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矽基薄膜電晶體及氮化鎵高電子遷移率電晶體之電性

分析與物理機制研究

Investigation of Electrical Performance and Establishment of  
Physical Mechanisms for Silicon-Based Thin-Film Transistors

and Gallium Nitride High Electron Mobility Transistors

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## 致謝

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## 摘要

隨著環保需求和新興科技的快速發展，汽車產業正經歷深刻的技術變革，電動車和智能汽車的興起逐步改變了人們對車輛的定義和期望。在這一轉型過程中，車用顯示器元件和高功率元件成為重要關注對象。顯示器元件是駕駛者與車輛間的主要互動介面，不僅需精準呈現車輛的關鍵數據，如速度、能耗和導航資訊，還應滿足智能化、數字化的駕駛體驗，而高功率元件則對電動車的快充技術發揮著關鍵作用，快速充電要求元件能夠有效管理高能量輸入，縮短充電時間並提升效率，以增強電動車的日常實用性。

在顯示器元件方面，當前主流技術採用非晶矽 (amorphous-Si, a-Si) 或低溫多晶矽 (Low-Temperature Polycrystalline Silicon, LTPS) 作為薄膜電晶體 (Thin-Film Transistor, TFT) 的主動層材料。各種材料在成本與性能上皆有所差異，如 a-Si 具備低成本，但性能表現相對較低；而 LTPS 具備更高的電子遷移率和高性能表現，但製程成本較高。此外，可撓式顯示器技術的發展正使得聚醯亞胺 (Polyimide, PI) 等材料成為新興的基板選擇。這些材料不僅具備良好的熱穩定性和化學特性，還可以應用於溶液製程，實現更高的製程效率。

本論文在顯示器元件研究中，針對 TFT 提出了一種快速檢測元件品質的量測方法，解決了目前量測速度受限的問題。從元件結構和製程方面提出優化設計，確保在高溫、高濕度條件下的元件穩定運行。另外針對可撓式顯示器應用，本研究深

入分析了基於柔性聚醯亞胺基板的 TFT 物理機制，探討了其在彎折應用中的結構穩定性，為可撓式顯示器元件的商業化應用提供了理論依據和技術支持。

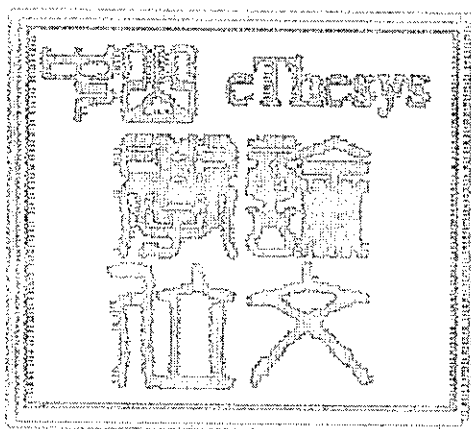
在高功率元件方面，本論文著重於氮化鎵（Gallium nitride, GaN）高電子遷移率電晶體（High electron mobility transistors, HEMTs）的性能優化。作為第三代寬能隙半導體材料之一，氮化鎵具有高擊穿電壓、高飽和電子速度以及二維電子氣的特性，使其在高功率、高頻率應用中擁有顯著優勢，被廣泛應用於功率放大器、開關器件和雷達等領域。為了進一步探索其在電動車快充中的應用，本研究針對光照對 GaN 元件性能的影響以及在不同環境壓力條件下的劣化行為進行了深入探討。

實驗結果顯示，氮化鎵元件在光照條件下會出現不同程度的性能波動，而在低氣壓環境下元件劣化速率顯著加快，這些發現為高功率元件的穩定性設計提供了依據。

此外，與碳化矽（Silicon carbide, SiC）材料相比，氮化鎵因具備更高的電子遷移率和更小的開關功率損耗，使其在高頻高功率應用中更具潛力。碳化矽雖然具有出色的高溫穩定性，但其表面散射機制的影響導致遷移率普遍偏低，限制了其在高頻應用中的發揮。

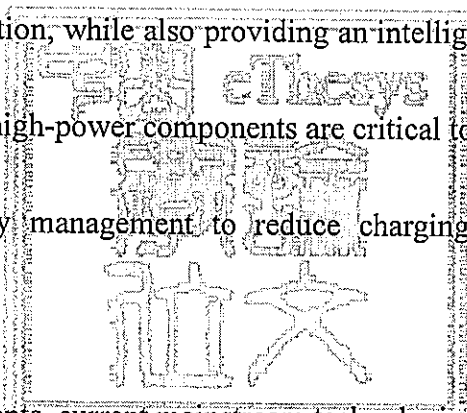
綜上所述，本論文通過對車用顯示器和高功率元件的性能優化和穩定性提升，為未來智能汽車和電動車技術的發展提供了理論支撐和技術指導。這些研究成果將在提升電動車高功率元件和車內顯示技術的應用中發揮至關重要的作用，不僅提高了駕駛體驗的數字化水平，還促進了車輛的安全性和使用便利性。

關鍵詞: 車用顯示器、薄膜電晶體、高功率元件、氮化鎵、可撓式顯示器、高電子遷移率電晶體



## Abstract

The automotive industry is undergoing a profound technological transformation driven by environmental demands and the rapid development of emerging technologies. The rise of electric vehicles (EVs) and smart cars has redefined public expectations of vehicles, highlighting the importance of automotive display components and high-power components. Display components serve as the primary interface between the driver and the vehicle, requiring precision in presenting critical data such as speed, energy consumption, and navigation, while also providing an intelligent and digitalized driving experience. Meanwhile, high-power components are critical to fast-charging technology, enabling efficient energy management to reduce charging times and enhance EV practicality.



For display components, current mainstream technologies utilize amorphous silicon (a-Si) or low-temperature polycrystalline silicon (LTPS) as the active layer materials for thin-film transistors (TFTs). Each material offers unique trade-offs in terms of cost and performance, with a-Si being cost-effective but relatively low-performing, and LTPS providing higher electron mobility and superior performance at a higher production cost. Additionally, advancements in flexible display technologies have introduced polyimide (PI) as an emerging substrate material due to its excellent thermal stability, chemical resistance, and compatibility with solution-based processes.



This research proposes a rapid quality assessment method for TFTs to overcome current measurement speed limitations, introducing structural and process optimizations to ensure device stability under high-temperature and high-humidity conditions. Furthermore, it explores the physical mechanisms of TFTs on flexible PI substrates, focusing on their structural stability under bending applications. These findings offer theoretical foundations and technical support for the commercialization of flexible display components.

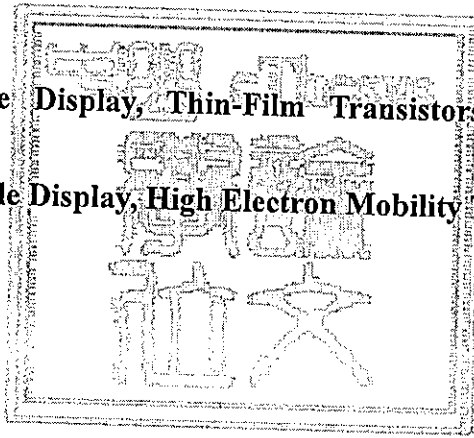
In the realm of high-power components, this study focuses on optimizing the performance of gallium nitride (GaN) high-electron-mobility transistors (HEMTs). As a third-generation wide-bandgap semiconductor material, GaN exhibits high breakdown voltage, high saturation electron velocity, and two-dimensional electron gas (2DEG) properties, making it advantageous for high-power and high-frequency applications such as power amplifiers, switching devices, and radar systems. This research investigates the impact of illumination on GaN device performance and its degradation behavior under various environmental stresses. Experimental results reveal performance fluctuations under illumination and accelerated degradation rates in low-pressure environments, offering insights into the stability design of high-power components.

Compared to silicon carbide (SiC), GaN demonstrates higher electron mobility and lower switching power losses, making it more suitable for high-frequency, high-power

applications. While SiC excels in high-temperature stability, its performance in high-frequency applications is limited by surface scattering mechanisms that reduce mobility.

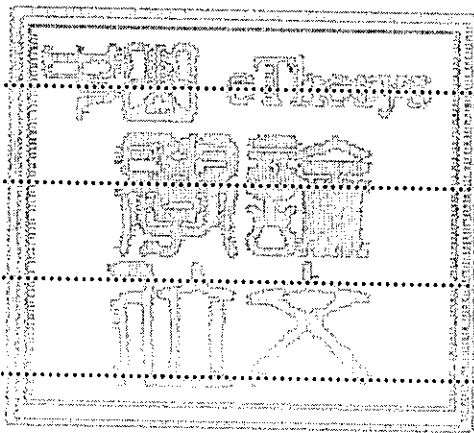
In summary, this dissertation advances the optimization and stability of automotive display and high-power components, providing theoretical and technical support for the development of smart cars and EVs. These findings contribute to the application of high-power components and in-vehicle display technologies, enhancing driving experiences, vehicle safety, and user convenience.

**Keywords: Automotive Display, Thin-Film Transistors, High-Power Devices, Gallium Nitride, Flexible Display, High Electron Mobility Transistors**



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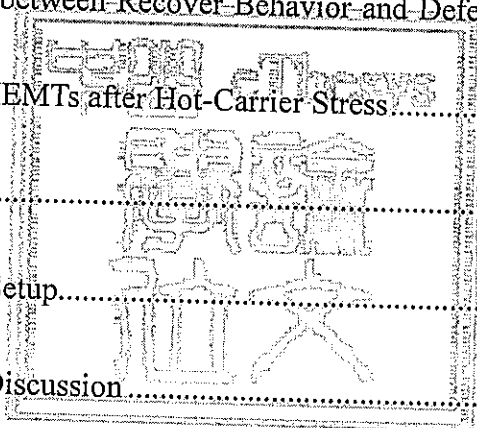
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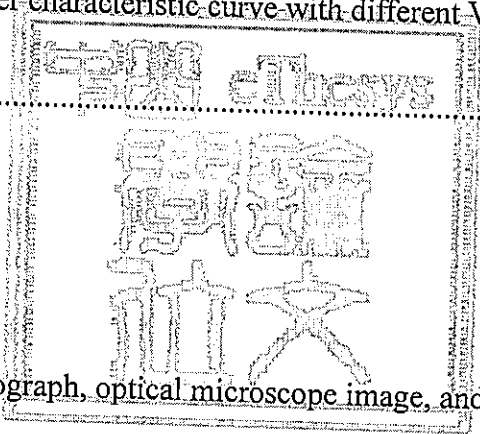
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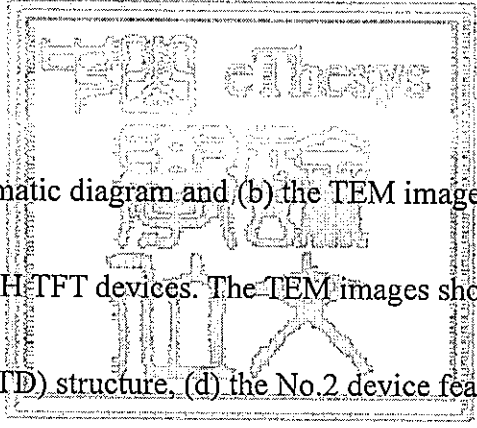
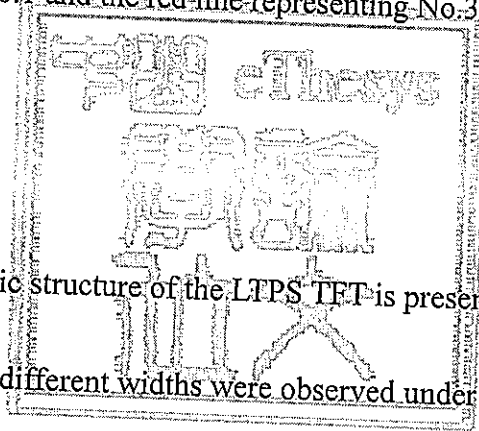


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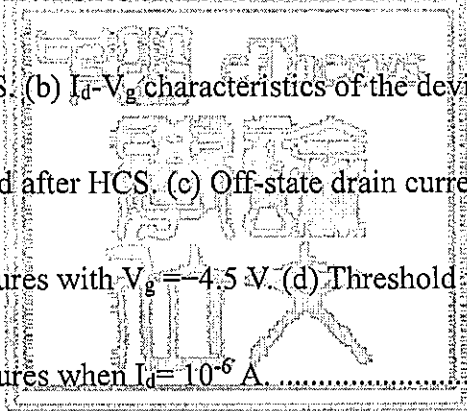


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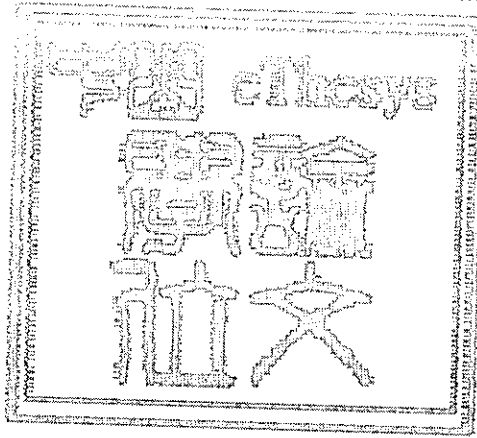
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## List of Acronyms

<i>a-Si</i>	Amorphous Silicon
<i>Poly-Si</i>	Polycrystalline Silicon
<i>TFT</i>	Thin-Film Transistor
<i>MOSFET</i>	Metal Oxide Semiconductor Field Effect Transistor
<i>HEMT</i>	High Electron Mobility Transistor
<i>G</i>	Gate
<i>S</i>	Source
<i>D</i>	Drain
<i>LCD</i>	Liquid Crystal Display
<i>OLED</i>	Organic Light Emitting Diode
<i>I<sub>D</sub> - V<sub>G</sub></i>	Transfer Characteristic Curve
<i>BCE</i>	Back Channel Etching
<i>PV</i>	Passivation
<i>GI</i>	Gate Insulator
<i>ILD</i>	Inter-Layer Dielectric
<i>DUT</i>	Device under Test
<i>PECVD</i>	Plasma Enhanced Chemical Vapor Deposition
<i>SiO<sub>x</sub></i>	Silicon Oxide
<i>SiN<sub>x</sub></i>	Silicon Nitride
<i>GaN</i>	Gallium Nitride
<i>AlGaN</i>	Aluminium Gallium Nitride
<i>TEM</i>	Transmission Electron Microscopy
<i>PBTS</i>	Positive Bias Temperature Stress