前瞻軟性顯示器之機械力學行為研究

Mechanical Behavior Investigation of Advanced Flexible Displays

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摘要(Abstract)

有機發光二極體(organic light-emitting diode, OLED)顯示元件不僅具有發光角寬、螢幕可觸控，和攜帶輕便等獨特的性能表現，而且亮度較傳統顯示元件更高且益加輕薄。這些優異性能致使有機發光二極體顯示元件備受下一世代的軟性電子產業青睞。由於有機發光二極體顯示元件在操作應用中經常會遭受到高強度的彎曲負載，仔細評估一個內嵌有機發光二極體元件的封裝結構其維持在高發光效率之長時使用壽命下，其可能出現之失效模式則是必需的。有鑑於此，本研究基於薄膜力學理論推導出了適用於多層堆疊式軟性薄膜的解析解，藉由此通解估算有機發光二極體元件封裝結構內部每層的彎曲應力大小和其分佈狀況；並可精準地預測出有機發光二極體元件的失效發生的可能性。另外，前述之力學模型的可靠度已經通過基於大變形假設的非線性有限元素模擬和相關的實際實驗驗證。在不同的彎曲半徑下，堆疊薄膜結構厚度方向上的中性軸精確位置、剛度，和每層薄膜的相關應力分佈皆能可由解析解予以估算。由於每層薄膜材料的厚度和楊氏係數大小為影響堆疊薄膜式有機發光二極體元件所受之應力幅度的主要因素，故本研究對帶有蓋板的有機發光二極體封裝結構進行參數化分析，用以分析由薄膜材料特性導致之可撓機械力學行為，其結果可作為前瞻軟性電子元件之長時可靠度分析與發展的參考準則。

Organic light-emitting diode (OLED) displays have absolute representatives, namely, wide viewing angles, portability, touchscreen capability, and are thinner and lighter than conventional displays. Such characteristics make OLED displays one of the favorite features for next-generation flexural electronics industries. In order to possess high luminous efficiency and accomplish long-duration utilization, the probable failure modes of OLED devices that are inserted into the packaging framework need to be comprehended because a high flexural load is constantly applied to the construction. These failure modes can be interpreted by predicting the profile and evaluating the magnitude of flexible stress in multi stacked films of OLED devices, respectively. Accordingly, this research presents an analytical solution which is on the basis of thin film mechanics for flexible multi-stacked films. Furthermore, a nonlinear finite element analysis (FEA), based on the supposition of a large deformation, and associated testing measurements are adopted to demonstrate the reliability of the mechanical model. Under dissimilar radii of flexural curvatures, the accurate location of the neutral plane alongside the orientation of total thickness, stiffness, and affiliated stress distribution of each layer is calculated by utilizing the derived formula; the result has a good agreement with that predicted by FEA. The Young's modulus and thickness of each stacked layer are the important factors that influence the stress extent and flexibility of the OLED device packaging structure. To illustrate the mechanical response induced by the intrinsic material characteristics of stacked films, a parametric analysis of a cover plate within an OLED packaging framework is performed. The analytic results can be regarded as a guideline to the development of advanced flexible electronics with a long lifespan and mechanical reliability.

1. 前言

1.1 可撓式顯示元件之產業市場需求

近年來隨著科技進步，桌上型個人電腦、筆記型電腦乃致於智慧型手機和平板電腦的普及化，這些不斷進步的科技產品帶動了顯示元件及其相關產業飛躍式的發展。目前市面上之主流技術為液晶顯示元件(liquid crystal display, LCD)，而在前瞻技術之平面顯示元件中，有機發光二極體(organic light-emitting dioide, OLED)顯示技術吸引了產業及學術界的密切關注，進而從事相關之開發與研究。含有機發光二極體可撓式元件跟傳統顯示元件材料及結構最大的不同點是，有機發光二極體為利用薄膜技術將材料沉積或蒸鍍多層薄膜結構於一可撓式軟性基板上，有助於把大螢幕顯示元件摺疊成小體積，且由於元件具一定程度之可撓性，因此可運用在穿載式之智慧型元件上，如 Google 眼鏡、VR 顯示元件以及智慧型手錶等產品。此外，可撓式電子顯示元件還可以用捲曲之方式收納，其收納後之體積可以達僅有一支筆的體積，而展開後即可在任何一個平面上使用，屆時

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