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(54) **Method and device for sealing of a thin film electroluminescent device**

(57) A method of forming a seal for a thin film electroluminescent device (10) includes using deposition techniques (36) to form an integral thin film encapsulating layer (26; 28). Plasma enhanced chemical vapor deposition is utilized, allowing the formation of the seal to take place at substantially room temperature. A pre-

bake (34) is performed at an elevated temperature in an evacuated environment prior to the formation of the thin film encapsulating layer. A silicon nitride film may be used as a single-film encapsulating layer, or may be used with another material (30) in the fabrication of a multi-film encapsulating layer.

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Description

The invention relates generally to thin film electroluminescent devices and more particularly to a method and structure for hermetically sealing such devices.

Thin film electroluminescent (TFEL) devices are employed in a variety of applications. For example, an array of TFEL devices may be used to form a printhead. A conventional TFEL device includes an active semiconductor layer sandwiched between two dielectric layers. Electrode layers are formed on the surfaces of the dielectric layers opposite to the active semiconductor layer.

A TFEL device is typically driven by an alternating current signal. Light is generated when the potential difference between the two electrode layers reaches a threshold voltage. Electroluminescence occurs in the active semiconductor layer when electrical current is passed through the layer. The electrical current excites the dopant material, e.g. manganese. The selection of materials for forming the active semiconductor layer determines the frequency of light emitted from the TFEL device.

TFEL devices include an hermetic seal to protect the thin film layers, particularly the active semiconductor layer. The hermetic seal isolates the layers from contaminants and moisture which would adversely affect a TFEL device. The primary concern is film degradation due to exposure of the layers to moisture. Humidity significantly shortens the useful-life of a TFEL device.

U.S. Pat. Nos. 5,017,824 to Phillips et al. and 4,951,064 to Kun et al. describe sealing structures for forming contaminant-free environments for TFEL devices. A glass package is formed over the device to provide a chamber into which an oil is filled. For example, a silicon oil may be used.

While liquid-filled packages for TFEL devices have functioned well over the years, there are concerns. Firstly, a packaging assembly that requires forming and filling a leak-proof cavity adds significantly to the expense of a TFEL array. Moreover, the packaging interferes with establishing a simple array and lens system, and may complicate the task of achieving adequate lightbeam performance characteristics. Another concern is that such a package may adversely affect manufacturing yields of TFEL devices. Life-test results indicate widely varying results in seal integrity.

Attempts have been made to provide liquid-free seals for TFEL devices. U.S. Pat. No. 4,767,679 to Kawachi describes a seal comprised of an inner layer made of a thermoplastic resin and an outer, moisture-proof film that is heated and then press-bonded at its periphery to the substrate that supports one or more TFEL device. That is, the moisture-proof film must be aligned, heated and press-bonded to the substrate. U.S. Pat. No. 5,194,027 to Kruskopf et al. describes a seal formed by spreading a gel material over the active area of a TFEL panel and pressing a protective cover onto

the gel material so as to squeeze excess gel material from underneath the protective cover. The gel material is then cured to a predetermined degree of hardness. Finally, the protective cover is sealed against the TFEL panel with an adhesive vapor barrier. Another liquid-free seal assembly is described in U.S. Pat. No. 5,258,690 to Leksell et al. This seal assembly is an adhesive coating of solid clear material to encapsulate the light-emitting portion of the TFEL device.

While liquid-free seal assemblies of TFEL devices are known, the oil/glass packaging remains as the conventional assembly for hermetically sealing such devices. The concern with the known liquid-free seals involves the tendency of defects to propagate. In the industry, solid seals are considered to be less efficient in "self-healing," i.e. self-limiting with respect to propagation of burnouts caused by short circuits. The above-identified patent to Kruskopf et al., for example, identifies the concern of limiting the self-healing effects if the liquid-free packaging material covering the panel is too hard.

What are needed are a method and structure for forming the seal of a thin film electroluminescent device which reduce the expense and complexity of forming such a device without adversely affecting the manufacturing yield and/or the useful-life of the device.

Summary of the Invention

Thin film deposition techniques are employed to form a thin encapsulating layer on a thin film electroluminescent (TFEL) device. In the preferred embodiment, the encapsulating layer is deposited utilizing chemical vapor deposition (CVD) techniques. Ideally, the thin encapsulating layer is deposited by plasma enhanced CVD, since such deposition allows the TFEL device to remain at a relatively low temperature during deposition. Moreover, plasma enhanced CVD is suitable for depositing an encapsulating layer of silicon nitride, with a low pinhole density and an adequate step coverage.

The first step is to form the TFEL device. While not critical to the invention, the conventional TFEL device includes an active semiconductor layer between two dielectric layers and opposed electrode layers. The five thin-film layers are formed on a substrate. It has been discovered that subjecting the TFEL device to a bake-out prior to depositing the encapsulating layer significantly improves the results of performance during life tests. That is, a greater percentage of devices exhibit desired performance characteristics if a pre-bake is performed in order to reduce moisture and other absorbed materials within the thin films to be encapsulated. The bake-out preferably takes place in an evacuated environment.

In the preferred embodiment, the TFEL device is an edge emitter device and the thin film encapsulating layer extends over the emitting edge. However, the utility of this invention is in no way limited to edge emission de-

vices, but may as readily be used on face emitting TFEL devices. Silicon nitride provides the desired properties, but silicon oxinitride, zinc sulfide plus silicon oxinitride, or aluminum nitride may be substituted.

The encapsulation is typically formed of a single layer. The bake-out is typically performed in an evacuated environment, but may be performed in a properly selected gas environment. However, multi-layer encapsulation is also contemplated.

An advantage of the invention is that a moisture-proof TFEL device may be formed without significantly increasing the expense or manufacturing complexity of the device.

Brief Description of the Drawings

Fig. 1 is a side sectional view of a thin film electroluminescent device formed in accordance with the invention.

Fig. 2 is a side sectional view of the thin film electroluminescent device of Fig. 1 having a thin film encapsulating layer in accordance with the invention.

Fig. 3 is a side sectional view of a second embodiment of an encapsulating structure in accordance with the invention.

Fig. 4 is an illustration of the method steps for forming the electroluminescent device of Fig. 3.

With reference to Fig. 1, a TFEL device 10 includes a multi-layer structure on a substrate 12. The substrate 12 may be formed of a transparent material, such as glass, but this is not critical.

A thin film active semiconductor layer 14 is sandwiched between an upper dielectric layer 16 and a lower dielectric layer 18. An acceptable material for forming the active semiconductor layer 14 is zinc sulfide that is doped with manganese. The dielectric layers may be silicon oxinitride, but other materials may be selected.

A drive signal is connected across an upper electrode layer 20 and a lower electrode layer 22. Typically, a TFEL device 10 is driven by an alternating current drive signal. Light is generated when the voltage across the TFEL device reaches a threshold voltage. Electroluminescence occurs in the active semiconductor layer 14 when electrical current is passed through the layer. The electrical current excites the electrons of the dopant material. The selection of materials for forming the active semiconductor layer determines the frequency of light emitted from the TFEL device.

The electrode layers 20 and 22 may be formed of indium tin oxide (ITO). ITO is an electrically conductive, optically transparent material for use in such applications as flat panel displays. Optionally, one or both of the electrode layers 20 and 22 may be optically opaque. In fact, in the preferred embodiment, the TFEL device 10 is an edge emitter device for radiating light from a forward edge 24. Edge emitter TFEL devices are designed to retard light radiation from the major surfaces of the devices. Typically, the substrate 12 supports an

array of TFEL devices, allowing the device to be used in such applications as printing.

Each of the layers 14, 16, 18, 20 and 22 is a thin film layer. "Thin film" is defined herein as a film having a maximum thickness of 15 microns. The layers may be formed using thin film deposition techniques known in the art. For example, electron beam evaporation or sputtering may be utilized.

Referring now to Fig. 2, an encapsulating layer 26 is deposited upon the upper surface of the TFEL device 10. In the preferred embodiment, the encapsulating layer is a silicon nitride layer deposited by plasma enhanced chemical vapor deposition (PECVD). An acceptable thickness is 4000 Å. PECVD utilizes radio frequency-induced glow discharge to transfer energy into a reactant gas, thereby allowing the substrate 12 to remain at a relatively low temperature. Room-temperature deposition is possible, so that the substrate and the layers 14-20 remain thermally stable during the formation of the encapsulating layer 26. PECVD is a technique in which deposited films have a low pinhole density and a good step coverage. Thus, the downward step from the upper electrode layer 20 to the surface of the substrate 12 is achieved without creating gaps.

Silicon nitride is the preferred material, but other materials may be substituted for forming the encapsulating layer 26. For example, silicon oxinitride, zinc sulfide plus silicon oxinitride, and aluminum nitride have been found to exhibit the desired characteristics for an encapsulating layer. Moreover, integrated circuit fabrication techniques other than PECVD may be used to form the encapsulating layer. Physical vapor deposition offers many of the same advantages afforded by PECVD.

If the TFEL device 10 is an edge emitter device and the encapsulating layer 26 is to cover the radiating surface, the encapsulating layer must be optically transparent. Moreover, the index of refraction of the encapsulating material must be considered. Preferably, the index of refraction of the encapsulating layer is matched to the index of refraction of the active semiconductor layer 14. Also, the thickness may be constrained by the desired spectra of the device. However, there may be some applications in which a mismatch achieves desired results.

Referring now to Fig. 3, in a second embodiment, the encapsulating layer is a multi-film structure. A lower film 28 may be selected for its desired characteristics with respect to hardness. An upper, capping film 30 can then be formed to fill and/or cover any pinholes that may be created during the deposition of the lower film 28. In this manner, the moisture impermeability of the structure is improved. As an example, a polycrystalline material, such as zinc sulfide, which has been shown to have excellent resistance to pinhole formation, or polymeric materials may be used to form the lower film 28. The capping film 30 may then be silicon nitride. Capping of polymeric films under controlled-stress conditions is possible, because of the use of a room-temperature deposi-

tion system.

Referring now to Fig. 4, the steps of fabricating the structure of Fig. 3 begin with the formation 32 of a TFEL array. This step may be performed using any of the known techniques for forming thin films on a substrate. In the preferred embodiment, the TFEL array is then subjected to a bake-out 34. For example, a 30-minute bake-out at 250°C in an evacuated environment has been used to fabricate TFEL arrays in which a high percentage of light-emitting devices have survived a life test of more than 1000 hours at 45°C and 85% relative humidity. The bake-out at an elevated temperature in an evacuated environment provides outgassing that acts against sealing in moisture or other volatile substances when the encapsulating layer is introduced. The bake-out may also be performed in a controlled gas environment.

Still describing the preferred embodiment, PECVD encapsulation 36 seals the TFEL array. The bake-out step 34 and the physics of PECVD substantially overcome the problem of propagating defects typical of prior art solid sealing structures. The final step is one of depositing 38 the capping layer. However, the PECVD encapsulation may be a step that takes place after formation of a lower layer in a multi-film encapsulating structure.

Claims

1. A method of forming a seal for a thin film electroluminescent device (10) comprising the steps of:
 - providing a thin film electroluminescent device having a plurality of layers (14, 16, 18, 20 and 22), including an active semiconductor layer (14), said thin film electroluminescent device having a first surface; and
 - using integrated circuit fabrication techniques (36) to encapsulate said thin film electroluminescent device, including forming an integral thin encapsulating layer (26; 28) on said first surface and on at least one edge (24) of said thin film electroluminescent device such that said active semiconductor layer is sealed from a surrounding atmosphere by said thin encapsulating layer formed using integrated circuit fabrication techniques.
2. The method of claim 1 wherein said step of using integrated circuit fabrication techniques (36) to encapsulate said thin film electroluminescent device (10) includes forming (38) at least one additional thin film layer (30) atop said integral thin encapsulating layer.
3. The method of claim 1 or 2 wherein said step of forming said thin encapsulating layer (26; 28) includes utilizing chemical vapor deposition techniques (36).
4. The method of claim 1 or 2 wherein said step of forming said thin encapsulating layer (26; 28) includes utilizing physical vapor deposition techniques.
5. The method of claim 1, 2, 3 or 4 further comprising pre-baking (34) said thin film electroluminescent device (10) prior to said step of forming said thin encapsulating layer (26; 28), said pre-baking being performed in an evacuated environment and at elevated temperatures.
6. The method of claim 1, 2, 3 or 4 further comprising pre-baking (34) said thin film electroluminescent device (10) at elevated temperatures and in a dry environment prior to said step of forming said thin encapsulating layer (26; 28).
7. The method of claim 3 wherein utilizing chemical vapor deposition techniques (36) includes plasma enhanced chemical vapor depositing a dielectric material (26; 28).
8. An electroluminescent device (10) comprising:
 - a substrate (12);
 - a layer stack (14, 16, 18, 20 and 22) supported on said substrate, including a thin film active layer (14) which generates light in response to conduction of electrical current and first and second thin film electrode layers (20 and 22) on opposed sides of said active layer, at least one of said electrode layers being spaced apart from said active layer by a thin film dielectric layer (16 and 18); and
 - a thin film encapsulating layer (26; 28) formed on said layer stack, said encapsulating layer being a nitride layer, said encapsulating layer extending across said layer stack on a side opposite to said substrate and coating at least one edge (24) of said active layer to seal said edge from a surrounding atmosphere.
9. The device of claim 8 wherein said encapsulating layer (26; 28) is silicon nitride.
10. The device of claim 8 further comprising a capping layer (30) coating said encapsulating layer (28), said capping layer being formed of a material that is substantially moisture-impervious.

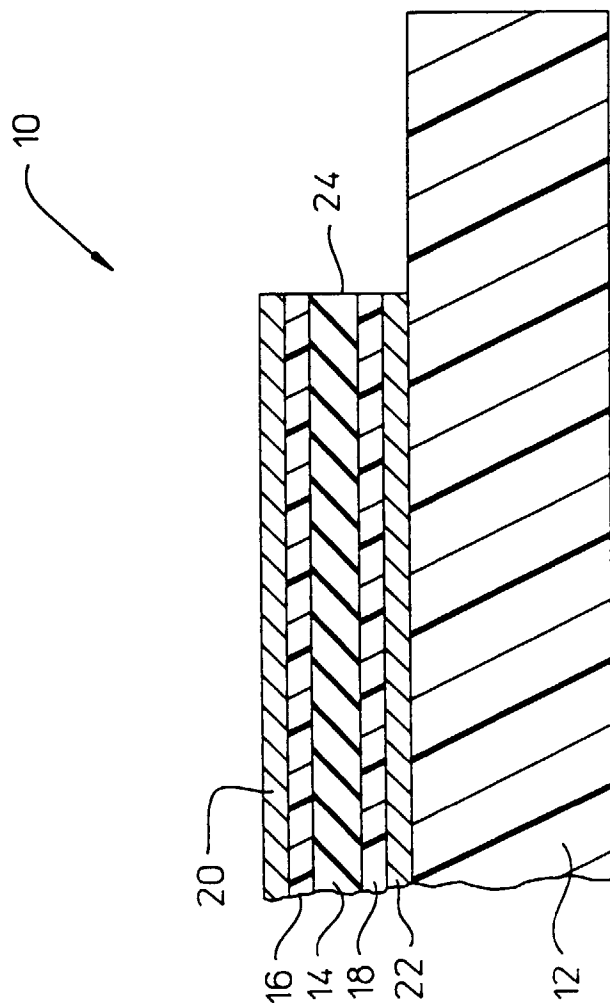


FIG. 1

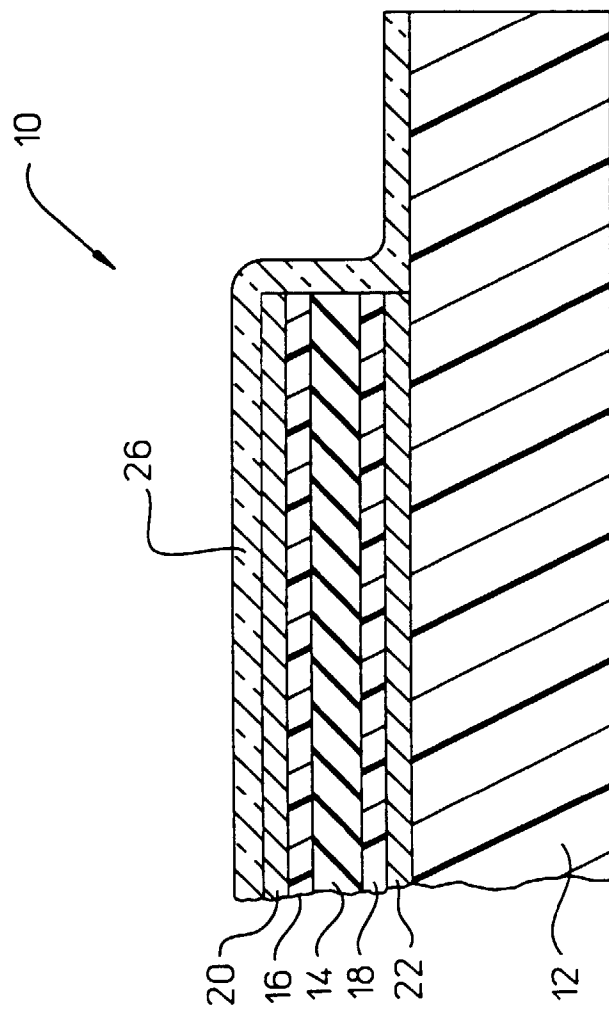


FIG. 2

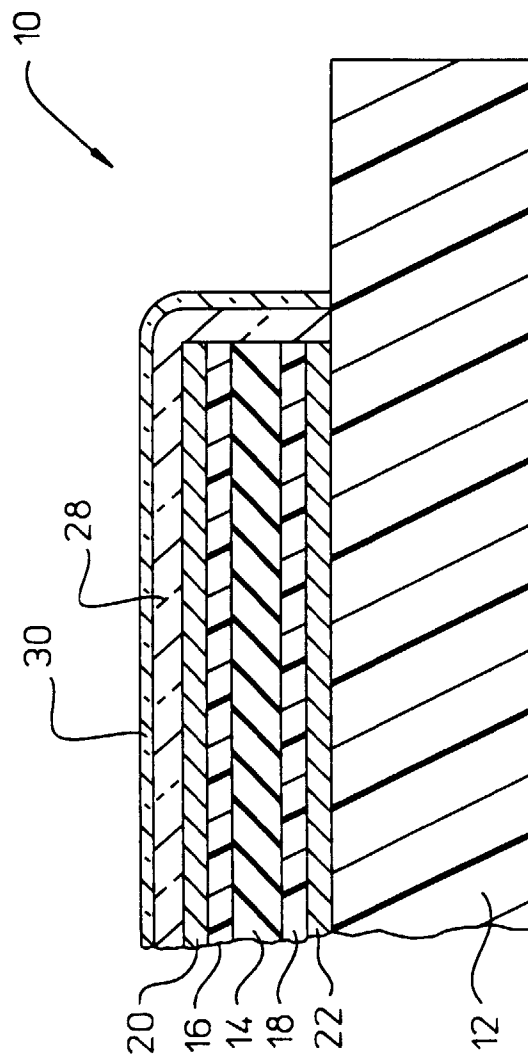
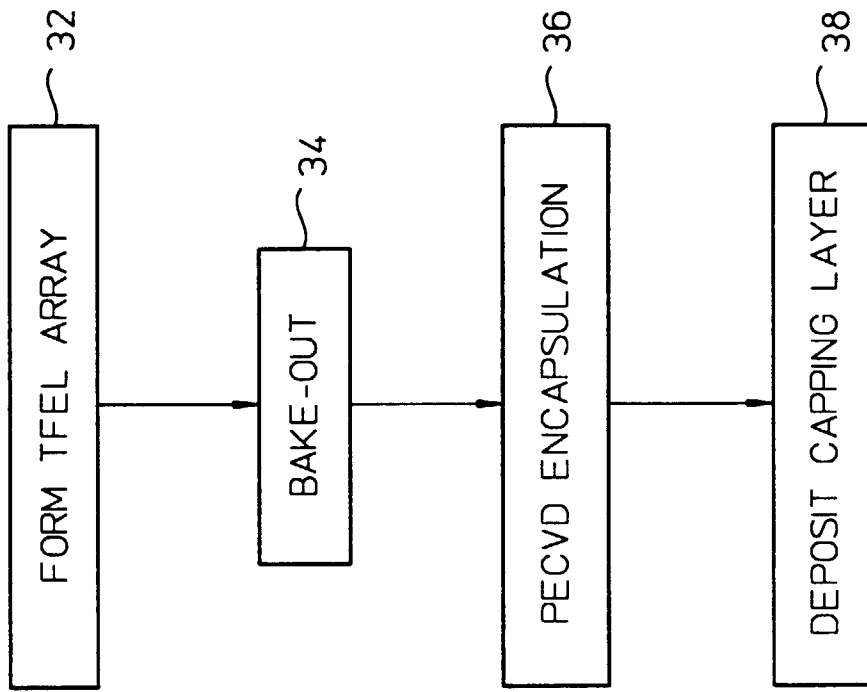


FIG. 3

**FIG. 4**