

PATENT SPECIFICATION (11)

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- (21) Application No. 57858/73 (22) Filed 13 Dec. 1973 (19)
 (31) Convention Application No. 333 431 (32) Filed 16 Feb. 1973 in
 (33) United States of America (US)
 (44) Complete Specification published 22 Oct. 1975
 (51) INT. CL.^a H05B 33/22
 (52) Index at acceptance
 C4S 33Y 68X 68Y 71S 73I 73J



(54) ELECTROLUMINESCENT SEMICONDUCTOR APPARATUS AND METHOD OF FABRICATING THE SAME

(71) We, HEWLETT-PACKARD COMPANY, of 1501 Page Mill Road, Palo Alto, California 94304, United States of America, a corporation organised and existing under the laws of the State of California, United States of America, 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 and by the following statement:—

This invention relates to electroluminescent semiconductor apparatus.

The present invention provides electroluminescent semiconductor apparatus comprising: a base, a body of material of selected thickness having upper and lower surfaces and having a cavity passing through the body from said upper surface to said lower surface, said lower surface of the body being substantially contiguous with said base, said cavity having side walls and having a bottom formed by said base, at least the side walls of said cavity forming non-specularly reflective surfaces; an electroluminescent semiconductor device attached to the base at the bottom of the cavity; optically transmissive material containing discrete particles for the scattering of light passing through said material, said material and discrete particles being disposed throughout the cavity; and means whereby a source of electrical signals can be connected to the electroluminescent semiconductor device.

Preferably at least the side walls of said cavity are formed of substantially white optically opaque material.

Preferably at least the upper surface of the body in the region surrounding the cavity is substantially absorptively opaque for absorbing light leaving the cavity through the body.

In an apparatus according to the invention we prefer that the shape of the cavity at the upper surface of the body is polygonal and the shape of the cavity at the lower surface is polygonal and the centres of the two polygons lie at least approximately on a common straight line extending normally to the two surfaces.

In a first example of an apparatus according to the invention the shape of the cavity at the upper surface of the body is a first rectangle having a length a and a width b ; and the shape of the cavity at the lower surface of the body is a second rectangle having a length a and a width c , where c is not less than b .

In a second example of an apparatus according to the invention the shape of the cavity at the upper surface of the body is a first rectangle of a length d and width e ; the shape of the cavity at the lower surface of the body is a second rectangle of length f and width g , where f is less than d , and g is greater than e ; the shape of the cavity at a selected intermediate plane parallel to and between the upper and the lower surfaces of the body is a third rectangle of length f and width e ; the centres of the first, second and third rectangles lie approximately on a straight line; the four side walls of the cavity between the upper surface and the selected intermediate plane are each planar; and the four side walls of the cavity between the lower surface and the selected intermediate plane are each planar.

In a third example of an apparatus according to the invention the shape of the cavity at the upper surface of the body is a first rectangle having a length h and a width i ; and the shape of the cavity at the lower surface of the body is a second rectangle having a length j and a width i where $h > i > j$.

Preferably the lower surface of the body in the region surrounding the cavity is substantially absorptively opaque for absorbing light in the region of said lower surface.

The optically transmissive material is preferably an epoxy resin and the discrete particles are preferably grains of powdered glass.

There now follows a detailed description, which is to be read with reference to the accompanying drawings, of the prior art and apparatuses according to the invention; it is to be clearly understood that the apparatuses according to the invention have been selected for description to illustrate the invention by

way of example and not by way of limitation.

In the accompanying drawings:—

Figure 1A is a cross-sectional view of a prior art apparatus exemplifying what is hereinafter referred to as a Category A apparatus;

Figure 1B is a cross-sectional view of the apparatus shown in Figure 1A taken on the line 1B—1B thereof;

Figure 2A is a cross-sectional view of a prior art apparatus exemplifying what is hereinafter referred to as a Category B apparatus;

Figure 2B is a cross-sectional view of the apparatus shown in Figure 2A taken on the line 2B—2B thereof;

Figures 3A and 3B illustrate the effect of converging side walls upon semiconductor displays utilizing specular reflection; and

Figures 4A and 4B, Figures 5A and 5B, Figures 6A and 6B and Figure 7 are cross-sectional views of preferred embodiments of the present invention.

The prior art in electroluminescent semiconductor displays will be divided for the purposes of discussion into two groups, herein referred to as Category A and Category B. In Category A, as depicted by Figures 1A and 1B, the apparent size of an electroluminescent semiconductor device 12a is enhanced by placing it in a cavity 13a filled with transparent plastics material 17a and having specularly reflecting walls 24a. These walls 24a are typically formed by metal deposits on some other material 16a. The electroluminescent semiconductor device 12a is placed on a substrate 18a in the center of the cavity and emits photons 30a isotropically into the transparent material 17a. The top surface 14a of the cavity 13a is illuminated by light coming directly from the device 12a or by specular reflection from the walls 24a. Roughening of the top surface 14a causes the light to refract randomly and thereby approximate a Lambertian distribution. To obtain uniform illumination at the upper surface 14a of the cavity 13a, however, it is important to achieve a reasonably uniform distribution of light at the location 15a where the light rays intersect the plastics material-air interface 14a that produces the random refraction. To achieve such uniformity, that is, to increase the illumination in regions away from the light-emitting electroluminescent semiconductor device 12a, the cavity 13a with its specularly reflecting walls 24a, must be properly shaped. A typical shape is shown in Figure 1A in which a cross-section through the length of the cavity has been taken. Figure 1B shows the cavity from a direction perpendicular to Figure 1A. The specularly reflecting metalized end walls 24a (in Figure 1A) of the cavity may approximate a parabola with straight line segments, or they may be parabolic curves.

In either case, the electroluminescent semiconductor device 12a is placed at the focal point of the parabola. Thus, light emitted from the sides of the device toward the end walls 24a as shown in Figure 1A will be specularly reflected upwardly toward the roughened surface 14a near the ends of the cavity 13a rather than the center, thereby compensating for the reduced direct emission in the direction of the ends. Light emitted toward the vertical side walls 24a (as shown in Figure 1B) may undergo several specular reflections before reaching the upper surface 14a. In addition to the constraint of approximately parabolically-shaped end walls, the apparatus of Category A also requires a device which emits light through its sides in an approximate isotropic emission pattern. Typically this type of emission pattern has been achieved by utilizing gallium phosphide semiconductor devices. In contrast, however, a gallium arsenide phosphide device which has Lambertian emission characteristics substantially from the upper surface emissions only, would not emit sufficient light toward the side and end walls to achieve the desired uniform illumination of the upper surface. Use of side-emitting electroluminescent semiconductor devices, however, results in a large portion of the light emitted toward the side walls of the cavity undergoing multiple reflections before reaching the surface. With the metalization deposited on the walls having a reflective coefficient of approximately 90% for gold, aluminum, silver or copper, it is evident that the multiple reflections will strongly attenuate the light emitted from the sides of the device in the direction of the sides of the cavity before it reaches the upper surface. Thus, electroluminescent semiconductor apparatus utilizing the design techniques of Category A appear to require or satisfy the following four criteria:

- (1) specularly reflecting walls;
- (2) sloped end walls, in particular the end walls must approximate a parabola with the light-emitting device placed at its focal point;
- (3) an isotropically emitting device, that is, a device with light emission through its sides. In practice, this requirement eliminates the use of gallium arsenide phosphide semiconductors because of their Lambertian emission characteristic;
- (4) a roughened or other non-flat surface forming the upper surface of the display apparatus to randomize the highly direct radiation into a nearly Lambertian distribution.

Criterion 1 constrains the side walls, i.e., those shown in Figure 1B, to be vertical or outwardly sloping. That is, the cross-section at the top of the display must be equal to or wider than the cross-section at the bottom of the display. Inwardly sloped side walls, wherein the top is narrower than the bottom,

could not be utilized in the prior art devices for the following reasons. As shown in Figure 3A, specular reflection will not change the angle of incidence between the light ray and the wall where there are parallel vertical walls. In the case of inwardly sloped walls, however, see Figure 3B) the angle of incidence changes after each reflection. It can be seen that a light ray emitted at a 45 degree angle from the device will reverse its direction after some number of reflections and may never reach the top of the cavity. Realizing that half of the light emitted by a Lambertian device is emitted at an angle of more than 45 degrees from the vertical, it becomes apparent that inwardly sloping walls should not be used in Category A designs. In some designs wherein the body of the display is to be fabricated by a molding process, the constraint of wall slope discussed above may be important.

The requirement for vertically or outwardly sloping side walls may have other consequences. First, the minimum width of the cavity at the top must be at least the device size plus twice the assembly tolerance, that is, a device chip 0.018 inches wide and an assembly tolerance of 0.006 inches requires a width of 0.030 inches. Such a width limitation is undesirable for two reasons. First, in order to maintain a visually pleasing ratio of character height to segment width the apparatus is limited to relatively large displays wherein the character height is approximately 0.3 of an inch. Second, a larger light flux is required to maintain constant brightness over a larger surface area. A further constraint imposed by criterion 1 for Category A electroluminescent semiconductor displays is that the interior of the cavity should be formed of a specularly reflecting metal upon some underlying material. This is a very expensive process, particularly if the material deposited on the cavity walls is gold or silver.

Further, in spite of the expensive design, Category A prior art devices have not produced uniform light distribution at the upper surface of the display. These irregularities are usually discernible with the naked eye and detract substantially from the overall appearance of the display.

Prior art apparatuses in Category B as shown in Figures 2A and 2B, have evolved along a slightly different design ideology. In Category B designs, a light source 12b which may be either a side-emitting or top-emitting electroluminescent semiconductor (typically gallium arsenide phosphide or gallium phosphide), is placed in a cavity 13b having reflective walls 24b. The cavity 13b is not filled with transparent material, but is merely covered with a randomly refracting surface layer 19b, for example, a fly's-eye lens as shown. Category B prior art devices

typically utilize vertical walls 24b with increased depth d of the cavity 13b in order to improve upon the resulting nonuniform output light flux. This change causes the light emitted from the device to make more reflections off the walls 24b but allows a non-isotropically emitting device 12b such as gallium arsenide phosphide to be used.

Category B designs typically require the following four criteria:

(1) A fly's-eye lens or other randomly refracting surface. This lens configuration is a substitute for the randomly refracting surface described in Category A prior art,

(2) An air-filled cavity between the light emitting semiconductor device and the lens. Such a lens is typically used on the cavity side of the upper surface because, if used on the side from which the display is viewed, oil or water or other liquid contaminant can destroy the randomly refractive effect of the lens. The efficiency of such a lens is based upon the difference in refractive indices of the lens material and the material within the cavity. Thus, the cavity cannot be filled with plastics material or other material without destroying the effectiveness of the lens. So air usually fills the cavity in Category B designs,

(3) Specularly reflecting metalized cavity walls,

(4) Vertical end walls and vertical side walls. Inwardly sloping side walls cannot be used for the same reasons as set forth in the discussion of Category A designs.

Category B devices have several other disadvantages. Typically, because they use more parts, they are more difficult and expensive to fabricate. Secondly, because of the air-filled cavity, they are not able to take advantage of the enhancement in coupling efficiency which results from embedding the light-emitting device in transparent plastics material. This reduction in coupling efficiency occurs because of the difference in refractive indices between the air within the cavity and the electroluminescent semiconductor from which the light is emitted. Not filling the cavity with transparent plastic material reduces the efficiency of the light emitting diode substantially, that is, the light flux emitted directly into air is approximately lower by a factor of $n^2 \approx 2.5$ compared with the case of emission from chip to plastic without an air interface. (n denotes the index of refraction of the plastics material.)

Devices designed utilizing Category B ideology also require plating of the interior of the cavity as discussed under Category A designs. This greatly increases cost and complicates manufacture of the electroluminescent semiconductor displays. And, as discussed earlier, the display provided by a Category B prior art design, is usually thicker than otherwise desirable in order to minimize

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the variation in light intensity at the upper surface of the cavity. The variations of light flux density between center and end is given by $\cos^m \alpha$ where m denotes a number equal or larger than 4 and α denotes the angle between two rays travelling to center and end, respectively. Thus it can be seen that variations in light flux density decreases with increasing cavity depth for a given cavity length. For all of the above reasons the uniformity of light distribution at the upper surface of Category B displays is not as good as that of Category A displays.

The present invention is based on the principle of an integrating sphere. In an integrating sphere, light is reflected from a low-loss diffusely reflecting surface. After many random reflections it will strike an exit slot, which may have the shape of a single segment of a 7-segment numerical display. Such an integrating structure need not be of spherical shape, but may have any arbitrary shape consistent with low cost assembly of such a display. For two reasons, a diffusely reflecting surface is preferred over a specularly reflecting surface. Firstly, it avoids the problem already discussed in conjunction with Figure 3B, and secondly, it randomly refracts the light within the cavity before the light reaches the exit slot.

Referring now to Figures 4A and 4B, there is shown a preferred embodiment of the invention. An electroluminescent semiconductor device 12 rests on a base 18, which may be any suitable material, e.g., ceramic. The semiconductor device 12 may be either top-emitting or side-emitting, typically either gallium arsenide phosphide or gallium phosphide. The semiconductor device 12 is placed in a cavity 13 surrounded by a body 16.

The body 16 has an upper surface 32 and a lower surface 34 and at the plane of the upper surface 32, the cavity 13 defines a rectangular opening having a dimension, arbitrarily referred to as the length, a , and a second dimension arbitrarily referred to as the width b where a is greater than b . At the plane of the lower surface 34, the cavity is of a rectangular shape having length a and width c where $a > c > b$. The centres of the two rectangles lie on the same vertical line, i.e. normal to the surfaces 32 and 34.

The cavity 13 is then filled with transparent material 17, for example epoxy resin, containing scattering centers 28 provided by discrete particles which for example can be grains of powdered glass. The color of the surface of the body material 16 determines the amount of reflection which occurs at the surface 21 of the body. White is preferred for this reason although it should be understood that a highly reflective color over the spectral range of the light emitted (e.g., red for red light, blue for blue light, etc.) may

also be used. In the prior art both categories A and B utilized a specularly reflecting surface. This surface is typically achieved by deposition of a very thin layer of metal, typically gold, silver, copper or aluminum, upon the surrounding body 16. This is shown in Figures 1A and 1B as the surface 24a and in Figures 2A and 2B as the surface 24b. In contrast, utilization of diffuse reflection and of a body having white walls 21 in accordance with the present invention has several advantages over the prior art. The prior art apparatuses are required to be plated with reflective material over the entire interior surface of the cavity. The costs of the material and of the plating process substantially increase the cost of such prior art apparatuses over the present invention.

The present invention overcomes this drawback by utilizing diffusely reflecting plastic (for example, of white color), as opposed to a specularly reflecting surface. The effect of this choice may best be seen from the following calculations. The amount of light eventually emitted from a display device is proportional to R^x where R is the reflectivity of the material and x is the number of reflective or scattering events occurring.

In the case of the prior art devices, R is approximately 0.90. In other words, the metallized surfaces 24a and 24b in Figures 1 and 2 reflect approximately 90 percent of the light impinging upon them. The remaining 10 percent is absorbed.

In accordance with the present invention, approximately 98.5 percent of the light which impinges upon the white walls 21 is reflected, a substantial advantage over the prior art. The light is bounced about the interior of the cavity 13 many times by the scattering centers 28 and by the white walls 21. Thus, the light 30 emitted is uniform in appearance over the length of the cavity 13 from one end to the other. For a given number of reflections, the emitted light 30 is more intense than that which would be emitted from a specularly reflecting design because the reflectivity of white walls is greater than the reflectivity of metallized walls. For example, if the light undergoes an average of 10 reflections from the metallized walls of the prior art apparatuses before leaving through the exit slot, the $R=90\%$ results in a total loss of 66%. In contrast, the white walls of the present invention with $R=98.5\%$ result in a loss of only 14%.

Figures 4A and B also show the path of a typical light ray 30 emanating from the electroluminescent semiconductor 12. It should be noted that this ray is provided only for the purposes of illustrating the effect of the scattering centers 28 and the white walls 24. To minimize the transfer of light from one cavity such as that in Figure 4A to an

adjoining cavity in some other portion of an overall display, surfaces 32 and 34 are blackened. Darkening the surface 34 prevents the light emanating from the electroluminescent semiconductor device 12 from traveling between the base 18 and the body 16. Certain prior art devices interpose a separate sheet of plastics material between the body 16 and the substrate 18 (see Figure 2) to prevent such light crossover. Darkening the surface 32 absorbs light which is transmitted through the body 16 and which strikes the surface 32. If this surface is not darkened the difference in refractive indices between the air above the surface 32 and the material of the body 16 causes almost total reflection back into the body 16 of the light striking the surface 32.

Another embodiment of the present invention is shown in Figures 5A and 5B. This embodiment may typically be used with displays wherein the height of the numeral or displayed number is less than 0.3 inches. In these displays the assembly tolerances for placing the electroluminescent semiconductor device 12 at the base of the cavity 13, before adding the transparent material 17 containing scattering centers 28 are very small, thus making it difficult to assemble properly. The cavity walls 58 may be cut away in the vicinity of the electroluminescent semiconductor device 12 to facilitate assembly with acceptable tolerances.

In this case the cavity is of more complex shape than that shown in Figures 4A and 4B. At the plane of the upper surface 32, the cavity defines a rectangular opening having length d and width e , where d is greater than e . At the plane of the lower surface 34, the cavity is of a rectangular shape having length f and width g where $d > g > f > e$. Intermediate the plane of the two surfaces 32 and 34, the walls of the cavity which are planar define a rectangle the plane of which is parallel to the surfaces 32 and 34 having length f and width e . The centres of each of the three rectangles lie on the same vertical line, i.e. normal to the surfaces 32 and 34.

For larger character heights in which the size of the segment cavities are much larger, and consequently the assembly tolerances less constraining, a cavity shaped like that shown in Figures 6A and 6B may be used. This cavity shape has the advantage that the body may be molded in one operation from one side with concomitant savings in fabrication costs. In this case the cavity 13 defines a rectangular opening at the plane of the upper surface, the opening having a length h and a width i where h is greater than i . At the plane of the lower surface 34, the cavity is of a rectangular shape having a length j and width i where $i > j$. The centres of the two rectangles lie on the same vertical line, i.e. normal to the surfaces 32 and 34. Addi-

tionally, the shape of the upper region of the cavity may have any one of a number of selected shapes quite independent of the shape of the cavity in the lower region. Thus, alphanumeric characters and symbols may be displayed with appropriate shaping of the upper region of the cavities. Where convenient, a single cavity may be employed prepared according to the present invention, with a separate legend plate 44 or aperture disposed over the upper surface as shown in Figure 7. And the lower region of the cavity may have an arbitrary shape suitable for convenience of fabrication, and may even include an opening 45 in the base 14 (with only negligible light loss therethrough) which opening may be the separation between electrodes of a stamped metal lead frame.

In the assembly process of the present invention, the body 16 may be cast to shape from for example a white plastics material with the appropriately shaped cavity or cavities 13 included. The upper surface 32 (i.e., the output or viewing surface) may then be attached to a tape containing an adhesive for the purpose of sealing the upper cavity surfaces and facilitating the automated handling of the bodies 16. The tape and adhesive should be capable of withstanding elevated processing temperatures and not be reactive with the solvents, filler materials or plastics materials used. Commercially available Teflon-base tape ("Teflon" is a Registered Trade Mark) including silicone-base pressure-sensitive adhesive (distributed as Type 60 Tape by Minnesota Mining and Manufacturing Company) is adequate for this purpose. The liquid filler material 17 (e.g., an epoxy resin) with the scattering centers 28 dispersed therein may then be introduced into the back side of the body to be distributed within the cavities and over the back surface of the body. In order to insure that the cavities are completely filled with the liquid filler material, the bodies with a quantity of liquid filler material therein may be positioned with viewing surface 32 disposed downwardly on swing-mounted platforms within a centrifuge in order to exert sufficient force upon the liquid filler material to exclude or displace entrapped air within the cavities 13 and thereby to assure complete filling of the cavities through the bodies from the back sides to the viewing surface 32. It has been determined that a minimum amount of force must be applied to the liquid filler material to force out the air bubbles entrapped within the cavity through the surface of the liquid filler material at the back side of the body 11. Thus, a force of at least 10 G must be exerted (for example, by centrifuging) substantially normal to and in the direction toward, the surface 32 with this surface firmly positioned on a swing-mounted platform of the centrifuge.

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After the liquid filler material 17 has been completely distributed throughout the cavities and rear side of the body in this manner and while the filler material is still liquid, the base 18 may be inserted in place. This base 18 is typically a lead frame which includes the semiconductor light emitting devices attached thereto and which includes wire-bonded connections between the upper surface of the light-emitting devices and adjacent electrodes. This lead frame assembly may be urged down into place, slightly displacing sufficient filler material to assure complete filling of all voids and to encapsulate the entire assembly in the liquid filler material in the single operation. Thereafter, the body and lead frame, together with the liquid filler material disposed throughout may then be heat treated to cure the liquid filler material to a solid state. After the filler material is cured, the tape may be removed from the viewing surface 32, to yield the completed unit having the viewing apertures and the associated cavities substantially flush-filled to the level of the viewing surface 32.

In summary, the present electroluminescent semiconductor apparatus according to the invention can provide a display which has a substantially uniformly illuminated surface using an electroluminescent semiconductor which may be either top-emitting, side-emitting, or both.

The display may be formed of one or more cavities of selected shapes which are filled with epoxy and glass. This provides diffuse reflection which eliminates the necessity of deposition of metal on the walls surrounding the light-emitting semiconductor with concomitant savings in fabrication costs. Also, the preferred white color of the diffusely reflecting cavity walls absorbs less light than conventional specularly reflecting walls of deposited metal. The blackened upper and lower outer surfaces of the body surrounding the cavity reduce the transfer of light from one cavity of the display to an adjacent cavity of the display. In accordance with the processing of the present invention, no roughening of the upper surface of the material which fills the cavity is necessary. The material which fills the cavity may have an index of refraction close to that of the electroluminescent semiconductor device for assuring efficient transfer of light out of the semiconductor device.

In addition, the processing of the present invention provides for complete filling of the body and centrifuging of the filler material into all cavities of the body before the base or lead frame is introduced and before the entire assembly is heat treated to cure the liquid filler material. This greatly simplifies alignment and assembly of parts and facili-

tates the inexpensive mass production of solid state display devices.

WHAT WE CLAIM IS:—

1. Electroluminescent semiconductor apparatus comprising: a base; a body of material of selected thickness having upper and lower surfaces and having a cavity passing through the body from said upper surface to said lower surface, said lower surface of the body being substantially contiguous with said base, said cavity having side walls and having a bottom formed by said base, at least the side walls of said cavity forming non-specularly reflective surfaces; an electroluminescent semiconductor device attached to the base at the bottom of the cavity; optically transmissive material containing discrete particles for the scattering of light passing through said material, said material and discrete particles being disposed throughout the cavity; and means whereby a source of electrical signal can be connected to the electroluminescent semiconductor device.

2. Apparatus according to claim 1 wherein at least the side walls of said cavity are formed of substantially white optically opaque material.

3. Apparatus according to either one of claims 1 and 2 wherein at least the upper surface of the body in the region surrounding the cavity is substantially absorptively opaque for absorbing light leaving the cavity through the body.

4. Apparatus according to any one of the preceding claims wherein the shape of the cavity at the upper surface of the body is polygonal and the shape of the cavity at the lower surface is polygonal and the centres of the two polygons lie at least approximately on a common straight line extending normally to the two surfaces.

5. Apparatus according to any one of claims 1 to 4 wherein: the shape of the cavity at the upper surface of the body is a first rectangle having a length a and a width b ; and the shape of the cavity at the lower surface of the body is a second rectangle having a length a and a width c , where c is not less than b .

6. Apparatus according to any one of claims 1 to 4 wherein: the shape of the cavity at the upper surface of the body is a first rectangle of a length d and width e ; the shape of the cavity at the lower surface of the body is a second rectangle of length f and width g , where f is less than d , and g is greater than e ; the shape of the cavity at a selected intermediate plane parallel to and between the upper and the lower surfaces of the body is a third rectangle of length f and width e ; the centres of the first, second and third rectangles lie approximately on a straight line; the four side walls of the cavity between the upper surface and the



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After the liquid filler material 17 has been completely distributed throughout the cavities and rear side of the body in this manner and while the filler material is still liquid, the base 18 may be inserted in place. This base 18 is typically a lead frame which includes the semiconductor light emitting devices attached thereto and which includes wire-bonded connections between the upper surface of the light-emitting devices and adjacent electrodes. This lead frame assembly may be urged down into place, slightly displacing sufficient filler material to assure complete filling of all voids and to encapsulate the entire assembly in the liquid filler material in the single operation. Thereafter, the body and lead frame, together with the liquid filler material disposed throughout may then be heat treated to cure the liquid filler material to a solid state. After the filler material is cured, the tape may be removed from the viewing surface 32, to yield the completed unit having the viewing apertures and the associated cavities substantially flush-filled to the level of the viewing surface 32.

In summary, the present electroluminescent semiconductor apparatus according to the invention can provide a display which has a substantially uniformly illuminated surface using an electroluminescent semiconductor which may be either top-emitting, side-emitting, or both.

The display may be formed of one or more cavities of selected shapes which are filled with epoxy and glass. This provides diffuse reflection which eliminates the necessity of deposition of metal on the walls surrounding the light-emitting semiconductor with concomitant savings in fabrication costs. Also, the preferred white color of the diffusely reflecting cavity walls absorbs less light than conventional specularly reflecting walls of deposited metal. The blackened upper and lower outer surfaces of the body surrounding the cavity reduce the transfer of light from one cavity of the display to an adjacent cavity of the display. In accordance with the processing of the present invention, no roughening of the upper surface of the material which fills the cavity is necessary. The material which fills the cavity may have an index of refraction close to that of the electroluminescent semiconductor device for assuring efficient transfer of light out of the semiconductor device.

In addition, the processing of the present invention provides for complete filling of the body and centrifuging of the filler material into all cavities of the body before the base or lead frame is introduced and before the entire assembly is heat treated to cure the liquid filler material. This greatly simplifies alignment and assembly of parts and facili-

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selected intermediate plane are each planar; and the four side walls of the cavity between the lower surface and the selected intermediate plane are each planar.

- 5 7. Apparatus according to any one of claims 1 to 4 wherein the shape of the cavity at the upper surface of the body is a first rectangle having a length h and a width i ; and the shape of the cavity at the lower
10 surface of the body is a second rectangle having a length j and a width i where $h > i > j$.

- 15 8. Apparatus according to any one of the preceding claims wherein the lower surface of the body in the region surrounding the cavity is substantially absorptively opaque for absorbing light in the region of said lower surface.

- 20 9. Apparatus according to any one of the preceding claims wherein the optically transmissive material is an epoxy resin.

- 25 10. Apparatus according to any one of the preceding claims wherein the discrete particles are grains of powdered glass.

- 30 11. A method of forming an electroluminescent semiconductor apparatus having a plurality of shaped cavities forming illuminatable regions, the method comprising the steps of: forming a body including the shaped cavities each of which traverses the thickness of the body from a viewing surface thereof through the body to the opposite surface thereof; filling the cavities of said body with a heat-curable, optically-transparent
35 liquid filler material having optical scattering centers dispersed therethrough; embedding on electroluminescent semiconductor device in the liquid filler material within each cavity from said opposite surface of the body; and
40 curing said liquid filler material to a substantially solid state.

- 45 12. A method according to claim 11 wherein the steps of filling the cavities of the body include the additional steps of: forming a liquid-impervious barrier across each cavity substantially flush with the viewing surface of the body; exerting force on the liquid filler material to completely fill

the cavities within the region between the viewing surface and said opposite surface of said body; and introducing said electroluminescent semiconductor device and connections therefor into the liquid filler material near said opposite surface of the body each in line with a respective cavity.

- 55 13. A method according to claim 12 wherein the step of exerting force on the liquid filler material includes the step of: subjecting the liquid filler material in the body to a centrifugal force aligned substantially normal to the viewing surface in a direction from said opposite surface of the body toward the viewing surface of said body.

- 60 14. A method according to claim 13 wherein said step of exerting force includes: subjecting the liquid filler material to a centrifugal force in excess of 10 G.

- 65 15. Apparatus according to claim 1 substantially as hereinbefore described with reference to:

- (a) Figures 4A and 4B of the accompanying drawings;
(b) Figures 5A and 5B of the accompanying drawings;
(c) Figures 6A and 6B of the accompanying drawings; or
(d) Figure 7 of the accompanying drawings.

- 80 16. A method according to claim 11 substantially as hereinbefore described with reference to:

- (a) Figures 4A and 4B of the accompanying drawings;
(b) Figures 5A and 5B of the accompanying drawings;
(c) Figures 6A and 6B of the accompanying drawings; or
(d) Figure 7 of the accompanying drawings.

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