五環素薄膜電晶體與主動式畫素架構

於前瞻顯示器應用之研究

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摘 要

五環素薄膜電晶體(Pentacene Thin Film Transistor)，屬於有機薄膜電晶體中的一種，自被發明以來，其進展迅速，短短十數年來，其重要的元件參數之一，載子遷移率就提升了數個等級，目前已經達到非晶矽薄膜電晶體的等級，約 1~5 cm^2/vs。但其特性與製程和傳統的非晶矽及複晶矽薄膜電晶體有相當多的不同之處，如五環素之間的分子結構主要以凡德瓦(Van der Waals)力相連結，而非共價鍵或離子鍵，因此其結構較為鬆散而存在許多缺陷。普遍認為，載子在分子內的傳遞為透過其特有的π電子軌域所形成之類能帶(Band like)傳輸而進行移動，而躍遷(Hopping)則為分子間的主要載子傳輸方式，這些綜合的效應導致了它較低的載子遷移率。另一方面，多數有機半導體為單一載子操作之材料，其薄膜電晶體多操作在聚積態(Accumulation mode)，因此在傳統矽基材的元件中常用的電流電壓公式，以及元件參數萃取方式須經過修改，才能應用於有機薄膜電晶體。

在本論文中，我們研究了五環素薄膜電晶體基本的操作特性，並進行元件參數的萃取。在眾多元件參數中，以載子遷移率(mobility)、整流比(on/off ratio)、次臨界斜率(Sub-threshold Slope)以及臨界電壓(Threshold Voltage)最為重要，其中又以載子遷移率及臨界電壓為主。我們採用各種萃取臨界電壓的方式，如定電流法、最大轉移電導法、均方根法等得到的數值，再與從電容電壓法所得到的數據

做比較，得到臨界電壓與五環素厚度呈現非線性關係的結果。經過檢驗後發現，這結果可能來自於非意圖的摻雜與五環素層中的缺陷造成臨界電壓的偏移，我們提出了一個可能的理論模型，並與實驗結果作一比較，得到相當良好的理論匹配。

此外針對五環素薄膜電晶體操作時對環境敏感的特性，我們量測了在不同氣氛下的元件特性，針對其在線性區與飽和區載子遷移率的變化作分析，觀察到隨閘極偏壓而改變的載子遷移率，同樣的現象也在複晶矽薄膜電晶體中出現。利用 Levincen Model 以及晶界能障理論(Grain Boundary Barrier Model)，可以得出在不同的氣氛下位於晶粒邊界中的缺陷密度，並得出空氣中的成分，特別是水氣會造成缺陷的增加，導致能障高度增加，進而降低載子於其中的傳輸速度。

前文考慮了五環素薄膜電晶體基本的參數定義與萃取方式，以及其對環境的敏感度。進一步考慮應用於顯示器上對元件的需求，因此我們同樣也量測了元件在局部區域的均勻度、對光的敏感性、以及可靠度、加上保護層之後的特性變化等等。將上列的各項因素加入主動式畫素設計的考量，我們設計出一以五環素薄膜電晶體驅動之液晶顯示器。

另一方面在本論文中，研究另一種新式的顯示器畫素架構，利用低溫多晶矽薄膜電晶體具有較好的元件特性以及耐溫性，我們提出一以兩顆薄膜電晶體以及一儲存電容之方式來驅動場發射奈米碳管顯示器，此一主動式畫素架構預計可提高顯示面板的均勻度，以及提升場發射顯示器的可靠度，並整合低溫多晶矽薄膜電晶體的優點局部整合驅動電路，進而降低周邊拉線的腳位。

我們考慮了各種影響五環素薄膜電晶體驅動液晶顯示器的因素，並成功設計製作出可展現影像之顯示器。同時提出新的主動式畫素架構，用以驅動場發射奈米碳管顯示器，同時也成功的設計製作出可展現影像之新式顯示器。

The Study on Pentacene Thin Film Transistors and the Active-Matrix Pixel Structure for Novel Display Applications

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Abstract

Pentacene Thin-Film Transistors (TFTs) had been improved dramatically over the last decade. The field effect mobility of pentacene TFTs has been raised several orders of magnitude (about 1-5 cm^2/vs) that almost overtook the value of amorphous silicon TFTs. Nevertheless, the fabrication technologies of pentacene TFTs are still not mature, yet. The detail mechanism of carrier transport and device modeling are also not fully understood. There are a lot of works to do before applying pentacene TFT based product to commercialization. The crystalline structure of pentacene is quite different from that of poly-silicon, such as the connection between pentacene molecules is mainly by van der waals powers, rather than covalent bond or ionic bond. Hence, the structure is loose and full of defects. The carrier transport of intra-molecular of pentacene is believed to be dominated by the band-like energy scheme formed by the specific π electron orbital. However, the carrier transport between inter-molecules of pentacene is governed by thermal hopping. Summing up the effects mentioned above, the lower field effect mobility of pentacene was deduced. Beside, most organic semiconductor TFTs only propose uni-polar operation and are biased in accumulation mode for TFTs. Thus, the extraction methods of device

parameters and the current-voltage equation for traditional TFTs must be modified to fit the real situation of pentacene TFTs.

In this dissertation, we study the basic electrical properties and also extract the device parameters of pentacene TFTs. Most of all, the field effect mobility, I_{on}/I_{off} ratio, sub-threshold slope and threshold voltage are the most important electrical properties. Even more, the mobility and threshold voltage are usually used to identify the performance of pentacene TFTs. The different methods such as the constant current method, maximum transconductance (Gm) method, and square root method were used to extract the threshold voltage. The obtained values were compared and verified with the data measured by the capacitance-voltage method. A non-linear result between threshold voltage and pentacene thickness was observed. After detail investigations, the threshold voltage variation behaviors might be caused by the unintentional dopant or defects of the pentacene film during fabrication. They could be calculated and modeled by estimating a bulk trap density. The proposed model got a good fit with theory and literature.

To detect the environmental sensitivity, the electrical properties of pentacene TFTs were measured under different atmospheres. The extracted mobility in linear and saturation regions was analyzed. The mobility was observed dependent on the gate bias. The phenomenon was also observed in poly silicon and CdSe TFTs. The Levincen Model and grain boundary barrier model were used to explain the gate bias dependent mobility. The trap density in the grain boundaries of pentacene TFT was obtained. The calculated result shows that the content of the normal air, especially humidity, could diffuse into the grain boundaries, change the trap density and increase the barrier height that would degrade the carrier transport of pentacene TFTs.

Since the extraction methods of device parameters and environmental sensitivity of pentacene TFTs were studied, further requirements of device characteristics for display applications, such as uniformity, sensitivity to illumination, reliability and passivation effect were also detail concerned. With integration of device considerations mentioned above, an active-matrix liquid crystal display driven by pentacene TFTs was designed and fabricated. It could demonstrate video image successfully.

In addition, a novel active-matrix pixel design was also investigated in this dissertation. The high performance and thermal stabile low-temperature poly silicon TFTs were used to drive a diode carbon nanotube field emission display. Two TFTs and one storage capacitor were adopted in one pixel. This pixel structure could perform a normally-on type active-matrix display. Active-matrix pixel structure was supposed to reduce the variation of field emission display and raise the uniformity of display. It also could lower down the anode voltage of field emission display that was supposed to increase reliability of phosphors and carbon nanotubes. Moreover, the partially system on panel due to the use of high performance poly silicon TFTs could be realized. That would reduce the complex of driving system.

In summary, we discussed every possible factor that influences the fabrication of active-matrix display driven by pentacene TFTs. We also successfully designed and fabricated a display capable of showing video images. We also proposed a novel pixel structure to drive the carbon nanotube field emissive display and realized it. It demonstrated video images successfully, too.