PATENT SPECIFICATION (11) 1 564 211

1 564 211

(21) Application No. 50393/76 (22) Filed 3 Dec. 1976 (19)
(31) Convention Application Nos. 2554226 (32) Filed 3 Dec. 1975
2616669 15 Apr. 1976
2640909 10 Sep. 1976 in
(33) Fed. Rep. of Germany (DE)
(44) Complete Specification Published 2 Apr. 1980
(51) INT. CL.[3] G097 9/30 G02F 1/13 G02B 5/14 // G09F 19/12
(52) Index at Acceptance
G5C A334 A342 A363 A373 A375 HG

(54) IMPROVEMENTS IN OR RELATING TO DISPLAY DEVICES

(71) We, SIEMENS AKTIENGESELLSCHAFT, a German Company of Berlin and Munich, German Federal Republic, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in any by the following statement:-

The present invention relates to monochrome or multichrome display devices.

The invention relates particularly, but not exclusively, to display devices which include an electro-optical light valve, by which term as used herein is meant a display in which at least one display element is switched between an opaque or diffused state and a transparent state by the application of an electric field, and for sake of clarity, the invention will be described with reference to such device. It will be appreciated, however, that the invention is applicable to devices in which switching of the display elements is effected by means other than the application of an electric field, e.g. by a change in ambient temperature.

Passive display devices are already known, examples including electrophoretic, electrochromatic, liquid crystal and ferroelectric displays. In principle, these displays have three essential advantages, namely a very small consumption of electrical energy, a contrast which is largely independent of ambient brightness and a flat construction. However, they do have the disadvantage that when operated by light transmission, i.e. when a light source is provided behind the display, these advantages are lost.

When operated by reflection, the ambient light entering the display from the side of the observer, undergoes spatial modulation in the display and is deflected (being either reflected or scattered) back into the line of vision of the observer by means located behind the display. In hitherto known display elements, this mode of operation has the disadvantage that reasonable good legibility of the display is obtained only under particular restricted observation conditions; thus, for example, the incident light may cause shadows of the display elements to be cast on a reflecting surface. Conditions are particularly unfavourable with displays that require polarisers, for instance liquid crystal displays working on a field-effect basis, since it is well known that such polarisers weaken the contrast of the display.

It is an object of the present invention, to provide a display device which has an improved display legibility as compared with known displays, by providing passive means which lead to more effective use of the ambient light.

According to the invention, there is provided an optical display device comprising a display having at least one optical element which is switchable between an opaque or diffused state and a transparent state, and a fluorscent plate associated with said display, and serving for the passive amplification of the brightness thereof. Preferably, the display will be in the form of a light valve, as hereinbefofore defined.

The brightness amplification provided by the use of a fluorescent plate in accordance with the invention is particularly applicable to display devices using any liquid crystal effect dependent on the use of an electric field to switch the display elements between an opaque and a transparent state. As is known, this light valve effect can be achieved with all liquid crystals phenomena used in displays by means of additional polarisers and further passive optical elements. Particular advantages are obtained when the fluorescent plate is combined with a so-called "rotary cell" by which term as used herein is meant a cell having a layer rematic-phase liquid crystal material having positive dielectric arisotropy parrallel polarises, such as is described in U.K. Patent Specification Nos 1,372,868 and 1,390,521.

The present invention essentially makes use of the phenomenon that, by means of a thin plate (e.g. of a synthetic resin) containing a fluroescent material, ambient light of a given wavelength range can be collected with a high degree of efficiency and guided and made to re-emerge visibly and in controllable amounts at any desired points on the plate. Such a fluorescent plate can be combined in various ways with an electro-optical passive display acting as a light valve to give the display elements, which are set electrically either to be transparent or to be opaque or diffused, a high level of luminance as compared with the ambient brightness.

The invention will now be further described with reference to the drawings, in which:-

Figure 1 is a schematic exploded view of a first form of display device according to the invention;

Figures 2 is a schematic side-sectional view of a second form of display device according to the invention;

Figure 3 is a similar view to that of Figure 2 of a third form of display device in accordance with the invention;

Figure 4 is a schematic perspective view of one form of fluorescent plate for use in a display device in accordance with the invention;

Figure 5 is a schematic front view of a fourth form of display device in accordance with the invention;

Figure 6 is a schematic perspective view of a second form of fluorescent plate for use in a display device in accordance with the invention;

Figure 7 is a schematic perspective view of third form of fluorescent plate for use in a display device in accordance with the invention;

Figure 8 is a schematic exploded view of a fourth form of display device in accordance with the invention;

Figure 9 is a schematic perspective view of a fifth form of fluorescent plate for use in a display device in accordance with the invention;

Figure 10 is a schematic perspective view of a sixth form of display device in accordance with the invention;

Figure 11 is a graph showing the relative reflected intensity I_r or unpolarised light striking against an air glass interface in relation to the angle of incidence α;

Figure 12 is another graph showing the relative reflected intensity of unpolarised light striking against a glass-air interface in relation to the angle of incidence;

Figure 13 (a), (b), (c) and *(d)* are diagrams illustrating four simple kinds of emergence window in a section through a fluorescent plate for use in a display device according to the invention;

Figure 14 is a graph and diagram illustrating on the basis of a typical example the angular observation range 2α in relation to the ratio of width of an emergence window on a fluorescent plate for use in a display device according to the invention to the width of display segment in a light valve (ratio x);

Figure 15 is a graph showing the light transmission curves for three commerically available, heterochromatic fluorescent Plexiglas plates; and

Figure 16 is a graph showing the light-emission curves for the Plexiglas plates of Figure 15.

The method of operation of the fluorescent plate used in the display devices of the invention will now be described with reference to certain of the Figures.

For this purpose, let us consider a plane plate of acrylic resin sold under the Trade Mark "Plexiglas" a few millimetres thick with a smooth surface in which a fluorescent substance is incorporated in such a concentration that, for example, the blue component of daylight falling on it is fully absorbed. Moreover, this plate is assumed to have end faces running at right-angles to the plane of the plate, which faces ideally should be light-reflective so that no light can escape at the edges of the plate. Referring to Figure 11, in which the relative reflected intensity I_r of unpolarised light in relation to the angle of incidence α is shown, about 82 % of the intensity enters the fluorescent plate with isotropic daylight distribution. The reflection at the less dense medium, which is shown in Figure 12 in relation to he angle of incidence, has a decisive influence upon the re-emergence of, for example, green light transmitted from the plate. It can be seen that a fair approximation can be obtained if it is assumed for the purposes of calculation that all the light striking the interface below the angle of total reflection α_{tot}, leaves the plate and that the light falling within the remaining angular range remains within the plate as a result of total reflection. The angle of total reflection is obtainable from the equation $n.\sin \alpha_{tot} = 1$ (for the refractive index $n = 1.49$ of "Plexiglas, α_{tot} is 42°). The percentage of the fluorescent light which is not totally reflected (referred to in the following as the loss factor V) is given by the equation :-

$$V = 1 - \cos \alpha_{tot} = \frac{n - \sqrt{n^2 - 1}}{n}$$

(in the example under consideration where n = 1.49; V = 25 %).

The light emitted within the angular range of total reflection (75 % in the case of "Plexiglas") is guided in the plane of the plate by extended loss-free total reflection (i.e. the mean diffusion path lies parallel with the plane of the plate). The fluorescent plate thus acts as a light trap.

The fluorescent light trapped in the fluorescent plate as a result of total reflection can be made to emerge from this plate through deflection or diffusion faces provided on the fluorescent plate. Such specially provided faces are hereinafter referred to as "emergence windows". Simple examples of this kind of light emergence from a fluorescent plate are illustrated in Figure 13.

Disregarding the reflection and inevitable re-emergence losses referred to above, and assuming that no other losses occur in the plate, the "brightness amplification factor", i.e. the factor indicating the increase in luminance (i.e. surface brightness) at the emergence windows of the fluorescent plate relative to the luminance of a non-fluorescent face of the same colour, is essentially defined by the ratio of the total light-absorbing area of the arrangement to the total area of the emergence windows for the fluorescent light.

In the preferred embodiment of the invention, the fluorescent plate is used in combination with a light valve (also referred to as a "light gate"). As stated above, light valves are displays in which the display elements are switched between the transparent and the opaque or diffused states by the application of an electric field. The field is usually applied to transparent electrodes in the form of a thin coating of electro-optical material. These displays often necessitate the use of polarisation films. It is known that with displays where switching takes place between the transparent and the didffused state, such as for example, in the case of liquid crystal displays using dynamic diffusion, the arrangement of the display between crossed polarisers converts the display to one permitting controlled switching between an opaque and a transparent state, so that light diffusion is always associated with depolarisation of the light.

A fluorescent plate can be used in combination with any known display device using one of the following groups of electro-optical effects:-

a) linear and quadrratic electro-optical double-refraction effects in ferroelectric ceramics (see G.H. Haertling and C.E. Land, Journal of the American Ceramic Society, 1971, Vol. 54, p. 1 and J.R. Maldonado and A. H. Meitzler, Proc. IEEE, 1971, Vol. 59, p. 368);

b) electrochromic effects such as, for example, in solid-state films of WO_3 and $Mo0_3$ with redox reactions at the interface with an electrolyte such as H_2SO_4 (see S.K. Deb, Appl. Opt. Suppl. 1969, Vol. 3, p. 192);

c) electro-optical diffusion effects in ferro-electric ceramics (see W.D. Smith and C.E. Land, Appl. Phys. Lett. 1972, Vol. 20, p. 169);

d) all known electro-optical effects in liquid crystals.

The combination in accordance with the invention of a fluorescent plate with a display device operated as a ligth valve will now be explained with reference to the embodiment illustrated in Figure 1.

The display device of Figure 1 consists of an electro-optical light valve 4 with individually actuatable electrode segments 5. The electrode segments in the example illustrated allow numerical displays to be effected by the seven-segment method. Arranged behind the light valve 4 there is a fluorescent plate 1*a* of synthetic resin material having silvered edge faces 2 and emergence "windows" 3 for the fluorescent light in the form of silvered recesses. The emergence windows 3 correspond in shape and position to the electrode segments 5 but they are broader than the electrode segments in order to compensate for the parallax between the electrode segments and the emergence windows. If desired, a light-absorbent film may be positioned behind the fluorescent plate, which film must not however be in optical contact with the fluorescent plate and serves to make the fluorescent plate, which naturally shows a characteristic colour of its own in transmitted light, appear to be as "black" as possible and thus has a favourable influence upon the contrast of the display. Should the optical effect made use of in the light valve 4 make it necessary to employ a polarised light, polarises are disposed on the front and the back of the light valve in the area of the electrode segments. (These polarisers are indicated in Figure 1 by dotted lines and given the reference numerals 6 and 7). The excitation light passes from the front of the device from all directions through the light valve and into the fluorescent plate. The fluorescent light leaves the fluorescent plate at its front face (as shown by an arrow 8, e.g. in Figure 2) passing through the emergence windows towards the light valve. Only those electrode segments 5 to which an electrical voltage is applied render the display element transparent; the others block the fluorescent light. In this case, the indicated numbers appear bright against a dark ground.

If polarisers 6 and 7 are used which are not neutral, i.e. of they do not polarise light of all wavelengths in the visible range, and if two selective polarisers are used which allow light in the excitation light range to pass in both polarisation directions and only polarise the remainder of the spectrum, the excitation light passes through the polarisers unweakened. In this way, the entire display area can be utilised as a light collector area and the amplification factor can thus be appreciably increased. A further modification of the device can be used to permit electrical switching between two different colours. For this purpose, the fluorescent plate contains a mixture of fluorescent materials which will emit light of two colours. Thus, for example, it may emit red and green fluorescent light. It is then only necessary to replace the polariser 6 in Figure 1 with a combination of a horizontally polarising selective polariser which leaves only green light unpolarised and a vertically polarising second selective polariser which leaves only red light unpolarised. Then after passing through this compound polarisation unit, the fluorescent light consists of horizontally polarised red light and vertically polarised green light. Consequently only the green light is allowed to pass by the arrangement as a whole at segments at which no voltage is present, whilst at segments to which a voltage is applied, only the red light can pass. The same effect is produced when the front polariser 7 is replaced by the compound polariser described above.

The use of the rear polariser 6 can be rendered unnecessary in a relatively simple manner if the emission from the fluorescent plate is itself polarised by suitable deposition of the molecules of the fluorescent material, i.e. with a perferential alignment of the longitudinal molecular axes. The alignment of these molecules can be effected, for example, by orienting fluorescent molecules which are anisotropic in shape incorporated in the plastic plate in one direction in known manner by stretching the synthetic resin plate.

A second embodiment of the invention is shown in Figure 2. In this embodiment, a fluorescent plate 1*b*, which absorbs the ambient light, is disposed in front of the light valve 4. The observer (indicated by an eye 14) thus sees the light valve 4 through the fluorescent plate. The fluorescent light 8 in the fluorescent plate is deflected through 180° by projections 9 on three sides of the fluorescent plate with silvered edge faces 2 and is thereby directed into a rear fluorescent plate 1*a* having emergence "windows" 3. The fluorescent light 8 deflected at these emergence wondows, leaves the display through the electrode segments 5 which are switched to the transparent state. Thus the fluorescent plates 1*a* and 1*b* combine with the projections 9 on three narrow sides of the light valve 4 to form a sort of cover which is placed over the light valve 4. Here again, as in Figure 1, polarisers 6 and 7 are used when necessary. This embodiment has the advantage that better use can be made of the ambient light since it does not have to pass through the light valve 4 before entering the fluorescent plate. In addition, neutral instead of selective polarisers can be used without any loss of light. Such a cover-shaped fluorescent plate can be produced by injection-moulding without any problems.

Another embodiment of the invention is illustrated in Figure 3. This shows a display device with passive brightness amplification in which the fluorescent plate is disposed in front of an electrically controllable liquid crystal display and in which the liquid crystal display itself forms part of the light trap. The arrangement consists of a fluorescent plate 1*b* with side projections 9 bounding the fluorescent plate and silvered edge faces 2 to deflect the light through 180°. The light valve 4 consists of a liquid crystal display containing a liquid crystal which is converted to a state in which it diffuses light under the influence of an electrical field, e.g. it shows the dynamic diffusion effect (see Heilmeier, Zanoni and Barton, Proc. IEEE, 1968, Vol. 56, p. 1162). At three of its edge faces, this liquid crystal display is optically in contact with the projections 9 and thus forms part of the light trap. Fluroescent light is partly deflected as a result of dynamic light diffusion at electrode segments 5 at which an electrical voltage is present in such a way that it can leave the liquid crystal cell. Since the dynamic diffusion the angles of diffusion are relatively small, the fluorescent light still leaves the liquid crystal cell at an acute angle. To ensure that this emergent fluorescent light can reach the eye 14 of an observer, the light is further deflected by a film 10 with a fluorescent pigment coating or a light-diffusive coating. To ensure that the film 10 with a fluroescent pigment coating cannot be made to fluoresce by the ambient light, it is covered with a filter film 11 which only allows the fluorescent light of the film 10 to pass through it. The embodiment of Figure 3 is distinguished by the fact that no stationary emergence windows (as shown at 3 in Figure 2) are required, and that the emergence of the fluorescent light from the light trap is controlled by the display elements themselves, i.e. its location can be varied. Consequently, this arrangement is particularly suitable for matrix displays.

Figure 4 shows one form of fluorescent plate for passive brightness amplification in which an additional light source is incorporated in order to operate the display in the dark. At one edge face, the fluorescent plate 1 having silvered edge faces 2 and emergence windows 3 for fluorescent light, is provided with a rectangular recess 12 in which an additional small light source 13 is located, e.g. a light-emitting diode (LED).

Figure 5 shows a quasi-analogue display in the form of a large clock forming a further embodiment of the invention, using a fluorescent plate 1*a* with a silvered edge face 2 which carries an inner ring and an outer ring each having 60 light-emergence windows 3 to indicate hours and minutes respectively. The light-emergence windows are associated with electrode segments correspondingly arranged in an electro-optical light valve. One electrode segment 5 in each ring of light-emergence windows is actuated at any one time to show the time of day in hours and minutes. The 120 elements of the display can be wired like a matrix and thus statically actuated with minimal expenditure on control electronics. Multiplex operation is not necessary.

Figure 6 shows another form of fluorescent plate for use in display devices according to the invention, having extra luminescence provided by a phosphorescent substance for operating a display in the dark. The arrangement consists of a fluroescent plate 1*a* having silvered egde faces 2 and emergence windows 3, in optical contact with a plate 17 of plastics material in which phosphorescent particles (not shown) having a long afterglow time, e.g. zinc sulphide, are embedded. The plate 17 also has three silvered edge faces. The contact face between the two plates carries a dichroic mirror 15 which allos the phosphorescent light marked 18 to pass through it so that this can stimulate the fluorescent plate 1*a* but reflects the fluorescent light 8.

Figure 7 shows a further form of fluorescent plate for use in display devices according to the invention having additional fluorescence stimulation provided by a phosphorescent substance. The arrangement consists of a fluorescent plate 1*a* with silvered edge faces 2 and emergence windows 3 which is coated on its rear face 20 with phosphorescent particles in such a way that they are not in optical contact with the fluroescent plate 1*a*. The part of the excitation light not absorbed by the fluroescent plate 1*a* is absorbed by the phosphorescent particles and causes the emission of phosphorescent light 18 which can further stimulate the fluorescent plate 1*a*. The phosphorescent coating is indicated at 16.

In many applications of the display devices according to the invention, it is possible for ambient light to enter from both the front and the back of the display. In order to be able to utilise the ambient light falling on the back of the display, a high-pass filter may be disposed behind the fluorescent plate, which filter lets through only that part of the spectrum which is absorbed in the fluorescent plate. This does not reduce the contrast of the display since, by using such a high-pass filter, no ambient light striking the display from the back can reach the eye of an observer located in front of the display. The high-pass filter can be made of an absorbent colour film, for example, with suitable spectral permeability.

An embodiment of the invention using a special high-pass filter is illustrated in Figure 8. In this embodiment, the high-pass filter is in the form of an additional fluorescent plate 21 with three silvered edge faces 22. Solar cells 24 are applied to the unsilvered edge face 23. The fluorescent molecules implanted in the additional fluorescent plate 21 are so chosen that they absorb in a range such that only light of the wavelength range will be absorbed in the main fluorescent plate 1*a* passes through the plate 21 to the plate 1*a*. Thus, no part of the ambient light falling on the back of the plate 21 can reach the eye of an observer located in front of the display, and thus reduce the display contrast since all such light is absorbed, either by the fluorescent plate 1*a* or by the additional fluorescent plate 21. The fluorescent particles of the additional plate 21 are also selected to re-emit the absorbed light in the remote red or near infrared ranges, where the solar cells 24 are still sensitive, so that all the ambient light falling on the plate 21 is made use of, that part of the spectrum which can be absorbed by the fluorescent plate 1*a* being passed through the plate 21 thereto, and that part of the spectrum which will not be absorbed in the plate 1*a*, being absorbed in the plate 21 and re-emitted in a wave-length range useful for feeding the solar cells 24.

Figure 9 shows yet another form of fluorescent plate for use in the display devices of the invention, in which additional fluorescence stimulation is provided by a phosphorescent substance.

The arrangement consists of a fluorescent plate 1*a* having silvered edge faces 2 and emergence windows 3. Behind the fluorescent plate 1*a* there is a coating 25 which contains phosphorescent particles and is not in optical contact with the fluorescent plate 1*a*. Behind this there is a high-pass filter, preferably in the form of an additional fluorescent plate 21. The part of the excitation light entering from the front face of the array which is not absorbed by the fluorescent plate 1*a* and that part of the excitation light entering from the rear face which is not absorbed by the high-pass filter or additional fluorescent plate are absorbed in the phosphorescent coating 25 and cause emission of phsophorescent light 18 which can further stimulate the fluorescent plate 1*a*. In this way, the display acquires an afterglow in darkness.

The amplification factor of the device can also be increased by means other than the choice of selective polarisers of high-pass filters, e.g. by skilful enlargement of the light-absorbent faces of the fluorescent plate. Figure 10 shows that it is also quite easy to utilise as an additional light-collecting face part of the are of a housing for a display, for instance, a liquid crystal display. In this embodiment, a fluorescent plate 1*a* with emergence windows 3 is connected by means of a silvered edge face 28 lying at an angle of 45° to the plate, to an additional collector plate 27 made of a fluorescent plastics material and serving for light-absorption.

The factors upon which depends the brightness amplification obtained in the display devices of the invention will now be listed and explained individually in greater detail. The factors governing the functions of the fluorescent plate in conjunction with the display (in particular a light valve) may be divided up under the following headings:-

A) light collection;
B) light reflection;
C) light output.

A - Light collection

1. Loss factor $V = 1 \cos\alpha_{tot} = \frac{n - \sqrt{n^2 - 1}}{n}$

(= percentage of the fluorescent light not totally reflected).

2. Fluorescence of quantum yield $= \frac{\text{Number of photons emitted}}{\text{Number of photons absorbed}}$

(should be as close to 1 as possible).

3. Ratio of absorption band-width to emission band-width (should be as large as possible; obtainable by mixing fluorescent substances having varying absorption bands but roughly the same emission band).

4. Concentration of fluorescent material. Intensity of light after passage through fluorescent plate $I = I_o \times e^{-\varepsilon C d}$ where I_o is the initial intensity;

ε is the extincation coefficient; typical value $5 \times 10^4 \frac{\text{Litres}}{\text{Mol} \times \text{cm}}$;

C is the molar concentration of fluorescent material; rational ceiling for C is the concentration level at which self-extinction of fluorescence sets in, e.g. $10^{-3} \frac{\text{Mol.}}{\text{Litre}}$;

d is the plate thickness in cm.

Full absorption of the main absorption band is easily obtainable with a plate 1 mm in thickness.

5. Chemical (photochemical) stability of the fluorescent material.

B - Light reflection

6. Reflective capacity of mirror coatings.

As an example:

Vapour-deposited aluminium coating : intensity reflection capacity R = 0.913. After 20 reflections, the intensity has fallen to 15 % of the initial value.

Vapour-deposited silver coating : intensity reflection capacity R = 0.985. After 20 reflections the intensity has dropped to 73.5 %. (R should be as close to 1 as possible).

7. Absorption (and diffusion) of basic synthetic resin material of plate. With a 4 mm thick, clear "Plexiglas" plate which actually absorbs 1 % of the light when this falls at right-angles, the intensity of the light would fall to 1/e of the initial intensity after a path of 40 cm. (Absorption should be as small as possible).

8. Light diffusion as a result of surface roughness or surface contamination. Since the fluorescent light is reflected much more frequently at the interfaces parallel with the plane of the plate than at the silvered edge faces, it is particularly important that these reflections take place free of losses, i.e. in this case, free diffusion. Plates made by injection-moulding generally satisfy this requirement well.

C - Light output

9. Brightness amplification factor $= \frac{\text{Light collection area}}{\text{Emergence window area}}$

10. Angular spread of emergent flourescent light. The angular spread of the emergent fluorescent light depends a great deal upon the nature of the output, which again affects the brightness of the display. This may be explained briefly with reference to the examples of

Figure 13. In examples a) and d), the front plane face of the plate determines the magnitude of the sector into which fluorescent light is actually refracted, namely 2π, steradians. In example b), however, the sector for the emergent light is already limited. With these simple examples, the considerably divergence of angular spread can also be more fully appreciated.

11. Shaping the reflecting edged and the emergence windows so that the light has a very short travel path.

It is easy so see that no losses occur during the light-reflection phase, the nature of the light output and its efficiency would have no effect on the luminance at the emergence windows. As this ideal state is approached, the requirements on the efficiency of the light stage diminish proportionally.

The optimum configuration for the reflecting edge faces of the fluorescent plate must be found empirically in each individual case. The rectangular form is certainly not always best. Moreover, it will also be easily appreciated that efficiency of light output and uniform illumination of the emergence windows cannot both be maximised at the same time. Thus an appropriate compromise has to be sought in each case.

Just how the observation sector for the display depends upon the ratio of the width of the emergence windows of the width of the display segment is shown with reference to a typical example in Figure 13. This Figure shows reflections at silvered notches (13*a* to 13*c*) and the diffusion at a pigment coating (13*d*) in which the pigment coating is indicated at 29.

The graph and diagram of Figure 14*a* and 14*b* respectively illustrate the relationship between the angular observation range 2α and the ratio *x* of the width of an emergence window of the fluorescent plate 1*a* to the width of a display segment in the light valve.

The relationship can be derived from the formula:-

$$\sin\alpha = n/\sqrt{4[d/b(c\text{-}1)]^2 + 1}$$

the dimensions *b* and *d* being indicated in the diagram of Figure 14*b*, *b* being the width of the display segment and $x \cdot b$, that of the emergence window; n is the refractive index of the fluorescent plate.

The relationship of 2α to *x* for a specific example, is shown in the graph of Figue 14*a* for various values of *x*.

It will be seen that the angle of 2α increases very rapidly as *x* is increased.

The diagram of Figure 14*b*, schematically illustrates the case where *x* is about 3; the angular observation range 2α is then approximately 85°.

Figures 15 and 16 show the light transmission curves or fluorescence emission curves for three heterochromatic fluroescent plates obtainable commerically. The invention was tested using these flourescent materials. In the graph in Figure 15, the transmission T in % is plotted against the light wavelength λ in nm. Here, the solid curve gives the values that were measured for a green fluorescent material (Grün 740), the broken line curve the values measured for a red fluorescent material (Rot 520) and the dash-dotted curve the results for the yellow fluorescent material (Gelb 323). The measurements were carried out on a 3 mm thick "Plexiglas" plate with reflection loss allowed for. In the graph of Figure 16, the emission E is plotted in arbitrary units against the wavelength λ (nm). The same fluorescent "Plexiglas" plates on which the transmission curves were plotted were used for measuring the emission. In both Figures. the curves obtained for the same fluorescent "Plexiglas" plate are drawn in the same way. (The designations "Grün 740", "Rot 520" abd "Gelb 332" are Trade names used by the firm of Röhm and Hass). The "Plexiglas" plate emitting green fluorescence was stimulated at a wavelength of 430 nm, the other two plates were excited at 535 nm.

In conclusion the essential advantages of the devices in accordance with the invention which considerably widens the application range of passive displays and in particular liquid crystal displays can be listed as follows:-

1. Without the use of any addition light source, extraordinarly high brightness of a level not hitherto achieved can be obtained, with a high degree of contrast;
2. the legibility of the display is independent of the ambient brightness to a degree not hitherto achieved;
3. the displays are free from parallax and shadows;
4. switching between two colours can be simply provided;
5. the device is simple, cheap and flexible, since owing to the ease with which the synthetic resin used for the fluorescent plate can be moulded, the plates can be produced cheaply in any required complex form using injection-moulding, so that special requirements for display illumination can easily be taken into account.

WHAT WE CLAIM IS:-

1. An optical display device comprising a display having at least one optical element

which is switchable between an opaque or diffused state and a transparent state, and a fluorusecent plate associated with said display and serving for the passive amplification of the brightness thereof.

2. A display device as claimed in Claim 1, wherein said display is in the form of a light valve, as hereibefore described.

3. A display device, wherein said fluorescent plate is provided with light-reflective edge faces so that said plate forms a light trap for light incident thereon.

4. A display device as claimed in any one of Claims 1 to 3, wherein said fluroescent plate is provided with stationary elements serving as emergence windows for the fluorescent light.

5. A display device as claimed in Claim 2 or either of Claims 3 or 4 as appendent thereto, wherein said electro-optical light valve makes use of a linear or quardratic double-refraction or an electro-optical diffusion effect in a ferro-electric ceramic.

6. A display device as claimed in Claim 2 or either of Claims 3 or 4 as appendent thereto, wherein said electro-optical light valve makes use of an electro chromic effort.

7. A display device as claimed in Claim 2 or either or Claims 3 or 4 as appendent thereto, wherein said electro-optical light valve makes use of a known liquid crystal electro-optical effect.

8. A display device as claimed in any one of the preceding Claims, wherein said fluroescent plate is disposed behind said display.

9. A display device as claimed in any one of Claims 1 to 7, wherein said fluorescent plate is disposed in front of said display.

10. A display device as claimed in Claim 9, wherein said fluorescent plate is provided with at least one edge projection serving to deflect light through 180°.

11. A display device as claimed in Claim 9 or Claim 10, wherein said display forms part of a light trap formed in said plate and thus serves to provide emergence windows for fluorescent light which are variable in location.

12. A display device as claimed in any one of the preceding Claims, wherein a film having a fluorescent pigment coating or a light-diffusive coating is located in front of said display.

13. A display device as claimed in Claim 12, wherein a filter film which only allows fluorescent light produced by said film to pass is disposed in front of said film.

14. A display device as claimed in any one of the preceding Claims, wherein said fluorescent plate is provided with an additional light source.

15. A display device as claimed in Claim 14, wherein said additional light souce is a light-emitting diode.

16. A display device as claimed in Claim 14 or Claim 15, wherein said additional light source is located in a recess in an edge face of said plate.

17. A display device as claimed in Claim 14, wherein said additional light source is in the form of a synthetic resin plate having phosphorescent particles implanted therein and with which said fluorescent plate is in optical contact at one end face thereof which is provided with a dichroic mirror.

18. A display device as claimed in claim 14, wherein said additional light source is in the form of phosphorescent particles applied on the rear face of said fluorescent plate in such a manner that there is not optical contact between said fluorescent plate and said phosphorescent particles.

19. A display device as claimed in Claim 4 or any one of Claims 5 to 18 as appendent thereto, wherein said emergence windows are so disposed that the operation of said device can be displayed in quasi-analogue form.

20. A display device as claimed in any one of the preceding Claims, wherein a filter which lets through light of only that part of the spectrum which is absorbed in said fluorescent plate is disposed behined said plate considered in the direction of observation.

21. A display device as claimed in Claim 20, wherein said filter is a high-pass filter.

22. A display device as claimed in Claim 21, wherein said high-pass filter is in the form of an absorbent colour film.

23. A display device as claimed in Claim 21, wherein said high-pass filter is in the form of the further fluorescent plate.

24. A display device as claimed in Claim 23, wherein said further fluorescent plate is silvered on three of its edge faces only, solar cells being mounted on the unsilvered edge face of the fluorescent plate.

25. A display device as claimed in any one of Claims 20 to 24, wherein a coating having phosphorescent particles therein which is not in optical contact with said fluorescent plate is located between said fluorescent plate and said filter.

26. A display device as claimed in any one of the preceding Claims, wherein fluorescent molecules which are anisotropic as regards their shape ae incorporated in a uniformly

oriented state in said fluorescent plate.

27. A display device as claimed in Claim 26, wherein the alingment of said anisotropic fluorescent molecules is effected by stretching the material of said fluorecent plate.

28. A display device as claimed in Claim 4, or any Claim appendent thereto, wherein said emergence windows individually correspond to the individual display elements of a light valve constituted by a liquid crystal.

29. A display device as claimed in Claim 28, wherein said display elements are located between two linear polarisers.

30. A display device as claimed in Claim 29, wherein said liquid crystal light valve is constituted by a "rotary cell" as hereinbefore defined.

31. A display device as claimed in Claim 29 or Claim 30, wherein said linear polarisers constitute a regularly formed cohesive surface which covers the display elements but leaves the remaining area of the liquid crystal light valve exposed.

32. A display device as claimed in any one of Claims 29 to 31, wherein the polarisation directions of said linear polarisers are arranged to be parallel with one another.

33. A display device as claimed in any one of Claims 29 to 31, wherein the polarisation directions of said linear polarisers are arranged to be at right-angles to one another; and wherein the emergence windows on said plate have substantially the same size and shape as the polariser surface on the liquid crystal light valve.

34. A display device as claimed in any one of Claims 29 to 33, wherein said linear polarisers are consituted by selective polarisers which leave iunpolarised only light produced by excitation of of said fluorescent plate.

35. A display device as claimed in any one of Claims 29 to 33, wherein a mixture of fluorescent material which fluoresce to give light of two different colours is incorpotated in said fluorescent plate; and wherein one of said two linear polarisers is constituted by a combination of two selective polarisers, the polarisation directions of which are arranged at 90° to one another and each of which polarisers light of a respective one of the two colour components at right-angles to light of the other colour component.

36. A display device as claimed in any one of Claims 28 to 33, wherein each of said emergence windows is constituted by a notch in the rear face of said fluorescent plate provided with a metallic reflective surface.

37. A display device as claimed in any one of Claims 28 to 33, wherein light-diffusing pigment coating is applied to said fluorescent plate.

38. A display device as claimed in any one of the preceding Claims, wherein the fluorescent material incorporated in said fluorescent plate comprises a mixture of fluorescent substances having differing light-absorption bands but substantially the same light-emission band.

39. A display device substantially as hereinbefore described with reference to and as shown in any of Figures 1, 2, 3, 5, and 8 or with reference to any of Figures 4, 6, 7, 9 and 10 to 16.

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Printed for Her Majesty's Stationery Office, by Croydon Printing Company Limited, Croydon, Surrey, 1980.
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

Fig.1

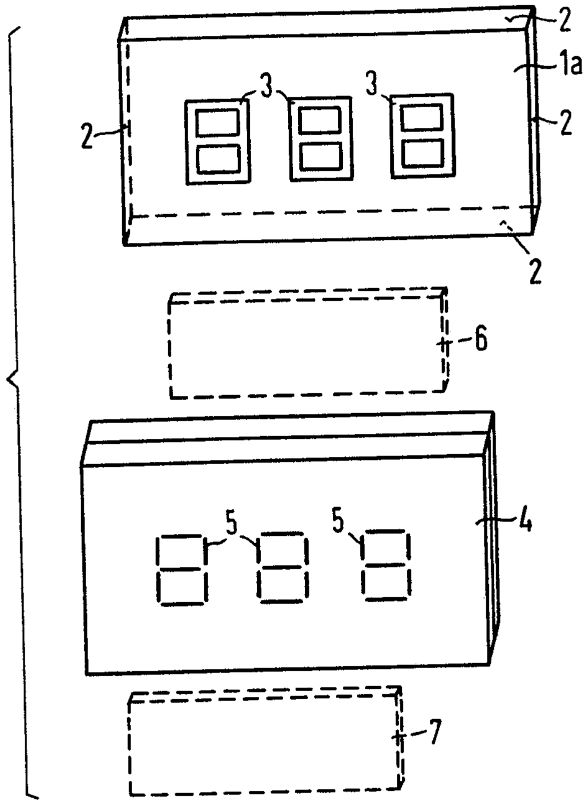
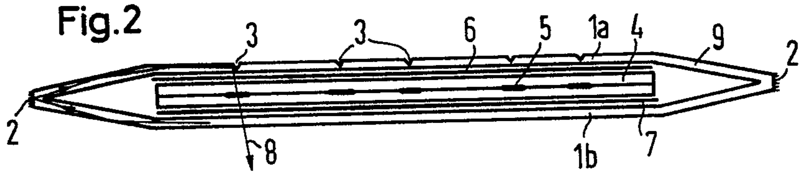
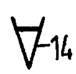


Fig.2





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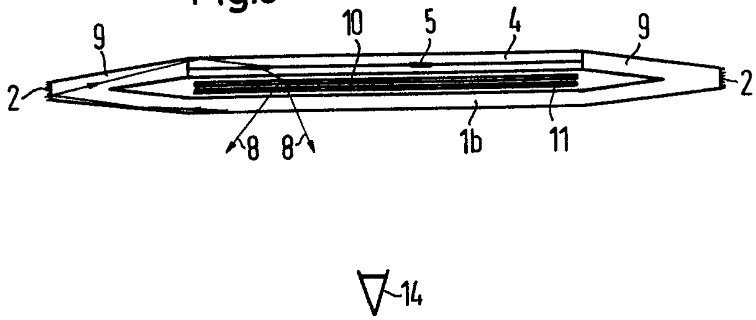

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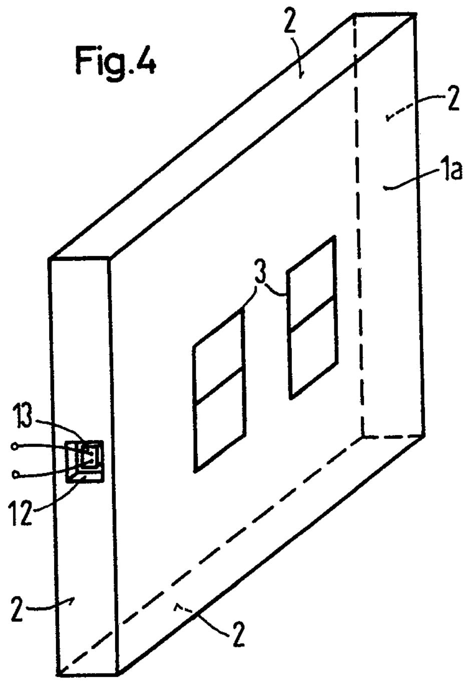

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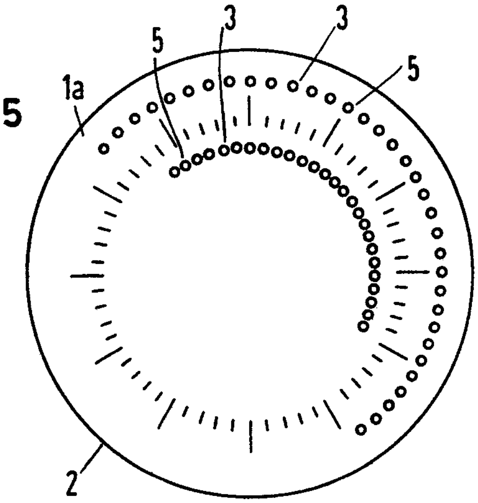

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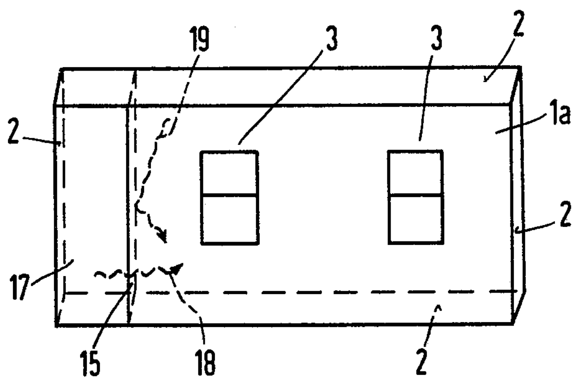

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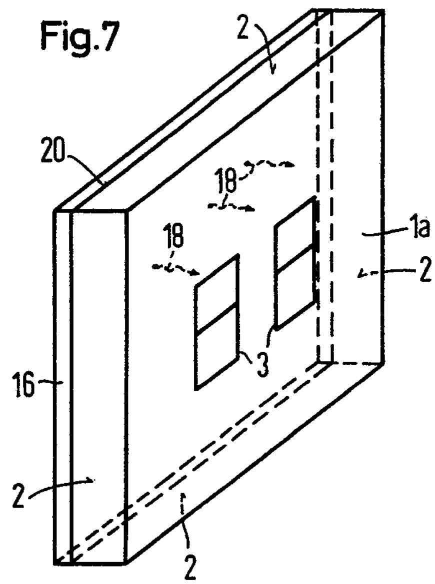

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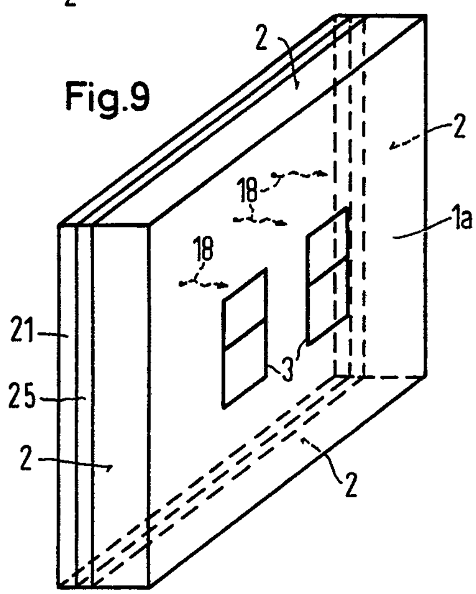
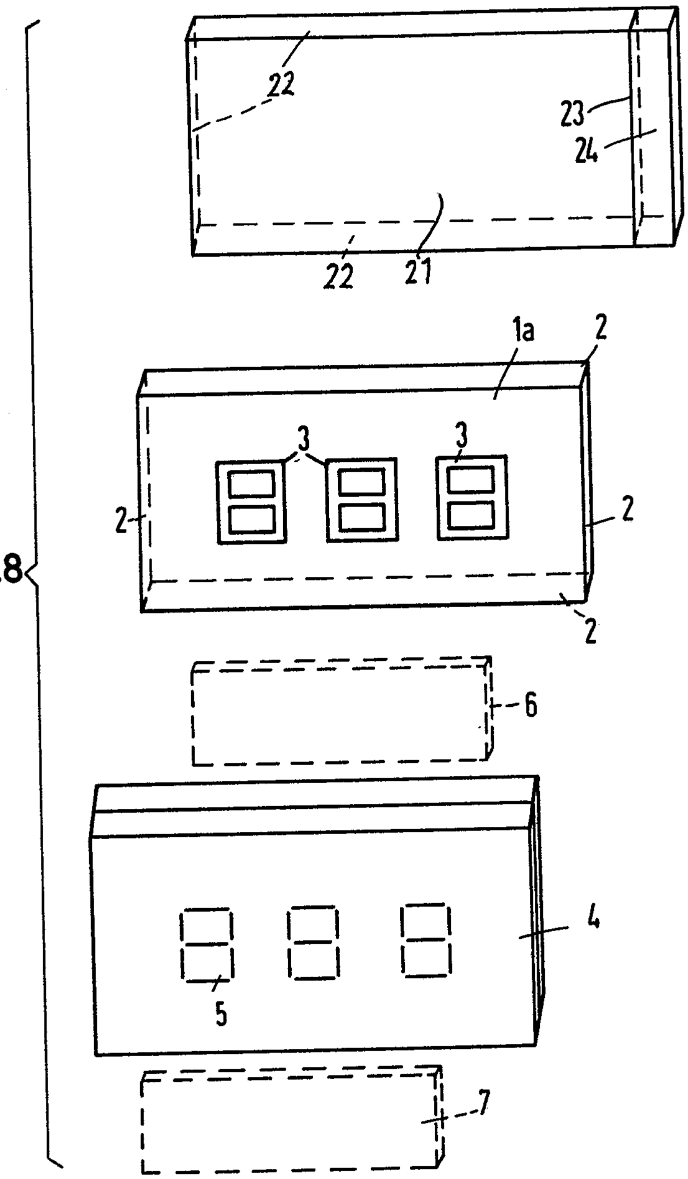


Fig.8


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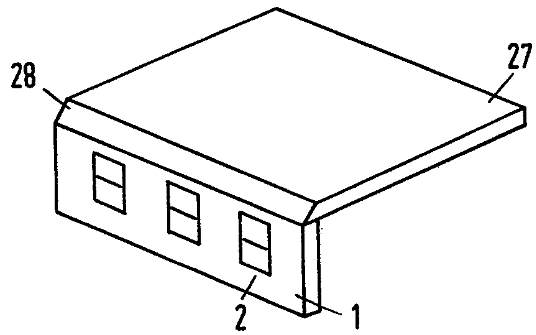

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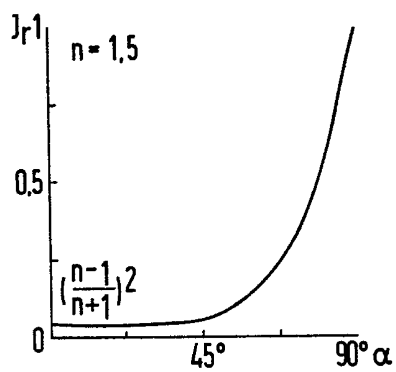

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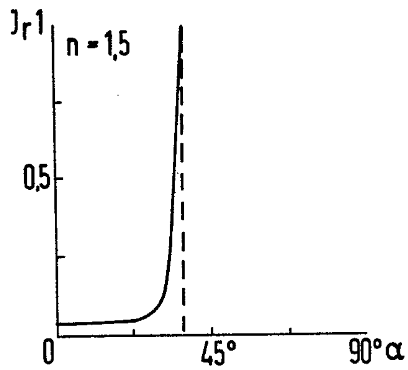


Fig.13

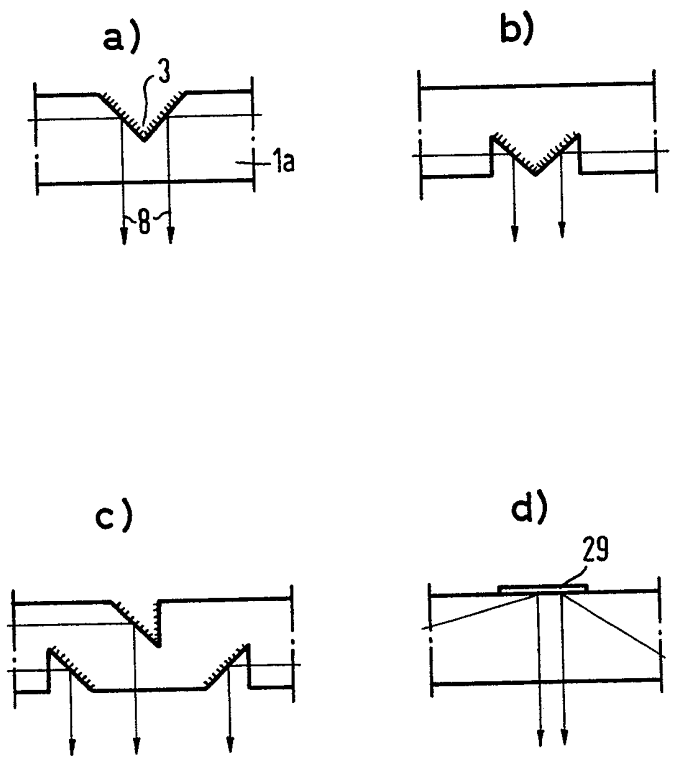
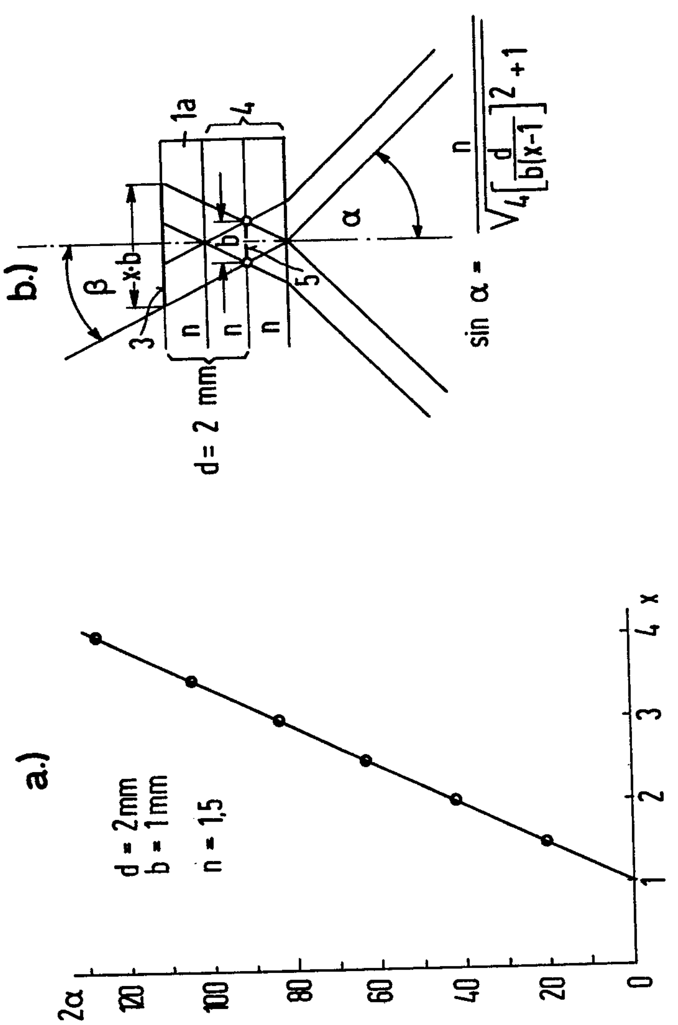


Fig.14


b.)
d= 2 mm
n
n
n
β
x·b
b
α
1a
4
3
5
sin α = n / √(4[d / b(x-1)]² + 1)
a.)
d = 2mm
b = 1mm
n = 1,5
2α
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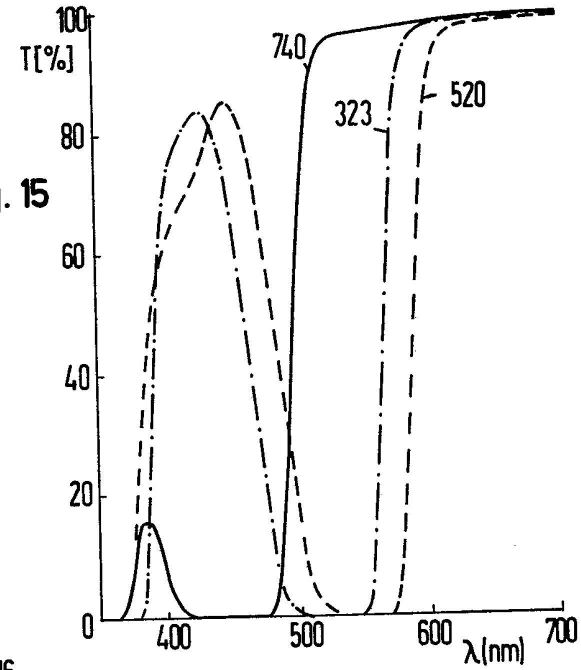
100
80
60
40
20
0
1
2
3
4
x

Fig. 15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500
600
700
λ(nm)
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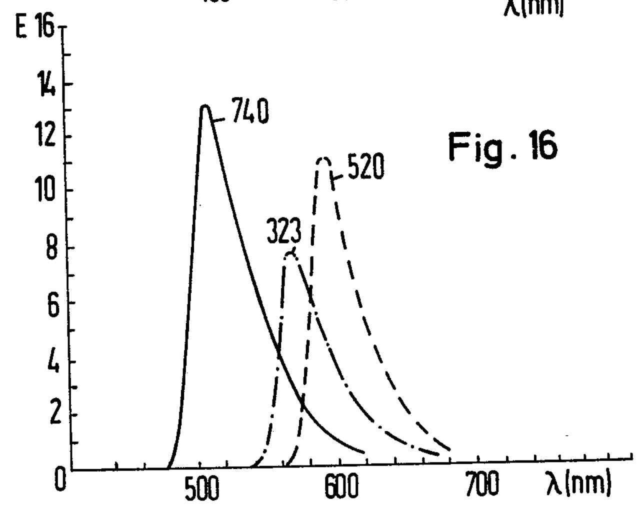
E 16
14
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2
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500
600
700
λ(nm)
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520
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Fig. 16