	5.60	8.20	8.00	7.00	6.60	6.00	5.60
1.67	1.47	1.37	1.91	1.81	1.62	1.47	1.37	2.01	1.96	1.72	1.62	1.47	1.37
1.225	1.575	1.925	0.875	1.225	1.575	1.925	2.275	0.875	1.225	1.575	1.925	2.275	2.625
0.06	0.06	0.06	0.08	0.08	0.08	0.08	0.08	0.1	0.1	0.1	0.1	0.1	0.1
11834	17712	24032	6211	8905	13512	18570	23797	6231	8103	10701	14834	19444	24657
0.139	0.068	0.023	0.279	0.189	0.121	0.078	0.050	0.279	0.199	0.149	0.107	0.077	0.054
0.7	0.38	0.24	2	1.6	0.88	0.56	0.4	2	2	1.7	1.08	0.74	0.52
1154	455.8	131.3	3463	2691	1435	807.9	472.1	3474	3227	2714	1712	1111	693.5

04 05 18

Fig. 7 (Cont. II)

04 05 18

26		27	28	29	30	31		34	35	36	37	38	39	40
		200x500						250x500						
30		8	13	19	26	34		8	10	15	21	27	35	43
3.6%		30.6%	19.0%	12.3%	8.1%	5.3%		30.6%	21.5%	14.8%	11.0%	8.1%	5.7%	3.8%
8		2	3	4	5	6		2	3	4	5	6	7	8
350		450	450	450	450	450		450	450	450	450	450	450	450
210		160	160	160	160	160		210	210	210	210	210	210	210
5000		5000	5000	5000	5000	5000		5000	5000	5000	5000	5000	5000	5000
31.62		31.62	31.62	31.62	31.62	31.62		31.62	31.62	31.62	31.62	31.62	31.62	31.62
2975		1125	1575	2025	2475	2925		1125	1575	2025	2475	2925	3375	3825
94		36	50	64	78	92		36	50	64	78	92	107	121
19		100	50	28	18	13		100	90	50	36	25	17	12
1.95		4.47	3.16	2.37	1.90	1.61		4.47	4.24	3.16	2.68	2.24	1.84	1.55
22		64	45	34	27	23		64	60	45	38	32	26	22
62		141	100	75	60	51		141	134	100	85	71	58	49
3.6		8.3	5.9	4.4	3.5	3.0		8.3	7.9	5.9	5.0	4.2	3.4	2.9
19		16	13	13	13	11		41	14	15	10	10	13	17
1.2		1.2	1.2	1.2	1.2	1.2		1.2	1.2	1.2	1.2	1.2	1.2	1.2
17		17	17	17	17	17		17	17	17	17	17	17	17
7		49	30	19	12	8		49	45	30	23	17	11	7
3.37		10.88	9.49	7.89	6.32	4.93		10.88	10.69	9.49	8.64	7.52	6.10	4.55
0.036		0.306	0.190	0.123	0.081	0.053		0.306	0.215	0.148	0.110	0.081	0.057	0.038
260		380	330	300	270	260		400	380	350	290	260	250	240
312		456	396	360	324	312		480	456	420	348	312	300	288
6.2%		9.1%	7.9%	7.2%	6.5%	6.2%		9.6%	9.1%	8.4%	7.0%	6.2%	6.0%	5.8%
85480		18734	32939	48225	73503	85480		15259	18734	26031	55229	85480	100000	117738
0.55		0.95	0.76	0.66	0.53	0.54		1.17	1.33	1.23	0.71	0.54	0.53	0.51
33.14		76.03	53.76	40.23	32.26	27.41		76.03	72.12	53.76	45.62	38.01	31.35	26.34
1.27		2.00	1.63	1.34	1.19	1.05		1.90	1.90	1.54	1.57	1.46	1.25	1.10
0.7		0.7	0.7	0.7	0.7	0.7		0.7	0.7	0.7	0.7	0.7	0.7	0.7
1.55		2.32	1.93	1.65	1.48	1.38		2.34	2.42	2.09	1.86	1.71	1.53	1.40
30254		7659	12920	19382	26380	33603		7611	10288	15330	21019	27063	34833	43221
5.20		7.60	6.60	6.00	5.40	5.20		8.00	7.60	7.00	5.80	5.20	5.00	4.80
1.27		2.39	2.08	1.89	1.70	1.64		2.52	2.39	2.21	1.83	1.64	1.58	1.51
2.975		1.125	1.575	2.025	2.475	2.925		1.125	1.575	2.025	2.475	2.925	3.375	3.825
0.1		0.1	0.1	0.1	0.1	0.1		0.125	0.125	0.125	0.125	0.125	0.125	0.125
30254		7659	12920	19382	26380	33603		7611	10288	15330	21019	27063	34833	43221
0.036		0.306	0.190	0.123	0.081	0.053		0.306	0.215	0.148	0.110	0.081	0.057	0.038
0.38		2	1	0.56	0.36	0.26		2	1.8	1	0.72	0.5	0.34	0.24
412.2		4683	2461	1338	767.4	465.4		4654	3976	2271	1671	1100	676.4	390

Fig. 8

200x500, N=5 reflections, optimizing DC

	Varient #	27	28	29	30	31	30	31
	System size (mm)	200x500						
Param	Resn, K	31	30	29	28	28	27	26
	Duty Cycle	7.7%	7.8%	7.7%	7.8%	7.7%	7.7%	7.6%
Size	# of reflections	5	5	5	5	5	5	5
	Length L, mm	450	450	450	450	450	450	450
	Width W, mm	160	160	160	160	160	160	160
TOF	K, eV	4000	5000	6000	7000	8000	9000	10000
	V tof, mm/us	28.28	31.62	34.64	37.42	40.00	42.43	44.72
	Leff, mm	2475	2475	2475	2475	2475	2475	2475
	TOF, us	88	78	71	66	62	58	55
Beam	Beam, eV	13.5	17	20	24	27	30	33
	V beam, mm/us	1.64	1.84	2.00	2.19	2.32	2.45	2.57
Trajectory	Z step, mm	26	26	26	26	26	26	26
	Inclination, mrad	58	58	58	59	58	58	57
	Inclination, deg	3.4	3.4	3.4	3.4	3.4	3.4	3.4
	Mirr Z edge, mm	15	14	15	14	15	15	15
OA	beam d, mm	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	beam ang, mrad	17	17	17	17	17	17	17
	OA length	11	11	11	11	11	11	11
	OA time, us	6.78	6.10	5.49	5.18	4.80	4.48	4.22
	Duty Cycle	0.077	0.078	0.077	0.078	0.077	0.077	0.076
dK	E, V/mm	260	320	380	450	520	570	640
	dK, eV	312	384	456	540	624	684	768
R(6%)	dK/K	7.8%	7.7%	7.6%	7.7%	7.8%	7.6%	7.7%
200000	Res(dK)	70026	74506	77693	73190	70026	77693	74506
	dT(dK)	0.62	0.53	0.46	0.45	0.44	0.38	0.37
Packets	Vx, m/s	27.93	31.35	34.00	37.25	39.50	41.64	43.67
	Turn Around, ns	1.07	0.98	0.89	0.83	0.76	0.73	0.68
	DAS and Det, ns	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Resolution	FWHM, ns	1.43	1.31	1.23	1.17	1.12	1.08	1.05
	Resolution	30673	29792	29149	28162	27536	27028	26461
Mesh	angle, mrad	6.50	6.40	6.33	6.43	6.50	6.33	6.40
	Y spread, mm	2.05	2.02	2.00	2.03	2.05	2.00	2.02
	Leff	2.475	2.475	2.475	2.475	2.475	2.475	2.475
	Square	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Resolution	30673	29792	29149	28162	27536	27028	26461
	Duty Cycle	0.077	0.078	0.077	0.078	0.077	0.077	0.076
	Transm OA	0.27	0.34	0.4	0.48	0.54	0.6	0.66
	Res*DC*Transm	641.79	788.86	895.99	1058.6	1152.3	1246.2	1332.8

04 05 18

Fig. 8 (Cont.)

34	35	36	37	38	39	40
250x500						
25	24	24	23	23	23	22
10.7%	10.7%	10.7%	10.7%	10.7%	10.7%	10.7%
5	5	5	5	5	5	5
450	450	450	450	450	450	450
210	210	210	210	210	210	210
4000	5000	6000	7000	8000	9000	10000
28.28	31.62	34.64	37.42	40.00	42.43	44.72
2475	2475	2475	2475	2475	2475	2475
88	78	71	66	62	58	55
26	33	39	46	52	59	65
2.28	2.57	2.79	3.03	3.22	3.44	3.61
36	37	36	36	36	36	36
81	81	81	81	81	81	81
4.7	4.8	4.7	4.8	4.7	4.8	4.7
14	14	14	14	14	14	14
1.2	1.2	1.2	1.2	1.2	1.2	1.2
17	17	17	17	17	17	17
21	22	21	21	21	21	21
9.33	8.39	7.62	7.08	6.60	6.24	5.90
0.107	0.107	0.107	0.107	0.107	0.107	0.107
270	350	410	460	520	600	650
324	420	492	552	624	720	780
8.1%	8.4%	8.2%	7.9%	7.8%	8.0%	7.8%
60214	52062	57330	67030	70026	63281	70026
0.73	0.75	0.62	0.49	0.44	0.46	0.40
38.77	43.67	47.48	51.56	54.82	58.40	61.29
1.44	1.25	1.16	1.12	1.05	0.97	0.94
0.7	0.7	0.7	0.7	0.7	0.7	0.7
1.75	1.62	1.49	1.41	1.34	1.28	1.24
24932	24213	23980	23445	23080	22709	22332
6.75	7.00	6.83	6.57	6.50	6.67	6.50
2.13	2.21	2.15	2.07	2.05	2.10	2.05
2.475	2.475	2.475	2.475	2.475	2.475	2.475
0.125	0.125	0.125	0.125	0.125	0.125	0.125
24932	24213	23980	23445	23080	22709	22332
0.107	0.107	0.107	0.107	0.107	0.107	0.107
0.52	0.66	0.78	0.92	1.04	1.18	1.3
1382.6	1713.4	1994.7	2309.2	2559.9	2866.3	3096.1

04 05 18

Fig. 9

200x500, N=6 reflections, optimizing DC

Optimum for R=20K

	Point	27	28	29	30	31	30	31
	System	200x500						
Param	Resn, K	39	38	37	36	35	34	33
	Duty Cycle	4.9%	4.9%	4.8%	4.7%	4.9%	4.8%	4.7%
Size	# of reflections	6	6	6	6	6	6	6
	Length L, mm	450	450	450	450	450	450	450
	Width W, mm	160	160	160	160	160	160	160
TOF	K, eV	4000	5000	6000	7000	8000	9000	10000
	V tof, mm/us	28.28	31.62	34.64	37.42	40.00	42.43	44.72
	Leff, mm	2925	2925	2925	2925	2925	2925	2925
	TOF, us	103	92	84	78	73	69	65
Beam	Beam, eV	9.5	12	14	16	19	21	23
	V beam, mm/us	1.38	1.55	1.67	1.79	1.95	2.05	2.14
Trajectory	Z step, mm	22	22	22	22	22	22	22
	Inclination, mrad	49	49	48	48	49	48	48
	Inclination, deg	2.9	2.9	2.8	2.8	2.9	2.8	2.8
	Mirr Z edge, mm	14	14	15	15	14	15	15
OA	beam d, mm	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	beam ang, mrad	17	17	17	17	17	17	17
	OA length	7	7	7	7	7	7	7
	OA time, us	5.03	4.55	4.03	3.64	3.56	3.29	3.07
	Duty Cycle	0.049	0.049	0.048	0.047	0.049	0.048	0.047
dK	E, V/mm	240	280	340	410	490	540	590
	dK, eV	288	336	408	492	588	648	708
R(6%)	dK/K	7.2%	6.7%	6.8%	7.0%	7.4%	7.2%	7.1%
200000	Res(dK)	96451	127104	121227	106210	88815	96451	103158
	dT(dK)	0.54	0.36	0.35	0.37	0.41	0.36	0.32
Packets	Vx, m/s	23.43	26.34	28.45	30.41	33.14	34.84	36.46
	Turn Around, ns	0.98	0.94	0.84	0.74	0.68	0.65	0.62
	DAS and Det, ns	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Resolution	FWHM, ns	1.32	1.23	1.15	1.08	1.06	1.02	0.99
	Resolution	39304	37673	36869	36050	34597	33900	33163
Mesh	angle, mrad	6.00	5.60	5.67	5.86	6.13	6.00	5.90
	Y spread, mm	1.89	1.76	1.79	1.85	1.93	1.89	1.86
	Leff	2.925	2.925	2.925	2.925	2.925	2.925	2.925
	Square	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Resolution	39304	37673	36869	36050	34597	33900	33163
	Duty Cycle	0.049	0.049	0.048	0.047	0.049	0.048	0.047
	Transm OA	0.19	0.24	0.28	0.32	0.38	0.42	0.46
	Res*DC*Transm	363.07	444.54	492.23	537.37	639.16	678.9	715.71

04 05 18

Fig. 9 (Cont.)

34	35	36	37	38	39	40
250x500						
32	31	31	30	29	29	29
7.7%	7.7%	7.7%	7.8%	7.7%	7.7%	7.7%
6	6	6	6	6	6	6
450	450	450	450	450	450	450
210	210	210	210	210	210	210
4000	5000	6000	7000	8000	9000	10000
28.28	31.62	34.64	37.42	40.00	42.43	44.72
2925	2925	2925	2925	2925	2925	2925
103	92	84	78	73	69	65
18	22	27	32	36	40	44
1.90	2.10	2.32	2.53	2.68	2.83	2.97
30	30	30	30	30	30	30
67	66	67	68	67	67	66
3.9	3.9	3.9	4.0	3.9	3.9	3.9
14	15	14	14	14	15	15
1.2	1.2	1.2	1.2	1.2	1.2	1.2
17	17	17	17	17	17	17
15	15	15	15	15	15	15
8.00	7.08	6.54	6.10	5.66	5.30	5.01
0.077	0.077	0.077	0.078	0.077	0.077	0.077
260	340	380	420	480	560	630
312	408	456	504	576	672	756
7.8%	8.2%	7.6%	7.2%	7.2%	7.5%	7.6%
70026	58462	77693	96451	96451	83393	79350
0.74	0.79	0.54	0.41	0.38	0.41	0.41
32.26	35.66	39.50	43.01	45.62	48.08	50.43
1.24	1.05	1.04	1.02	0.95	0.86	0.80
0.7	0.7	0.7	0.7	0.7	0.7	0.7
1.60	1.49	1.37	1.30	1.24	1.18	1.14
32227	31069	30906	29954	29493	29153	28675
6.50	6.80	6.33	6.00	6.00	6.22	6.30
2.05	2.14	2.00	1.89	1.89	1.96	1.98
2.925	2.925	2.925	2.925	2.925	2.925	2.925
0.125	0.125	0.125	0.125	0.125	0.125	0.125
32227	31069	30906	29954	29493	29153	28675
0.077	0.077	0.077	0.078	0.077	0.077	0.077
0.36	0.44	0.54	0.64	0.72	0.8	0.88
897.97	1046.3	1291.7	1495.3	1643.6	1794.1	1931.3

04 05 18

Fig. 10

DC=10%

	Variant	1	2	3	4	5	6	7
Param	Resn, K	9	9	13	14	15	17	23
	Duty Cycle	9.8%	11.9%	7.7%	12.8%	12.0%	10.7%	10.4%
Size	# of reflections	3	4	5	3	4	5	4
	Length L, mm	250	250	250	350	350	350	450
	Width W, mm	110	160	160	110	160	210	150
TOF	K, eV	6000	6000	6000	6000	6000	6000	9200
	V tof, mm/us	34.64	34.64	34.64	34.64	34.64	34.64	42.90
	Leff, mm	875	1125	1375	1225	1575	1925	2200
	TOF, us	25	32	40	35	45	56	51
Beam	Beam, eV	50	100	65	36	52	65	42
	V beam, mm/us	3.16	4.47	3.61	2.68	3.22	3.61	2.90
Trajectory	Z step, mm	23	32	26	27	33	36	30
	Inclination, mrad	91	129	104	77	93	104	68
	Inclination, deg	5.4	7.6	6.1	4.6	5.5	6.1	4.0
	Mirr Z edge, mm	21	15	15	14	15	14	14
OA	beam d, mm	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	beam ang, mrad	17	17	17	17	17	17	17
	OA length	8	17	11	12	18	21	15
	OA time, us	2.47	3.86	3.06	4.51	5.45	5.94	5.32
	Duty Cycle	0.098	0.119	0.077	0.128	0.120	0.107	0.104
dK	E, V/mm	500	540	500	470	460	470	660
	dK, eV	600	648	600	564	552	564	792
R(6%)	dK/K	10.0%	10.8%	10.0%	9.4%	9.2%	9.4%	8.6%
250000	Res(dK)	32400	23815	32400	41499	45227	41499	58992
	dT(dK)	0.39	0.68	0.61	0.43	0.50	0.67	0.43
Packets	Vx, m/s	53.76	76.03	61.29	45.62	54.82	61.29	49.27
	Turn Around, ns	1.08	1.41	1.23	0.97	1.19	1.30	0.75
	DAS and Det, ns	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Resolution	FWHM, ns	1.34	1.71	1.54	1.27	1.47	1.62	1.11
	Resolution	9419	9475	12897	13920	15457	17104	23064
Mesh	angle, mrad	8.33	9.00	8.33	7.83	7.67	7.83	7.17
	Y spread, mm	1.46	1.58	1.46	1.92	1.88	1.92	2.26
	Leff	0.875	1.125	1.375	1.225	1.575	1.925	2.2
	Square	0.045	0.06	0.06	0.06	0.08	0.1	0.1
	Resolution	9419	9475	12897	13920	15457	17104	23064
	Duty Cycle	0.098	0.119	0.077	0.128	0.120	0.107	0.104
	Transm OA	1	2	1.3	0.72	1.04	1.3	0.84
	Res*DC*Transm	922.3	2254	1291	1279	1928	2378	2008

04 05 18

Fig. 10 (Cont.)

8	9	10	11	12
26	31	38	51	64
9.3%	13.9%	10.8%	13.8%	10.9%
5	4	6	5	6
450	650	650	950	950
200	200	350	350	350
9200	9200	9200	9200	9200
42.90	42.90	42.90	42.90	42.90
2650	3000	4300	5150	6100
62	70	100	120	142
50	38	60	36	25
3.16	2.76	3.46	2.68	2.24
33	42	52	59	50
74	64	81	63	52
4.3	3.8	4.8	3.7	3.1
17	16	18	26	26
1.2	1.2	1.2	1.2	1.2
17	17	17	17	17
18	27	37	44	35
5.75	9.71	10.82	16.56	15.44
0.093	0.139	0.108	0.138	0.109
640	600	580	530	510
768	720	696	636	612
8.3%	7.8%	7.6%	6.9%	6.7%
66719	86371	98914	141863	165459
0.46	0.40	0.51	0.42	0.43
53.76	46.87	58.89	45.62	38.01
0.84	0.78	1.02	0.86	0.75
0.7	0.7	0.7	0.7	0.7
1.19	1.12	1.33	1.19	1.11
26014	31103	37593	50558	64106
6.96	6.52	6.30	5.76	5.54
2.19	2.97	2.87	3.83	3.69
2.65	3	4.3	5.15	6.1
0.125	0.175	0.28	0.4	0.4
26014	31103	37593	50558	64106
0.093	0.139	0.108	0.138	0.109
1	0.76	1	0.72	0.5
2420	3283	4059	5020	3480

04 05 18

250x700mm

Fig. 11

	Variant	1	2	3	4	5	6	7
Param	Resn, K	33	32	30	29	45	44	42
	Duty Cycle	14.9%	14.9%	14.9%	14.8%	10.7%	10.6%	10.4%
Size	# of reflections	4	4	4	4	5	5	5
	Length L, mm	650	650	650	650	650	650	650
	Width W, mm	210	210	210	210	210	210	210
Acc	Acceleartion, V	3000	4000	6000	8000	3000	4000	6000
Push	Push amplitude	1400	1400	2400	2400	1400	1400	2400
TOF	K, eV	3700	4700	7200	9200	3700	4700	7200
	V tof, mm/us	27.20	30.66	37.95	42.90	27.20	30.66	37.95
	Leff, mm	2925	2925	2925	2925	3575	3575	3650
	TOF, us	108	95	77	68	131	117	96
Beam	Beam, eV	18	23	35	44	11.5	14.5	22
	V beam, mm/us	1.90	2.14	2.65	2.97	1.52	1.70	2.10
Trajectory	Z step, mm	45	45	45	45	36	36	36
	Inclination, mrad	70	70	70	69	56	56	55
	Inclination, deg	4.1	4.1	4.1	4.1	3.3	3.3	3.3
	Mirr Z edge, mm	14	14	14	15	14	15	15
OA	beam d, mm	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	beam ang, mrad	17	17	17	17	17	17	17
	OA length	30	30	30	30	21	21	21
	OA time, us	15.99	14.21	11.46	10.10	14.00	12.39	9.98
	Duty Cycle	0.149	0.149	0.149	0.148	0.107	0.106	0.104
dK	E, V/mm	230	330	460	600	230	290	440
	dK, eV	276	396	552	720	276	348	528
R(6%)	dK/K	7.5%	8.4%	7.7%	7.8%	7.5%	7.4%	7.3%
250000	Res(dK)	104644	64292	93782	86371	104644	107800	112031
	dT(dK)	0.51	0.74	0.41	0.39	0.63	0.54	0.43
Packets	Vx, m/s	32.26	36.46	44.98	50.43	25.78	28.95	35.66
	Turn Around, ns	1.40	1.10	0.98	0.84	1.12	1.00	0.81
	DAS and Det, ns	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Resolution	FWHM, ns	1.65	1.50	1.27	1.16	1.46	1.33	1.15
	Resolution	32594	31722	30328	29319	44910	43711	41685
Mesh	angle, mrad	6.22	7.02	6.39	6.52	6.22	6.17	6.11
	Y spread, mm	2.83	3.19	2.91	2.97	2.83	2.81	2.78
	Leff	2.925	2.925	2.925	2.925	3.575	3.575	3.65
	Square	0.175	0.175	0.175	0.175	0.175	0.175	0.175
	Resolution	32594	31722	30328	29319	44910	43711	41685
	Duty Cycle	0.149	0.149	0.149	0.148	0.107	0.106	0.104
	Transm OA	0.36	0.46	0.7	0.88	0.23	0.29	0.44
	Res*DC*Transm	1745	2173	3156	3820	1101	1347	1903
	OA length	13.04	12.12	13.04	13.33	13.04	13.79	13.64
	OA gap	6.087	4.242	5.217	4	6.087	4.828	5.455

04 05 18

Fig. 11 (Cont.)

04 05 18

8		9	10	11	12
40		59	57	52	50
10.4%		7.6%	7.6%	7.6%	7.6%
5		6	6	6	6
650		650	650	650	650
210		210	210	210	210
8000		3000	4000	6000	8000
2400		1400	1400	2400	2400
9200		3700	4700	7200	9200
42.90		27.20	30.66	37.95	42.90
3650		4300	4300	4300	4300
85		158	140	113	100
28		8	10	15.5	20
2.37		1.26	1.41	1.76	2.00
36		30	30	30	30
55		46	46	46	47
3.2		2.7	2.7	2.7	2.7
15		14	15	15	14
1.2		1.2	1.2	1.2	1.2
17		17	17	17	17
21		15	15	15	15
8.81		12.04	10.59	8.61	7.65
0.104		0.076	0.076	0.076	0.076
560		210	270	420	520
672		252	324	504	624
7.3%		6.8%	6.9%	7.0%	6.8%
113820		150574	143468	134944	153094
0.37		0.52	0.49	0.42	0.33
40.23		21.50	24.04	29.93	34.00
0.72		1.02	0.89	0.71	0.65
0.7		0.7	0.7	0.7	0.7
1.07		1.35	1.23	1.08	1.01
39747		58681	56846	52287	49514
6.09		5.68	5.74	5.83	5.65
2.77		2.58	2.61	2.65	2.57
3.65		4.3	4.3	4.3	4.3
0.175		0.175	0.175	0.175	0.175
39747		58681	56846	52287	49514
0.104		0.076	0.076	0.076	0.076
1		0.16	1	0.31	0.4
4117		714.9	4294	1232	1512
14.29		14.29	14.81	14.29	15.38
4.286		6.667	5.185	5.714	4.615

MULTI-REFLECTING TIME-OF-FLIGHT MASS SPECTROMETERS

CROSS-REFERENCE TO RELATED APPLICATION

None.

FIELD OF THE INVENTION

The present invention relates generally to mass spectrometers and in particular to multi reflecting time-of-flight mass spectrometers (MR-TOF-MS) and methods of their use.

BACKGROUND

A time-of-flight mass spectrometer is a widely used tool of analytical chemistry, characterized by high speed analysis of wide mass ranges. It has been recognized that multi-reflecting time-of-flight mass spectrometers (MR-TOF-MS) provide a substantial increase in resolving power by reflecting the ions multiple times so as to extend the flight path of the ions. Such an extension of the ion flight paths has been achieved by reflecting ions between ion mirrors.

SU 1725289 discloses an MR-TOF-MS instrument having an ion mirror arranged on either side of a field-free region. An ion source is arranged in the field-free region, which ejects ions into one of the ion mirrors. The ions are reflected back and forth between the ion mirrors as they drift along the instrument until the ions reach an ion detector. The mass to charge ratio of an ion can then be determined by detecting the time it has taken for the ion to travel from the ion source to the ion detector.

WO 2005/001878 discloses a similar instrument having a set of periodic lenses within the field-free region between the ion mirrors so as to prevent the ion beam diverging significantly in the direction orthogonal to the dimension in which the ions are reflected by the ion mirror, thereby increasing the duty cycle of the spectrometer.

SUMMARY

According to a first aspect the present invention provides a multi-reflecting time of flight mass analyser comprising:

an ion accelerator;

two ion mirrors arranged for reflecting ions in a first dimension (x-dimension) and being elongated in a second dimension (z-dimension); and

an ion detector;

wherein the ion accelerator is arranged and configured for accelerating ions into a first of the ion mirrors at an angle to the first dimension such that the ions are repeatedly reflected between the ion mirrors in the first dimension (x-dimension) as they travel in the second dimension (z-dimension);

wherein the ions are not spatially focussed in the second dimension (z-dimension) as they travel from the ion accelerator to the detector; and

wherein the mass analyser has a duty cycle of ≥ 5%, a resolution of ≥ 20,000, wherein the distance in the first dimension (x-dimension) between points of reflection in the two ion mirrors is ≤ 1000 mm; and wherein the mass analyser is configured such that the ions travel a distance in the second dimension (z-dimension) from the ion accelerator to the detector of ≤ 700 mm.

No focusing of the ions is provided in the second dimension (z-dimension) between the ion mirrors, e.g. there are no periodic lenses focussing the ions in the second dimension (z-dimension). As such, each packet of ions expands in the second dimension (z-dimension) as it travels from the ion accelerator to the detector. MR-TOF-MS instruments have conventionally sought to obtain a very high resolution and hence require a high number of reflections between the ion mirrors. Therefore, conventionally it has been considered necessary to provide second dimension (z-dimension) focussing between the ion mirrors to prevent the width of the ion packet diverging to the extent that it becomes larger than the detector width by the time it has completed the high number of mirror reflections and reached the detector. This was considered necessary to maintain an acceptable transmission, and hence sensitivity, of the instrument. Also, if the ion packets diverge too much in the second dimension (z-dimension), then some ions may reach the detector having only been reflected a first number of times, whereas other ions may reach the detector having been reflected a larger number of times. Ions may therefore have significantly different flight path lengths through the field-free region on the way to the detector, which is undesirable in time of flight mass analysers.

However, the inventors of the present invention have realised that if the ion flight path within the instrument is maintained relatively small and the duty cycle (as defined herein below, i.e. D/L) is made relatively high, then the second dimension (z-dimension) focussing can be eliminated whilst maintaining a reasonably high sensitivity and resolution. More specifically, each ion packet that is pulsed out of the ion accelerator expands in the second dimension (z-dimension) as it travels towards the detector, due to thermal velocities of the ions. This is particularly problematic in multi reflecting time-of-flight mass spectrometers because on one hand the ion detector must be relatively short in the second dimension (z-dimension) so that ions do not collide with it until the desired number of ion mirror reflections have been performed, but on the other hand it must be long enough to receive the expanded ion packet. The more the ion packet expands in the second dimension (z-dimension), relative to its original length in this dimension, the more problematic this becomes. The inventors have recognised that by maintaining the initial size of the ion packet (i.e. D) relatively high and the distance between the ion accelerator and the detector (i.e. L) relatively small (i.e. by providing a relatively high duty cycle, D/L), the proportional expansion of the ion packet between the ion accelerator and the detector remains relatively low.

The first aspect of the invention also provides a method of time of flight mass analysis comprising: providing a mass analyser as described above; controlling the ion accelerator so as to accelerate ions into the first ion mirror at an angle to the first dimension such that the ions are repeatedly reflected between the ion mirrors in the first dimension (x-dimension) as they travel in the second dimension (z-dimension), wherein the distance in the first dimension (x-dimension) between points of reflection in the two ion mirrors is ≤ 1000 mm, wherein the ions travel a distance in the second dimension (z-dimension) from the ion accelerator to the detector of ≤ 700 mm, and wherein the ions are not spatially focussed in the second dimension (z-dimension) as they travel from the ion accelerator to the detector; and wherein the ions are detected by the detector and time of flight mass analysed with a duty cycle of ≥ 5% and a resolution of ≥ 20,000.

From a second aspect the present invention provides a multi-reflecting time of flight mass analyser comprising:

an ion accelerator;

two ion mirrors arranged for reflecting ions in a first dimension (x-dimension) and being elongated in a second dimension (z-dimension); and

an ion detector;

wherein the ion accelerator is arranged and configured for accelerating ions into a first of the ion mirrors at an angle to the first dimension such that the ions are repeatedly reflected between the ion mirrors in the first dimension (x-dimension) as they travel in the second dimension (z-dimension); and

wherein the ions are reflected so as to pass from one of the ion mirrors to the other of the ion mirrors n times, and wherein the ions are not spatially focussed in the second dimension (z-dimension) during ≥ 60 % of these n times.

The second aspect of the invention also provides a method of time of flight mass analysis comprising: providing a mass analyser as described above; and controlling the ion accelerator so as to accelerate ions into the first ion mirror at an angle to the first dimension such that the ions are repeatedly reflected between the ion mirrors in the first dimension (x-dimension) as they travel in the second dimension (z-dimension),wherein the ions are reflected so as to pass from one of the ion mirrors to the other of the ion mirrors n times, and wherein the ions are not spatially focussed in the second dimension (z-dimension) during ≥ 60 % of these n times.

From a third aspect the present invention provides a multi-reflecting time of flight mass analyser comprising:

an ion accelerator;

two ion mirrors arranged for reflecting ions in a first dimension (x-dimension) and being elongated in a second dimension (z-dimension); and

an ion detector;

wherein the ion accelerator is arranged and configured for accelerating ions into a first of the ion mirrors at an angle to the first dimension such that the ions are repeatedly reflected between the ion mirrors in the first dimension (x-dimension) as they travel in the second dimension (z-dimension).

The third aspect of the invention also provides a method of time of flight mass analysis comprising: providing a mass analyser as described above; and controlling the ion accelerator so as to accelerate ions into the first ion mirror at an angle to the first dimension such that the ions are repeatedly reflected between the ion mirrors in the first dimension (x-dimension) as they travel in the second dimension (z-dimension).

The spectrometers herein may comprise an ion source selected from the group consisting of: (i) an Electrospray ionisation ("ESI") ion source; (ii) an Atmospheric Pressure Photo Ionisation ("APPI") ion source; (iii) an Atmospheric Pressure Chemical Ionisation ("APCI") ion source; (iv) a Matrix Assisted Laser Desorption Ionisation ("MALDI") ion source; (v) a Laser Desorption Ionisation ("LDI") ion source; (vi) an Atmospheric Pressure Ionisation ("API") ion source; (vii) a Desorption Ionisation on Silicon ("DIOS") ion source; (viii) an Electron Impact ("EI") ion source; (ix) a Chemical Ionisation ("CI") ion source; (x) a Field Ionisation ("FI") ion source; (xi) a Field Desorption ("FD") ion source; (xii) an Inductively Coupled Plasma ("ICP") ion source; (xiii) a Fast Atom Bombardment ("FAB") ion source; (xiv) a Liquid Secondary Ion Mass Spectrometry ("LSIMS") ion source; (xv) a Desorption Electrospray Ionisation ("DESI") ion source; (xvi) a Nickel-63 radioactive ion source; (xvii) an Atmospheric Pressure Matrix Assisted Laser Desorption Ionisation ion source; (xviii) a Thermospray ion source; (xix) an Atmospheric Sampling Glow Discharge Ionisation (“ASGDI”) ion source; (xx) a Glow Discharge (“GD”) ion source; (xxi) an Impactor ion source; (xxii) a Direct Analysis in Real Time ("DART") ion source; (xxiii) a Laserspray Ionisation ("LSI") ion source; (xxiv) a Sonicspray Ionisation ("SSI") ion source; (xxv) a Matrix Assisted Inlet Ionisation ("MAII") ion source; (xxvi) a Solvent Assisted Inlet Ionisation ("SAII") ion source; (xxvii) a Desorption Electrospray Ionisation (“DESI”) ion source; (xxviii) a Laser Ablation Electrospray Ionisation (“LAESI”) ion source; and (xxix) Surface Assisted Laser Desorption Ionisation (“SALDI”).

The spectrometer may comprise one or more continuous or pulsed ion sources.

The spectrometer may comprise one or more ion guides.

The spectrometer may comprise one or more ion mobility separation devices and/or one or more Field Asymmetric Ion Mobility Spectrometer devices.

The spectrometer may comprise one or more ion traps or one or more ion trapping regions.

The spectrometer may comprise one or more collision, fragmentation or reaction cells selected from the group consisting of: (i) a Collisional Induced Dissociation ("CID") fragmentation device; (ii) a Surface Induced Dissociation ("SID") fragmentation device; (iii) an Electron Transfer Dissociation ("ETD") fragmentation device; (iv) an Electron Capture Dissociation ("ECD") fragmentation device; (v) an Electron Collision or Impact Dissociation fragmentation device; (vi) a Photo Induced Dissociation ("PID") fragmentation device; (vii) a Laser Induced Dissociation fragmentation device; (viii) an infrared radiation induced dissociation device; (ix) an ultraviolet radiation induced dissociation device; (x) a nozzle-skimmer interface fragmentation device; (xi) an in-source fragmentation device; (xii) an in-source Collision Induced Dissociation fragmentation device; (xiii) a thermal or temperature source fragmentation device; (xiv) an electric field induced fragmentation device; (xv) a magnetic field induced fragmentation device; (xvi) an enzyme digestion or enzyme degradation fragmentation device; (xvii) an ion-ion reaction fragmentation device; (xviii) an ion-molecule reaction fragmentation device; (xix) an ion-atom reaction fragmentation device; (xx) an ion-metastable ion reaction fragmentation device; (xxi) an ion-metastable molecule reaction fragmentation device; (xxii) an ion-metastable atom reaction fragmentation device; (xxiii) an ion-ion reaction device for reacting ions to form adduct or product ions; (xxiv) an ion-molecule reaction device for reacting ions to form adduct or product ions; (xxv) an ion-atom reaction device for reacting ions to form adduct or product ions; (xxvi) an ion-metastable ion reaction device for reacting ions to form adduct or product ions; (xxvii) an ion-metastable molecule reaction device for reacting ions to form adduct or product ions; (xxviii) an ion-metastable atom reaction device for reacting ions to form adduct or product ions; and (xxix) an Electron Ionisation Dissociation (“EID”) fragmentation device.

The ion-molecule reaction device may be configured to perform ozonlysis for the location of olefinic (double) bonds in lipids.

The spectrometer may comprise a mass analyser selected from the group consisting of: (i) a quadrupole mass analyser; (ii) a 2D or linear quadrupole mass analyser; (iii) a Paul or 3D quadrupole mass analyser; (iv) a Penning trap mass analyser; (v) an ion trap mass analyser; (vi) a magnetic sector mass analyser; (vii) Ion Cyclotron Resonance ("ICR") mass analyser; (viii) a Fourier Transform Ion Cyclotron Resonance ("FTICR") mass analyser; (ix) an electrostatic mass analyser arranged to generate an electrostatic field having a quadro-logarithmic potential distribution; (x) a Fourier Transform electrostatic mass analyser; and (xi) a Fourier Transform mass analyser.

The spectrometer may comprise one or more energy analysers or electrostatic energy analysers.

The spectrometer may comprise one or more mass filters selected from the group consisting of: (i) a quadrupole mass filter; (ii) a 2D or linear quadrupole ion trap; (iii) a Paul or 3D quadrupole ion trap; (iv) a Penning ion trap; (v) an ion trap; (vi) a magnetic sector mass filter; (vii) a Time of Flight mass filter; and (viii) a Wien filter.

The spectrometer may comprise a device or ion gate for pulsing ions; and/or a device for converting a substantially continuous ion beam into a pulsed ion beam.

The spectrometer may comprise a C-trap and a mass analyser comprising an outer barrel-like electrode and a coaxial inner spindle-like electrode that form an electrostatic field with a quadro-logarithmic potential distribution, wherein in a first mode of operation ions are transmitted to the C-trap and are then injected into the mass analyser and wherein in a second mode of operation ions are transmitted to the C-trap and then to a collision cell or Electron Transfer Dissociation device wherein at least some ions are fragmented into fragment ions, and wherein the fragment ions are then transmitted to the C-trap before being injected into the mass analyser.

The spectrometer may comprise a stacked ring ion guide comprising a plurality of electrodes each having an aperture through which ions are transmitted in use and wherein the spacing of the electrodes increases along the length of the ion path, and wherein the apertures in the electrodes in an upstream section of the ion guide have a first diameter and wherein the apertures in the electrodes in a downstream section of the ion guide have a second diameter which is smaller than the first diameter, and wherein opposite phases of an AC or RF voltage are applied, in use, to successive electrodes.

The spectrometer may comprise a device arranged and adapted to supply an AC or RF voltage to the electrodes. The AC or RF voltage optionally has an amplitude selected from the group consisting of: (i) about < 50 V peak to peak; (ii) about 50-100 V peak to peak; (iii) about 100-150 V peak to peak; (iv) about 150-200 V peak to peak; (v) about 200-250 V peak to peak; (vi) about 250-300 V peak to peak; (vii) about 300-350 V peak to peak; (viii) about 350-400 V peak to peak; (ix) about 400-450 V peak to peak; (x) about 450-500 V peak to peak; and (xi) > about 500 V peak to peak.

The AC or RF voltage may have a frequency selected from the group consisting of: (i) < about 100 kHz; (ii) about 100-200 kHz; (iii) about 200-300 kHz; (iv) about 300-400 kHz; (v) about 400-500 kHz; (vi) about 0.5-1.0 MHz; (vii) about 1.0-1.5 MHz; (viii) about 1.5-2.0 MHz; (ix) about 2.0-2.5 MHz; (x) about 2.5-3.0 MHz; (xi) about 3.0-3.5 MHz; (xii) about 3.5-4.0 MHz; (xiii) about 4.0-4.5 MHz; (xiv) about 4.5-5.0 MHz; (xv) about 5.0-5.5 MHz; (xvi) about 5.5-6.0 MHz; (xvii) about 6.0-6.5 MHz; (xviii) about 6.5-7.0 MHz; (xix) about 7.0-7.5 MHz; (xx) about 7.5-8.0 MHz; (xxi) about 8.0-8.5 MHz; (xxii) about 8.5-9.0 MHz; (xxiii) about 9.0-9.5 MHz; (xxiv) about 9.5-10.0 MHz; and (xxv) > about 10.0 MHz.

The spectrometer may comprise a chromatography or other separation device upstream of an ion source. The chromatography separation device may comprise a liquid chromatography or gas chromatography device. Alternatively, the separation device may comprise: (i) a Capillary Electrophoresis (“CE”) separation device; (ii) a Capillary Electrochromatography (“CEC”) separation device; (iii) a substantially rigid ceramic-based multilayer microfluidic substrate (“ceramic tile”) separation device; or (iv) a supercritical fluid chromatography separation device.

The ion guide may be maintained at a pressure selected from the group consisting of: (i) < about 0.0001 mbar; (ii) about 0.0001-0.001 mbar; (iii) about 0.001-0.01 mbar; (iv) about 0.01-0.1 mbar; (v) about 0.1-1 mbar; (vi) about 1-10 mbar; (vii) about 10-100 mbar; (viii) about 100-1000 mbar; and (ix) > about 1000 mbar.

Analyte ions may be subjected to Electron Transfer Dissociation (“ETD”) fragmentation in an Electron Transfer Dissociation fragmentation device. Analyte ions may be caused to interact with ETD reagent ions within an ion guide or fragmentation device.

The spectrometer may be operated in various modes of operation including a mass spectrometry ("MS") mode of operation; a tandem mass spectrometry ("MS/MS") mode of operation; a mode of operation in which parent or precursor ions are alternatively fragmented or reacted so as to produce fragment or product ions, and not fragmented or reacted or fragmented or reacted to a lesser degree; a Multiple Reaction Monitoring ("MRM") mode of operation; a Data Dependent Analysis ("DDA") mode of operation; a

Data Independent Analysis ("DIA") mode of operation a Quantification mode of operation or an Ion Mobility Spectrometry ("IMS") mode of operation.

BRIEF DESCRIPTION OF THE DRAWINGS

Various embodiments will now be described, by way of example only, and with reference to the accompanying drawings in which:

Fig. 1 shows an MR-TOF-MS instrument according to the prior art;

Fig. 2 shows another MR-TOF-MS instrument according to the prior art;

Fig. 3 shows a schematic of an embodiment of the invention;

Fig. 4 show a schematic of another embodiment of the invention;

Figs. 5A-5B show the resolution and duty cycle modelled for different sized MR-TOF-MS instruments, for ions having an energy in the field-free region between the mirrors of 9.2 keV;

Fig. 6A-6B show data for corresponding parameters to those shown in Figs. 5A-5B, except that the data is modelled for ions having an energy in the field-free region between the mirrors of 6 keV;

Fig. 7 shows data for corresponding parameters to those shown in Figs. 5A-5B, except that the data is modelled for ions having an energy in the field-free region between the mirrors of 3 keV, 4 keV and 5 keV;

Fig. 8 shows data for corresponding parameters to those shown in Figs. 5A-5B, except that the data is modelled for ions being reflected in the mirrors five times and having an energy in the field-free region between the mirrors of between 4-10 keV;

Fig. 9 shows data for corresponding parameters to those shown in Figs. 8, except that the data is modelled for ions being reflected in the mirrors six times;

Fig. 10 shows data for corresponding parameters to those shown in Figs. 5A-5B, except that the data is modelled for achieving a duty cycle of around 10%; and

Fig. 11 shows data for corresponding parameters to those shown in Figs. 5A-5B, for instruments having a medium size.

DETAILED DESCRIPTION

Fig. 1 shows the MR-TOF-MS instrument of SU 1725289. The instrument comprises two ion mirrors 10 separated in the x-dimension by a field-free region 12. Each ion mirror 10 comprises three pairs of electrodes 3-8 that are elongated in the z-dimension. An ion source 1 is arranged in the field-free region 12 at one end of the instrument (in the z- dimension) and an ion detector 2 is arranged at the other end of the instrument (in the z- dimension).

In use, the ion source 1 accelerates ions into a first of the ion mirrors 10 at an inclination angle to the x-axis. The ions therefore have a velocity in the x-dimension and also a drift velocity in the z-dimension. The ions enter into the first ion mirror 10 and are reflected back towards the second of the ion mirrors 10. The ions then enter the second mirror and are reflected back to the first ion mirror. The first ion mirror then reflects the ions back to the second ion mirror. This continues and the ions are continually reflected between the two ion mirrors as they drift along the device in the z- dimension until the ions impact upon ion detector 2. The ions therefore follow a substantially sinusoidal mean trajectory within the x-z plane between the ion source 1 and the ion detector 2.

Fig. 2 shows an MR-TOF-MS instrument disclosed in WO 2005/001878. This instrument is similar to that of SU 1725289 in that ions from an ion source 24 are reflected multiple times between two ion mirrors 21 as they drift in the z-dimension towards an ion detector 26. However, the instrument of WO 2005/001878 also comprises a set of periodic lenses 23 within the field-free region 27 between the ion mirrors 21. These lenses 23 are arranged such that the ion packets pass through them as they are reflected between the ion mirrors 21. Voltages are applied to the electrodes of the lenses 23 so as to spatially focus the ion packets in the z-dimension. This prevents the ion packets from diverging excessively in the z-dimension and overlapping with each other, and from becoming longer than the detector 26 in the z-dimension by the time they reach the detector 26.

Embodiments of the present invention relate to an MR-TOF-MS instrument not having a set of lenses 23 within the field-free region between the ion mirrors.

According to a first aspect the present invention provides a multi-reflecting time of flight mass analyser comprising:

an ion accelerator;

two ion mirrors arranged for reflecting ions in a first dimension (x-dimension) and being elongated in a second dimension (z-dimension); and

an ion detector;

wherein the ion accelerator is arranged and configured for accelerating ions into a first of the ion mirrors at an angle to the first dimension such that the ions are repeatedly reflected between the ion mirrors in the first dimension (x-dimension) as they travel in the second dimension (z-dimension);

wherein the ions are not spatially focussed in the second dimension (z-dimension) as they travel from the ion accelerator to the detector; and

wherein the mass analyser has a duty cycle of ≥ 5%, a resolution of ≥ 20,000, wherein the distance in the first dimension (x-dimension) between points of reflection in the two ion mirrors is ≤ 1000 mm; and wherein the mass analyser is configured such that the ions travel a distance in the second dimension (z-dimension) from the ion accelerator to the detector of ≤ 700 mm.

Although the term “duty cycle” is well understood to the person skilled in the art, for the avoidance of doubt, duty cycle is the proportion of time that ions from a continuous ion source are accepted into a mass analyser. For orthogonal acceleration ion accelerators, such as those according to the embodiments of the invention, the duty cycle is given by:

$$DutyCycle = \frac{D}{L}\sqrt{\frac{m/z}{(m/z)_{max}}}$$

where D is the length in the second dimension (z-dimension) of the ion packet when it is orthogonally accelerated by the ion accelerator (i.e. the length in second dimension of the orthogonal acceleration region of the ion accelerator); L is the distance, in the second dimension, from the centre of the orthogonal acceleration region of the ion accelerator to the centre of the detection region of the ion detector; (m/z) is the mass to charge ratio of an ion being analysed; and $(m/z)_{max}$ is the maximum mass to charge ratio of interest desired to be analysed.

It is therefore apparent that the duty cycle of the mass analyser is mass dependent. This is because ions of higher mass to charge ratio take longer to pass through and fill the extraction region of the ion accelerator. However, when describing a mass analyser, the skilled person considers the duty cycle of the mass analyser to be the duty cycle for the maximum mass to charge ratio of interest, i.e. the duty cycle when $(m/z) = (m/z)_{max}$ in the equation above. Accordingly, when duty cycle is referred to herein, it refers to the ratio of D/L (as a percentage), which is a value defined purely by the geometric parameters D and L of the mass analyser. This may also be known as the “sampling efficiency”.

Also, for the avoidance of doubt, the term resolution used herein has its normal meaning in the art, i.e. $m/(\Delta m)$ at FWHM, where m is mass to charge ratio.

The following features are disclosed in relation to the first aspect of the invention.

Each mirror may have at least four electrodes arranged and configured such that the first order time of flight focussing of ions is substantially independent of the position of the ions in the plane orthogonal to the first dimension (y-z plane).

Therefore, the first order time of flight focussing of ions may be substantially independent of the position of the ions in both the second dimension (z-dimension) and a third dimension (y-dimension) that is orthogonal to the first and second dimensions (x and z dimensions).

The mass analyser may comprise voltage sources for applying at least four different voltages to the four different electrodes in each ion mirror for reflecting ions and achieving said time of flight focussing.

The ions are not spatially focussed in the second dimension (z-dimension) as they travel from the ion accelerator to the detector. As such, ion lenses are not provided between the ion mirrors for spatially focussing ions in the second dimension (z-dimension).

Similarly, the ion mirrors are not configured to spatially focus the ions in the second dimension (z-dimension).

The ion detector may be spaced from the ion accelerator in the second dimension (z-dimension). Alternatively, the ions may travel from the ion accelerator in a first direction in the second dimension (z-dimension) and may then be reflected by a reflecting electrode so as to travel in a second, opposite direction in the second dimension (z-dimension) to the detector. One or more further reflection electrodes may be provided to cause one or more further z-dimension reflections, with the detector positioned appropriately to detect the ions after these z-dimension reflections.

Embodiments of the invention provide a spectrometer comprising the mass analyser described herein.

The spectrometer may comprise an ion source for supplying said ions to the ion accelerator, wherein the ion source is arranged such that said ion accelerator receives ions from the ion source travelling in the second dimension (z-dimension).

This arrangement provides the mass analyser with a relatively high duty cycle. As described above, the duty cycle is the ratio of length in second dimension (z-dimension) of the ion packet, when it is accelerated by the ion accelerator, to the distance from the centre of the ion accelerator to the centre of the detector. The embodiments of the invention relate to a relatively small mass analyser and therefore it is desired for the ion accelerator to pulse out a relatively elongated ion packet (in the second, z-dimension) in order to achieve a relatively high duty cycle. The relatively elongated ion packet in the second dimension (z-dimension) is facilitated by providing the ions to the ion accelerator travelling in the second dimension (z-dimension). This is contrary to conventional multi-reflecting TOF spectrometers, in which the ion packet is desired to be maintained very small in the second dimension (z-dimension) so that a high number of ion mirror reflections can be performed before the ion packets diverge in the second dimension (z-dimension) to the extent that they overlap in the second dimension (z-dimension). In order to achieve this, such conventional instruments provide the ions to the ion accelerator in a direction corresponding to a third dimension that is perpendicular to the first and second dimensions described herein. Consequently, such conventional instruments suffer from a relatively low duty cycle.

The ion source may be a continuous ion source for substantially continually generating ions, or may be a pulsed ion source.

The mass analyser may have a duty cycle of ≥ 10%.

As described above, the mass analyser has a duty cycle of ≥ 5%. It is contemplated that the mass analyser may have a duty cycle of: ≥ 6%, ≥ 7%, ≥ 8%, ≥ 9%, ≥ 10%, ≥ 11%, ≥ 12%, ≥ 13%, ≥ 14%, ≥ 15%, ≥ 16%, ≥ 17%, ≥ 18%, ≥ 19%, ≥ 20%, ≥ 25%, ≥ 30%. Additionally, or alternatively, it is contemplated that the mass analyser may have a duty cycle of: ≤ 30%, ≤ 25%, ≤ 20%, ≤ 19%, ≤ 18%, ≤ 17%, ≤ 16%, ≤ 15%, ≤ 14%, ≤ 13%, ≤ 12%, ≤ 11%, ≤ 10%, ≤ 9%, ≤ 8%, ≤ 7%, or ≤ 6%.

Any one of these listed upper end points of the duty cycle may be combined with any one of the lower end points of the duty cycle listed above (where the upper end point is higher than the lower end point. Any one or combination of these end points may also be combined with any one of the ranges (or combination or ranges) described in relation to any one, or any combination, of the other parameters discussed herein. For example, any one or combination of the end points or ranges described in relation to the duty cycle may be combined with any one or any combination of ranges described in relation to: resolution; and/or distance in the second dimension (z-dimension) from the ion accelerator to the detector; and/or distance in the first direction (x-dimension) between points of reflection in the two ion mirrors; and/or number of reflections; and/or ion energy in the second dimension; and/or electric field strength; and/or kinetic energy.

The mass analyser may be configured such that the ions travel a first distance in the second dimension (z-dimension) from the ion accelerator to the detector, wherein the ion accelerator is arranged and configured to pulse packets of ions having an initial length in the second dimension (z-dimension), and wherein the first distance and initial length are such that the spectrometer has a duty cycle of ≥ 5%.

However, the first distance and initial length may be arranged such that the duty cycle is any of the other ranges of duty cycle disclosed herein.

The mass analyser may have a resolution of ≥ 30,000.

However, it is contemplated that the mass analyser may have a resolution of: ≥ 22000, ≥ 24000, ≥ 26000, ≥ 28000, ≥ 30000, ≥ 35000, ≥ 40000, ≥ 45000, ≥ 50000, ≥ 60000, ≥ 70000, ≥ 80000, ≥ 90000, or ≥ 100000. Additionally, or alternatively, it is contemplated that the mass analyser may have a resolution of: ≤ 100000, ≤ 90000, ≤ 80000, ≤ 70000, ≤ 60000, ≤ 50000, ≤ 45000, ≤ 40000, ≤ 35000, ≤ 30000, ≤ 28000, ≤ 26000, ≤ 24000, or ≤ 22000.

Any one of these listed upper end points of the resolution may be combined with any one of the lower end points of the resolution listed above (where the upper end point is higher than the lower end point. Any one or combination of these end points may also be combined with any one of the ranges (or combination or ranges) described in relation to any one, or any combination, of the other parameters discussed herein. For example, any one or combination of the end points or ranges described in relation to the resolution may be combined with any one or any combination of ranges described in relation to: duty cycle; and/or distance in the second dimension (z-dimension) from the ion accelerator to the detector; and/or distance in the first direction (x-dimension) between points of reflection in the two ion mirrors; and/or number of reflections; and/or ion energy in the second dimension; and/or electric field strength; and/or kinetic energy.

The distance in the second dimension (z-dimension) from the ion accelerator to the detector may be one of: ≤ 650 mm; ≤ 600 mm; ≤ 550 mm; ≤ 500 mm; ≤ 480 mm; ≤ 460 mm; ≤ 440 mm; ≤ 420 mm; ≤ 400 mm; ≤ 380 mm; ≤ 360 mm; ≤ 340 mm; ≤ 320 mm; ≤ 300 mm; ≤ 280 mm; ≤ 260 mm; ≤ 240 mm; ≤ 220 mm; or ≤ 200 mm; and/or the first distance in the second dimension (z-dimension) from the ion accelerator to the detector may be one of: ≥100 mm; ≥120 mm; ≥140 mm; ≥160 mm; ≥180 mm; ≥200 mm; ≥220 mm; ≥240 mm; ≥260 mm; ≥280 mm; ≥300 mm; ≥320 mm; ≥340 mm; ≥360 mm; ≥380 mm; or ≥400 mm.

Any one of these listed upper end points of the first distance in the second dimension (z-dimension) may be combined with any one of the lower end points of the first distance in the second dimension (z-dimension) that are listed above (where the upper end point is higher than the lower end point. Any one or combination of these end points may also be combined with any one of the ranges (or combination or ranges) described in relation to any one, or any combination, of the other parameters discussed herein. For example, any one or combination of the end points or ranges described in relation to the distance from the ion accelerator to the detector may be combined with any one or any combination of ranges described in relation to: duty cycle; and/or resolution; and/or distance in the first direction (x-dimension) between points of reflection in the two ion mirrors; and/or number of reflections; and/or ion energy in the second dimension; and/or electric field strength; and/or kinetic energy.

The distance in the first direction (x-dimension) between points of reflection in the two ion mirrors may be: ≤ 950 mm; ≤ 900 mm; ≤ 850 mm; ≤ 800 mm; ≤ 750 mm; ≤ 700 mm; ≤ 650 mm; ≤ 600 mm; ≤ 550 mm; ≤ 500 mm; ≤ 450 mm; or ≤ 400 mm; and/or the distance in the first direction (x-dimension) between points of reflection in the two ion mirrors may be: ≥350 mm; ≥360 mm; ≥380 mm; ≥400 mm; ≥450 mm; ≥500 mm; ≥550 mm; ≥600 mm; ≥650 mm; ≥700 mm; ≥750 mm; ≥800 mm; ≥850 mm; or ≥900 mm.

Any one of these listed upper end points of the distance between points of reflection in the two ion mirrors may be combined with any one of the lower end points of the distance between points of reflection in the two ion mirrors that are listed above (where the upper end point is higher than the lower end point. Any one or combination of these end points may also be combined with any one of the ranges (or combination or ranges) described in relation to any one, or any combination, of the other parameters discussed herein. For example, any one or combination of the end points or ranges described in relation to the distance between the points of reflection may be combined with any one or any combination of ranges described in relation to: duty cycle; and/or resolution; and/or distance in the second dimension (z-dimension) from the ion accelerator to the detector; and/or number of reflections; and/or ion energy in the second dimension; and/or electric field strength; and/or kinetic energy.

The ion accelerator, ion mirrors and detector may be arranged and configured so that the ions are reflected at least x times by the ion mirrors as the travel from the ion accelerator to the detector; wherein x is: ≥ 2, ≥ 3, ≥ 4, ≥ 5, ≥ 6, ≥ 7, ≥ 8, ≥ 9, ≥ 10, ≥ 11, ≥ 12, ≥ 13, ≥ 14, or ≥ 15; and/or wherein x is: ≤ 15; ≤ 14; ≤ 13; ≤ 12; ≤ 11; ≤ 10; ≤ 9; ≤ 8; ≤ 7; ≤ 6; ≤ 5; ≤ 4; ≤ 3; or ≤ 2; and/or wherein x is 3-10; wherein x is 4-9; wherein x is 5-10; wherein x is 3-6; ; wherein x is 4-5; or ; wherein x is 5-6.

Any one of these listed upper end points of the number of reflections may be combined with any one of the lower end points of the number of reflections that are listed above (where the upper end point is higher than the lower end point. Any one or combination of these end points may also be combined with any one of the ranges (or combination or ranges) described in relation to any one, or any combination, of the other parameters discussed herein. For example, any one or combination of the end points or ranges described in relation to the number of reflections may be combined with any one or any combination of ranges described in relation to: duty cycle; and/or resolution; and/or distance in the second dimension (z-dimension) from the ion accelerator to the detector; and/or distance in the first direction (x-dimension) between points of reflection in the two ion mirrors; and/or ion energy in the second dimension; and/or electric field strength; and/or kinetic energy.

The ions may travel between 100 mm and 450 mm in the second dimension (z-dimension) from the ion accelerator to the detector; wherein the distance in the first direction (x-dimension) between points of reflection in the two ion mirrors may be between 350 and 950 mm; and wherein the ions may be reflected between 2 and 15 times by the ion mirrors as the travel from the ion accelerator to the detector.

Alternatively, the ions may travel between 150 mm and 400 mm in the second dimension (z-dimension) from the ion accelerator to the detector; wherein the distance in the first direction (x-dimension) between points of reflection in the two ion mirrors may be between 400 and 900 mm; and wherein the ions may be reflected between 3 and 10 times by the ion mirrors as the travel from the ion accelerator to the detector. Alternatively, the ions may travel between 150 mm and 350 mm in the second dimension (z-dimension). Alternatively, or additionally, the distance in the first direction (x-dimension) between points of reflection in the two ion mirrors may be between 400 and 600 mm.

It is contemplated that the ions may travel between 100 mm and 400 mm in the second dimension (z-dimension) from the ion accelerator to the detector; wherein the distance in the first direction (x-dimension) between points of reflection in the two ion mirrors may be between 300 and 700 mm; and wherein the ions may be reflected between 3 and 6 times by the ion mirrors as the travel from the ion accelerator to the detector. Alternatively, the ions may travel between 150 mm and 350 mm in the second dimension (z-dimension) from the ion accelerator to the detector. Alternatively, or additionally, the distance in the first direction (x-dimension) between points of reflection in the two ion mirrors is between 400 and 600 mm. Additionally, or instead of either one of both of these parameters, the ions may be reflected between 4 and 5 times, or between 5 and 6 times, by the ion mirrors as the travel from the ion accelerator to the detector.

The spectrometer may be configured to cause the ions to travel in the second dimension (z-dimension) with an energy of: ≤ 140 eV; ≤ 120 eV; ≤ 100 eV; ≤ 90 eV; ≤ 80 eV; ≤ 70 eV; ≤ 60 eV; ≤ 50 eV; ≤ 40 eV; ≤ 30 eV; ≤ 20 eV; or ≤ 10 eV; and/or the spectrometer may be configured to cause the ions to travel in the second dimension (z-dimension) with an energy of: ≥ 120 eV; ≥ 100 eV; ≥ 90 eV; ≥ 80 eV; ≥ 70 eV; ≥ 60 eV; ≥ 50 eV; ≥ 40 eV; ≥ 30 eV; ≥ 20 eV; or ≥ 10 eV. The spectrometer may be configured to cause the ions to travel in the second dimension (z-dimension) with an energy between: 15-70 eV; 10-65 eV; 10-60 eV; 20-100 eV; 25-100 eV; 20-90 eV; 40-60 eV; 30-50 eV; 20-30 eV; 20-45 eV; 25-40 eV; 15-40 eV; 10-45 eV; or 10-25 eV.

Any one of these listed upper end points of the energy may be combined with any one of the lower end points of the energy that are listed above (where the upper end point is higher than the lower end point. Any one or combination of these end points may also be combined with any one of the ranges (or combination or ranges) described in relation to any one, or any combination, of the other parameters discussed herein. For example, any one or combination of the end points or ranges described in relation to the energy in the second dimension may be combined with any one or any combination of ranges described in relation to: duty cycle; and/or resolution; and/or distance in the second dimension (z-dimension) from the ion accelerator to the detector; and/or distance in the first direction (x-dimension) between points of reflection in the two ion mirrors; and/or number of reflections; and/or electric field strength; and/or kinetic energy.

The ranges of resolution, duty cycle and size of the mass analyser (i.e. the distance in the first direction between points of reflection in the two ion mirrors, and the distance travelled between the ion accelerator and detector in the second dimension) described herein are for practical values of Time of Flight energies and mirror voltages.

The ion accelerator may be configured to generate an electric field of y V/mm for accelerating the ions; wherein y is: ≥ 700; ≥ 650; ≥ 600; ≥ 580; ≥ 560; ≥ 540; ≥ 520; ≥ 500; ≥ 480; ≥ 460; ≥ 440; ≥ 420; ≥ 400; ≥ 380; ≥ 360; ≥ 340; ≥ 320; ≥ 300; ≥ 280; ≥ 260; ≥ 240; ≥ 220; or ≥ 200; and/or wherein y is: ≤ 700; ≤ 650; ≤ 600; ≤ 580; ≤ 560; ≤ 540; ≤ 520; ≤ 500; ≤ 480; ≤ 460; ≤ 440; ≤ 420; ≤ 400; ≤ 380; ≤ 360; ≤ 340; ≤ 320; ≤ 300; ≤ 280; ≤ 260; ≤ 240; ≤ 220; or ≤ 200.

Any one of these listed upper end points of the electric field may be combined with any one of the lower end points of the electric field that are listed above (where the upper end point is higher than the lower end point. Any one or combination of these end points may also be combined with any one of the ranges (or combination or ranges) described in relation to any one, or any combination, of the other parameters discussed herein. For example, any one or combination of the end points or ranges described in relation to the electric field strength may be combined with any one or any combination of ranges described in relation to: duty cycle; and/or resolution; and/or distance in the second dimension (z-dimension) from the ion accelerator to the detector; and/or distance in the first direction (x-dimension) between points of reflection in the two ion mirrors; and/or number of reflections; and/or ion energy in the second dimension; and/or kinetic energy.

A region substantially free of electric fields may be arranged between the ion mirrors such that when the ions are reflected between the ion mirrors they travel through said region.

The ions may have a kinetic energy E, when between the ion mirrors and/or in said region substantially free of electric fields; wherein E is: ≥ 1 keV; ≥ 2 keV; ≥ 3 keV; ≥ 4 keV; ≥ 5 keV; ≥ 6 keV; ≥ 7 keV; ≥ 8 keV; ≥ 9 keV; ≥ 10 keV; ≥ 11 keV; ≥ 12 keV; ≥ 13 keV; ≥ 14 keV; or ≥ 15 keV; and/or wherein E is ≤ 15 keV; ≤ 14 keV; ≤ 13 keV; ≤ 12 keV; ≤ 11 keV; ≤ 10 keV; ≤ 9 keV; ≤ 8 keV; ≤ 7 keV; ≤ 6 keV; or ≤ 5 keV; and/or between 5 and 10 keV.

Any one of these listed upper end points of the kinetic energy may be combined with any one of the lower end points of the kinetic energy that are listed above (where the upper end point is higher than the lower end point. Any one or combination of these end points may also be combined with any one of the ranges (or combination or ranges) described in relation to any one, or any combination, of the other parameters discussed herein. For example, any one or combination of the end points or ranges described in relation to the kinetic energy may be combined with any one or any combination of ranges described in relation to: duty cycle; and/or resolution; and/or distance in the second dimension (z-dimension) from the ion accelerator to the detector; and/or distance in the first direction (x-dimension) between points of reflection in the two ion mirrors; and/or number of reflections; and/or ion energy in the second dimension; and/or electric field strength.

The spectrometer may comprise an ion guide for guiding ions into the ion accelerator and a heater 39 for heating said ion guide.

The spectrometer may comprise a heater for heating electrodes of the ion accelerator.

The spectrometer may comprise a heater arranged and configured to heat the ion guide and/or accelerator to a temperature of: ≥ 100 °C, ≥ 110 °C, ≥ 120 °C, ≥ 130 °C, ≥ 140 °C, or ≥ 150 °C. Heating the various components as described herein may assist in reducing interface charging.

The ion accelerator disclosed herein may be a gridless ion accelerator. If the ion accelerator is heated, then a gridless ion accelerator does not suffer from sagging of the grid that would otherwise be caused by the heating.

The spectrometer may comprise a collimator for collimating the ions passing towards the ion accelerator, the collimator configured to collimate ions in the first dimension (x-dimension) and/or a dimension (y-dimension) orthogonal to both the first and second dimensions.

The spectrometer may comprise ion optics 33 arranged and configured to expand the ion beam passing towards the ion accelerator in the first dimension (x-dimension) and/or a dimension (y-dimension) orthogonal to both the first and second dimensions.

The spectrometer may comprise an ion separator for separating ion spatially, or according to mass to chare ratio or ion mobility, in the second dimension (z-dimension) prior to the ions entering the ion accelerator.

From a second aspect the present invention provides a multi-reflecting time of flight mass analyser comprising:

an ion accelerator;

two ion mirrors arranged for reflecting ions in a first dimension (x-dimension) and being elongated in a second dimension (z-dimension); and

an ion detector;

wherein the ion accelerator is arranged and configured for accelerating ions into a first of the ion mirrors at an angle to the first dimension such that the ions are repeatedly reflected between the ion mirrors in the first dimension (x-dimension) as they travel in the second dimension (z-dimension); and

wherein the ions are reflected so as to pass from one of the ion mirrors to the other of the ion mirrors n times, and wherein the ions are not spatially focussed in the second dimension (z-dimension) during ≥ 60 % of these n times.

The mass analyser according to said second aspect may have any of the features disclosed herein in relation to said first aspect, except wherein the mass analyser may or may not be limited to the ions not being spatially focussed in the second dimension (z-dimension) as they travel from the ion accelerator to the detector (e.g. during the entire flight from the ion accelerator to the detector), as described in relation to the first aspect. It is contemplated that there may be some spatial focussed in the second dimension (z-dimension) between some of the mirror reflections. Therefore, according to the second aspect of the invention, the ions are not spatially focussed in the second dimension (z-dimension) during ≥ 60 % of said n times. Optionally, the ions are not spatially focussed in the second dimension (z-dimension) during ≥ 65%, ≥ 70%, ≥ 75%, ≥ 80%, ≥ 85%, ≥ 90%, ≥ or 95% of said n times.

The mass analyser according to said second aspect may have any of the features disclosed herein in relation to said first aspect, except wherein the mass analyser may or may not be limited to the duty cycle being ≥ 5%,as described in relation to the first aspect.

The mass analyser according to said second aspect may have any of the features disclosed herein in relation to said first aspect, except wherein the mass analyser may or may not be limited to the resolution being ≥ 20,000, as described in relation to the first aspect.

The mass analyser according to said second aspect may have any of the features disclosed herein in relation to said first aspect, except wherein the mass analyser may or may not be limited to said distance in the first dimension (x-dimension) between points of reflection in the two ion mirrors being ≤ 1000 mm, as described in relation to the first aspect

The mass analyser according to said second aspect may have any of the features disclosed herein in relation to said first aspect, except wherein the mass analyser may or may not be limited to the distance the ions travel in the second dimension (z-dimension) from the ion accelerator to the detector being ≤ 700 mm, as described in relation to the first aspect.

The first aspect of the invention also provides a method of time of flight mass analysis comprising:

providing a mass analyser as described in relation to said first aspect of the invention; and

controlling the ion accelerator so as to accelerate ions into the first ion mirror at an angle to the first dimension such that the ions are repeatedly reflected between the ion mirrors in the first dimension (x-dimension) as they travel in the second dimension (z-dimension), wherein the distance in the first dimension (x-dimension) between points of reflection in the two ion mirrors is ≤ 1000 mm, wherein the ions travel a distance in the second dimension (z-dimension) from the ion accelerator to the detector of ≤ 700 mm, and wherein the ions are not spatially focussed in the second dimension (z-dimension) as they travel from the ion accelerator to the detector;

wherein the ions are detected by the detector and time of flight mass analysed with a duty cycle of ≥ 5% and a resolution of ≥ 20,000.

The second aspect of the invention also provides a method of time of flight mass analysis comprising:

providing a mass analyser as described in relation to said second aspect of the invention; and

controlling the ion accelerator so as to accelerate ions into the first ion mirror at an angle to the first dimension such that the ions are repeatedly reflected between the ion mirrors in the first dimension (x-dimension) as they travel in the second dimension (z-dimension), wherein the ions are reflected so as to pass from one of the ion mirrors to the other of the ion mirrors n times, and wherein the ions are not spatially focussed in the second dimension (z-dimension) during ≥ 60 % of these n times.

Specific embodiments of the invention will now be described with reference to the drawings in order to assist in the understanding of the invention.

Fig. 3 shows a schematic of an embodiment of the present invention. The spectrometer comprises an ion entrance 30 for receiving an ion beam 32 along an entrance axis, an ion accelerator 34 for orthogonally accelerating the received ions in a pulsed manner, a pair of ion mirrors 36 for reflecting the ions, and an ion detector 38 for detecting the ions. Each ion mirror 36 comprises a plurality of electrodes (arranged along the x-dimension) so that different voltages may be applied to the electrodes to cause the ions to be reflected. The electrodes are elongated in the Z-dimension, which allows the ions to be reflected multiple times by each mirror, as will be described in more detail below. Each ion mirror may form a two-dimensional electrostatic field in the X-Y plane. The drift space 40 arranged between the ion mirrors 36 may be substantially electric field-free such that when the ions are reflected and travel in the space between the ion mirrors they travel through a substantially field-free region.

In use, ions are supplied to the ion entrance 30, either as a continuous ion beam or an intermittent or pulsed manner. The ions are desirably transmitted into the ion entrance along an axis aligned with the z-dimension. This allows the duty cycle of the instrument to remain high. However, it is contemplated that the ions could be introduced along an entrance axis that is aligned with the y-dimension. The ions pass from the ion entrance to the ion accelerator 34, which pulses the ions (e.g. periodically) in the x-dimension such that packets of ions 31 travel in the x-dimension towards and into a first of the ion mirrors 36. The ions retain a component of velocity in the z-dimension from that which they had when passing into the ion accelerator 34, or a provided with such a component of velocity in the z-dimension (e.g. if the ion entered the ion accelerator along the y-dimension). As such, ions are injected into the time of flight region 40 of the instrument at a small angle of inclination to the x-dimension, with a major velocity component in the x-dimension towards the ion mirror 36 and a minor velocity component in the z-dimension towards the detector 38.

The ions pass into a first of the ion mirrors and are reflected back towards the second of the ion mirrors. The ions pass through the field-free region 40 between the mirrors 38 as they travel towards the second ion mirror and they separate according to their mass to charge ratios in the known manner that occurs in time of flight mass analysers. The ions then enter the second mirror and are reflected back to the first ion mirror, again passing through the field-free region between the mirrors as they travel towards the first ion mirror. The first ion mirror then reflects the ions back to the second ion mirror. This continues and the ions are continually reflected between the two ion mirrors as they drift along the device in the z-dimension until the ions impact upon ion detector. The ions therefore follow a substantially sinusoidal mean trajectory within the x-z plane between the ion source and the ion detector. Although four ion reflections are shown in Fig. 3, other numbers of ion reflections are contemplated, as described elsewhere herein.

The time that has elapsed between a given ion being pulsed from the ion accelerator to the time that the ion is detected may be determined and used, along with the knowledge of the flight path length, to calculate the mass to charge ratio of that ion.

As described above, when duty cycle is referred to herein it refers to the ratio of D/L (as a percentage), where D is the length in the z-dimension of the ion packet 31 when it is orthogonally accelerated by the ion accelerator 34 (i.e. the length in z-dimension of the orthogonal acceleration region of the ion accelerator 31), and L is the distance in the z-dimension from the centre of the orthogonal acceleration region of the ion accelerator 34 to the centre of the detection region of the ion detector 38.

No focusing of the ions is provided in the z-dimension between the ion mirrors, e.g. there are no periodic lenses focussing the ions in the z-dimension. As such, each packet of ions expands in the z-dimension as it travels from the ion accelerator to the detector. MR-TOF-MS instruments have conventionally sought to obtain a very high resolution and hence require a high number of reflections between the ion mirrors. Therefore, conventionally it has been considered necessary to provide z-dimension focussing between the ion mirrors to prevent the width of the ion packet diverging to the extent that it becomes larger than the detector width by the time it has completed the high number of mirror reflections and reached the detector. This was considered necessary to maintain an acceptable sensitivity of the instrument. Also, if the ion packets diverge too much in the z-dimension, then some ions may reach the detector having only been reflected a first number of times, whereas other ions may reach the detector having been reflected a larger number of times. Ions may therefore have significantly different flight path lengths through the field-free region on the way to the detector, which is undesirable in time of flight mass analysers. However, the inventors of the present invention have realised that if the ion flight path within the instrument is maintained relatively small and the duty cycle (i.e. D/L) made relatively high, then the z-dimension focussing can be eliminated.

Therefore, the distance S between the points of reflection in the two ion mirrors is maintained relatively small, and the distance W that the ions travel in the z-dimension from the ion accelerator to the detector is maintained relatively small.

It is contemplated that collimators may be provided to collimate the ions packets in the z-dimension as they travel from the ion accelerator to the detector. This ensures that all ions perform the same number of reflections in the ion mirrors between the ion accelerator and detector (i.e. prevents aliasing at the detector).

Optionally, each ion mirror may have at least four electrodes to which four different (non-grounded) voltages are applied. Each ion mirror may comprise additional electrodes, which may be grounded or maintained at the same voltages as other electrodes in the mirror. Each mirror optionally has at least four electrodes arranged and configured such that the first order time of flight focussing of ions is substantially independent of the position of the ions in the y-z plane, i.e. independent of the position of the ions in both the y-dimension and z-dimension (to the first order approximation). Fig. 3 shows exemplary voltages that may be applied to the electrodes of one of the ion mirrors. Although not illustrated, the same voltages may be applied to the other ion mirror in a symmetrical manner. For example, the entrance electrode of each ion mirror is maintained at a drift voltage (e.g. -5 kV), thereby maintaining a field-free region between the ion mirrors. An electrode further into the ion mirror may be maintained at a lower (or higher, depending on ion polarity) voltage (e.g. -10 kV). An electrode further into the ion mirror may be maintained at the drift voltage (e.g. -5 kV). An electrode further into the ion mirror may be maintained at a lower (or higher) voltage (e.g. -10 kV). One or more further electrodes into the ion mirror may be maintained at one or more higher, optionally progressively higher, voltages (e.g. 11 kV and +2 kV) so as to reflect the ions back out of the mirror.

The ion entrance may receive ions from an ion guide 33 that may, for example, collimate the ions in the y-dimension and/or x-dimension, e.g. using a slit collimator. The ion guide may be heated, e.g. to ≥ 100 °C, ≥ 110 °C, ≥ 120 °C, ≥ 130 °C, ≥ 140 °C, or ≥ 150 °C.

It is contemplated that the ion beam may be expanded in the y-dimension and/or x-dimension prior to entering the ion accelerator 34. Alternatively, or additionally, the ions may be separated in the z-dimension prior to entering the ion accelerator 34.

The electrodes of the ion accelerator34 may be heated, e.g. to ≥ 100 °C, ≥ 110 °C, ≥ 120 °C, ≥ 130 °C, ≥ 140 °C, or ≥ 150 °C. Alternatively, or additionally, a gridless ion accelerator be used. If the ion accelerator is heated, then a gridless ion accelerator does not suffer from sagging of the grid that would otherwise be caused by the heating.

Heating the various components as described herein may assist in reducing interface charging.

Although the ion accelerator 34 has been described as receiving a beam of ions, it is contemplated that the ion accelerator may alternatively comprise a pulsed ion source.

Fig. 4 shows another embodiment of the present invention. This embodiment is substantially the same as that shown in Fig. 3, except that the detector 38 is located on the same side of the instrument (in the z-dimension) as the ion accelerator 34, and the instrument comprises a reflection electrode 42 for reflecting the ions back in the z-dimension towards the detector 38. In use, the ions pass through the instrument in the same way as in Fig. 3 and are reflected multiple times between the ion mirrors 36 as they pass in a first direction in the z-dimension. After a number of reflections, the ions pass to the reflection electrode 42, which may be arranged between the ion mirrors. The reflection electrode 42 reflects the ions back in the z-dimension such that they drift in a second direction opposite to the first direction. As the ions drift in the second direction they continue to be reflected between the ion mirrors 36 until they impact upon the ion detector 38. This embodiment allows more reflections to occur in a given physical space, as compared to the embodiment of Fig. 3. It is contemplated that the ions could be reflected in the z-dimension one or more further times and the detector located appropriately to receive ions after these one or more further z-reflections.

Figs. 5A-5B show the resolution and duty cycle modelled for different sized MR-TOF-MS instruments (i.e. having different W and S distances) and having no z-dimension focussing. The data is modelled for ions having an energy in the field-free region between the mirrors of 9.2 keV.

Fig. 6A-6B show data for corresponding parameters to those shown in Figs. 5A-5B, except that the data is modelled for ions having an energy in the field-free region between the mirrors of 6 keV.

Fig. 7 shows data for corresponding parameters to those shown in Figs. 5A-5B, except that the data is modelled for ions having an energy in the field-free region between the mirrors of 3 keV, 4 keV and 5 keV.

Fig. 8 shows data for corresponding parameters to those shown in Figs. 5A-5B, except that the data is modelled for ions being reflected in the mirrors five times and having an energy in the field-free region between the mirrors of between 4-10 keV.

Fig. 9 shows data for corresponding parameters to those shown in Figs. 8, except that the data is modelled for ions being reflected in the mirrors six times.

Fig. 10 shows data for corresponding parameters to those shown in Figs. 5A-5B, except that the data is modelled for achieving a duty cycle of around 10%.

Fig. 11 shows data for corresponding parameters to those shown in Figs. 5A-5B, for instruments having a medium size.

Although the present invention has been described with reference to preferred embodiments, it will be understood by those skilled in the art that various changes in form and detail may be made without departing from the scope of the invention as set forth in the accompanying claims.

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Claims

1. A multi-reflecting time of flight mass analyser comprising:

a gridless ion accelerator;

two ion mirrors arranged for reflecting ions in a first dimension (x-dimension) and being elongated in a second dimension (z-dimension); and

an ion detector;

wherein the ion accelerator is arranged and configured for accelerating ions into a first of the ion mirrors at an angle to the first dimension such that the ions are repeatedly reflected between the ion mirrors in the first dimension (x-dimension) as they travel in the second dimension (z-dimension;

wherein the ions are not spatially focussed in the second dimension (z-dimension) as they travel from the ion accelerator to the ion detector; and

wherein the mass analyser has a duty cycle of ≥ 5%, a resolution of ≥ 20,000, wherein the distance in the first dimension (x-dimension) between points of reflection in the two ion mirrors is between 300 and 700 mm; wherein the mass analyser is configured such that the ions travel a distance in the second dimension (z-dimension) from the ion accelerator to the ion detector ofbetween 100 and 400 mm; and wherein the ion accelerator, ion mirrors and ion detector are arranged and configured so that the ions are reflected between 4 and 5 times, or between 5 and 6 times, by the ion mirrors as the travel from the ion accelerator to the ion detector.

2. The mass analyser of claim 1, wherein each mirror has at least four electrodes arranged and configured such that the first order time of flight focussing of ions is substantially independent of the position of the ions in the plane orthogonal to the first dimension (y-z plane).

3. The mass analyser of claim 1 or 2, coupled to an ion source for supplying said ions to the ion accelerator, wherein the ion source is arranged such that said ion accelerator receives ions from the ion source travelling in the second dimension (z-dimension).

4. The mass analyser of any preceding claim, wherein the mass analyser has a duty cycle of ≥ 10%.

5. The mass analyser of any preceding claim, wherein the mass analyser is configured such that the ions travel a first distance in the second dimension (z-dimension) from the ion accelerator to the ion detector, wherein the ion accelerator is arranged and configured to pulse packets of ions having an initial length in the second dimension (z-dimension), and wherein the first distance and initial length are such that the mass analyser has a duty cycle of ≥ 5%.

6. The mass analyser of any preceding claim, wherein the mass analyser has a resolution of ≥ 30,000.

7. The mass analyser of any preceding claim, wherein ions travel in the second dimension (z-dimension) with an energy of: ≤ 140 eV; ≤ 120 eV; ≤ 100 eV; ≤ 90 eV; ≤ 80 eV; ≤ 70 eV; ≤ 60 eV; ≤ 50 eV; ≤ 40 eV; ≤ 30 eV; ≤ 20 eV; or ≤ 10 eV.

8. The mass analyser of any preceding claim, wherein the ion accelerator is configured to generate an electric field of y V/mm for accelerating the ions; wherein y is: ≥ 700; ≥ 650; ≥ 600; ≥ 580; ≥ 560; ≥ 540; ≥ 520; ≥ 500; ≥ 480; ≥ 460; ≥ 440; ≥ 420; ≥ 400; ≥ 380; ≥ 360; ≥ 340; ≥ 320; ≥ 300; ≥ 280; ≥ 260; ≥ 240; ≥ 220; or ≥ 200.

9. The mass analyser of any preceding claim, wherein a region substantially free of electric fields is arranged between the ion mirrors such that when the ions are reflected between the ion mirrors they travel through said region.

10. The mass analyser of claim 9, wherein the ions have a kinetic energy E, when in said region substantially free of electric fields; wherein E is: ≥ 1 keV; ≥ 2 keV; ≥ 3 keV; ≥ 4 keV; ≥ 5 keV; ≥ 6 keV; ≥ 7 keV; ≥ 8 keV; ≥ 9 keV; ≥ 10 keV; ≥ 11 keV; ≥ 12 keV; ≥ 13 keV; ≥ 14 keV; or ≥ 15 keV.

07 12 22

11. The mass analyser of any preceding claim, coupled to an ion guide for guiding ions into the ion accelerator and a heater for heating said ion guide.

12. The mass analyser of any preceding claim, comprising a heater for heating electrodes of the ion accelerator.

13. The mass analyser of claim 11 or 12, comprising a heater arranged and configured to heat the ion guide and/or ion accelerator to a temperature of: ≥ 100 °C, ≥ 110 °C, ≥ 120 °C, ≥ 130 °C, ≥ 140 °C, or ≥ 150 °C.

14. The mass analyser of any preceding claim, coupled to a slit collimator for collimating the ions passing towards the ion accelerator, the collimator configured to collimate ions in the first dimension (x-dimension).

15. The mass analyser of any preceding claim, coupled to ion optics arranged and configured to expand a beam of the ions passing towards the ion accelerator in the first dimension (x-dimension).

16. The mass analyser of any preceding claim, coupled to ion optics arranged and configured to expand a beam of the ions passing towards the ion accelerator in a dimension (y-dimension) orthogonal to both the first and second dimensions.

17. The mass analyser of any preceding claim, coupled to an ion separator for separating ion spatially, or according to mass to charge ratio or ion mobility, in the second dimension (z-dimension) prior to the ions entering the ion accelerator.

18. A method of time of flight mass analysis comprising:

providing a mass analyser as claimed in any preceding claim; and

controlling the ion accelerator so as to accelerate ions into the first ion mirror at an angle to the first dimension such that the ions are repeatedly reflected between the ion mirrors in the first dimension (x-dimension) as they travel in the second dimension (z-dimension);

wherein the ions are detected by the ion detector and time of flight mass analysed with a duty cycle of ≥ 5% and a resolution of ≥ 20,000.

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