



非晶InGaZnO基薄膜晶体管研究

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IGZO研究背景介绍

a-IGZO TFT的优势

a-Si:H TFT的局限:

具有较低的迁移率($<1\text{cm}^2/\text{Vs}$)
低的光学透过率 ($E_g\sim 1.7\text{ eV}$)
光稳定性差等缺点限制了其应用前景.



Flexible LCD

a-IGZO TFT的潜在优势:

1. 高的沟道电子迁移率
2. 高的光学透过率 ($E_g>3.0\text{ eV}$)
3. 低的漏电流
4. 低的制备温度
5. 低成本



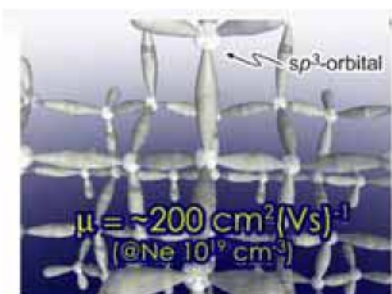
AMOLED

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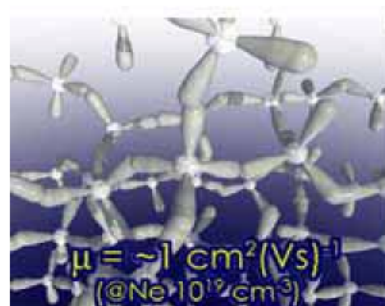
a-IGZO特殊的导电机制

共价半导体

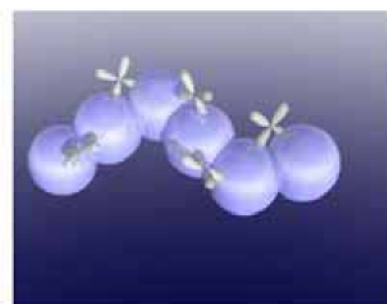
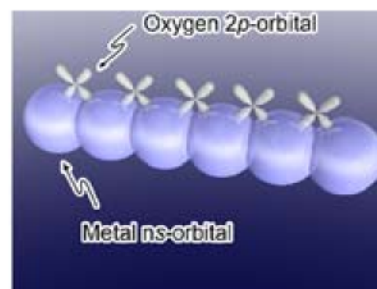
单晶



非晶



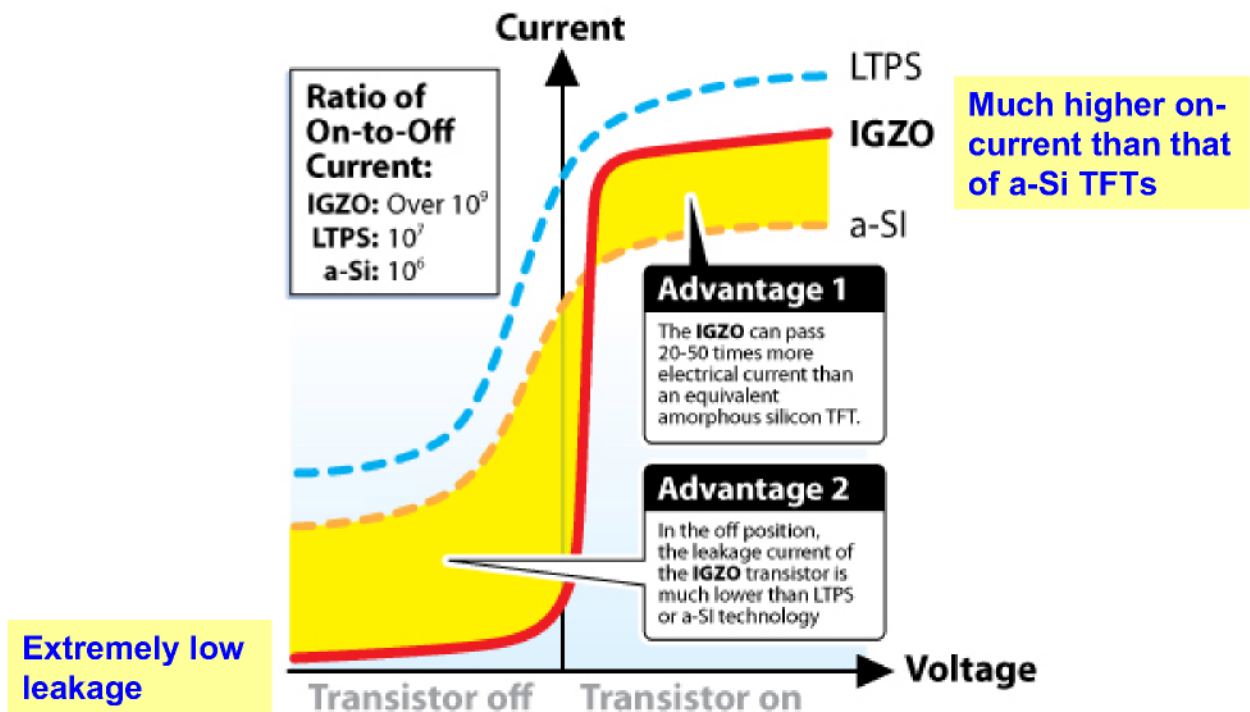
离子氧化物半导体



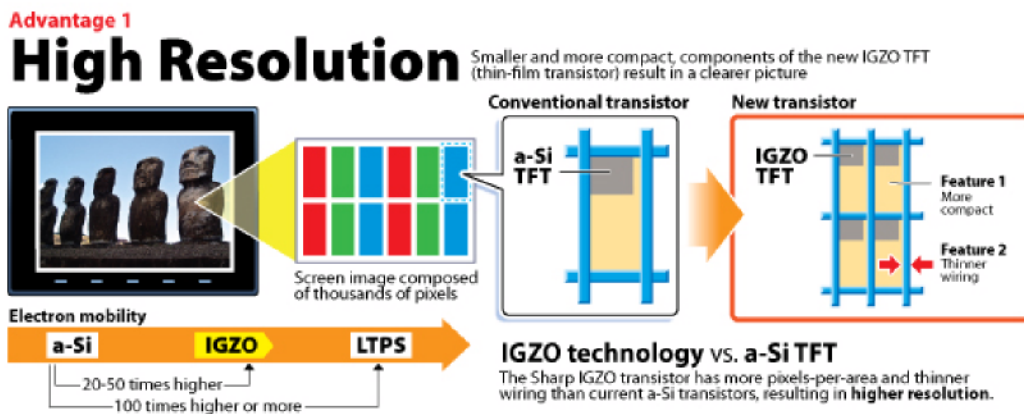
a-IGZO中金属的ns轨道交叠程度受晶格无序性的影响较小。

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Basic transfer I-V characteristics of IGZO TFTs



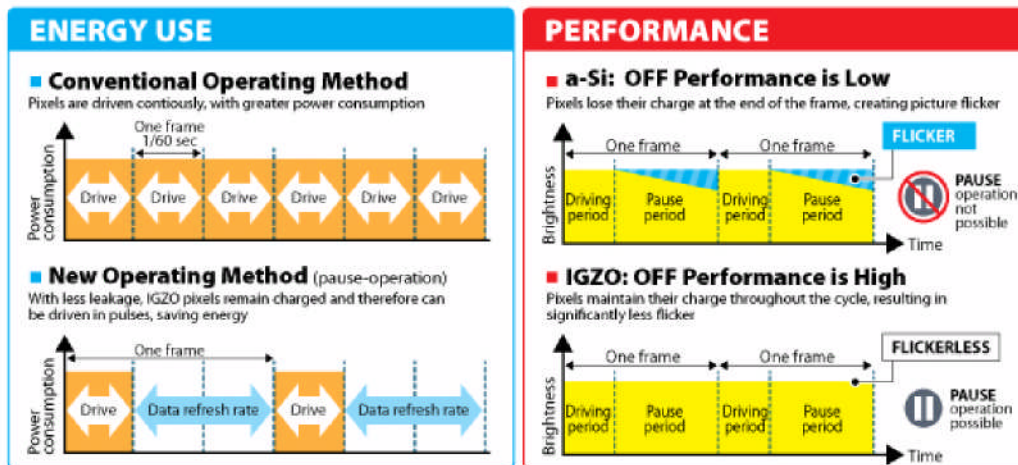
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- Since the electron mobility of IGZO is 30-50 times higher than that of a-Si, **the on-current of IGZO TFTs is considerably higher**. As a result, the IGZO transistor can be made smaller and the width of the signal line narrower.
- For LCD panels, the higher the resolution, the more difficult it is to achieve larger aperture ratio. But **the IGZO technology enables high resolution while keeping aperture ratio large**.
- Large aperture ratio is essential to retain brightness, or the body of the transistor would block too much light. It means **less back-lighting is needed**.

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Less Power Consumption



Most important advantage in my view!

- Currently, a panel needs to be refreshed or “driven” continually because leakage current causes the cell to discharge.
- Due to their ultra-low leakage, IGZO panels can retain their active state longer. It’s then possible to **save significant power by skipping drive cycles**.

A comparative study reported in 2012

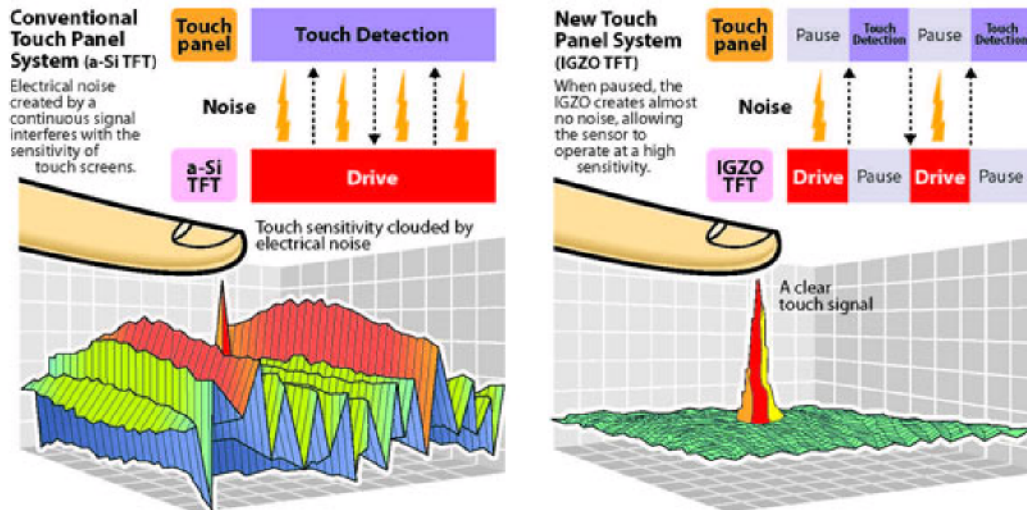


- Panel driving power is reduced by 62%;
- LED backlighting power is reduced by 50%;
- Approximately **56%** less power is used in standard operation with an IGZO LCD as compared to an a-Si LCD. **This will benefit hand-held and other battery-powered devices by dramatically extending battery life.**

Advantage 3

Less Noise Influence

The IGZO transistor creates almost no noise, which improves the sensitivity of touch-screen technology



- Noise is a natural byproduct of any transistor switching on and off, and the millions of them in a display create a steady background noise. Then the voltage spike caused by touching the panel is hard to detect.
- Because touch panel systems with IGZO will experience significantly less noise interference, the **touch-sensitive displays can become much more sensitive and accurate.**

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Industrial facts

- Until 2013 **Sharp** is the only company having commercialized IGZO panels.



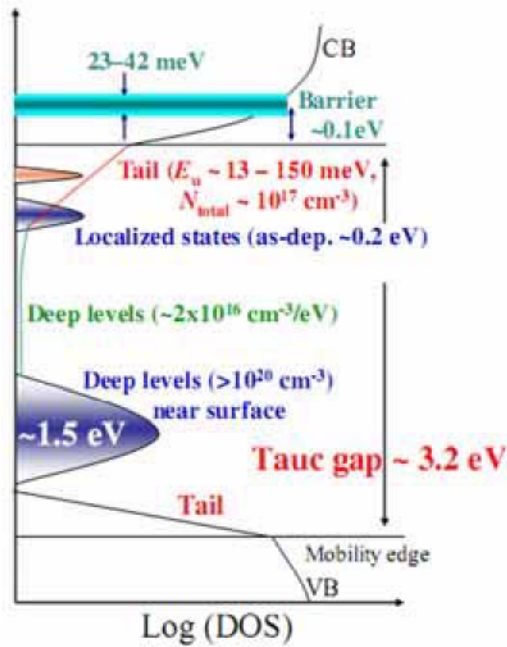
- **Apple** has been planning to use IGZO displays for its future iPads. But at present Sharp is unable to supply enough panels in time.



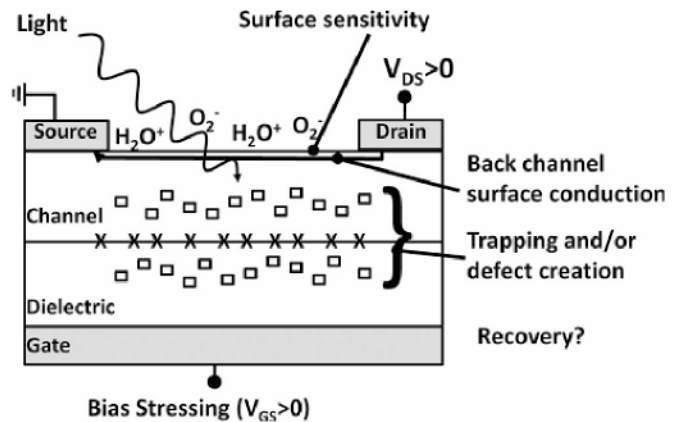
- Besides LCD panels, until 2013 99% OLED panels are produced by **Samsung**. Samsung invests significantly on IGZO technology, as its next generation OLED panels are expected to be driven by IGZO TFTs.

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a-IGZO TFT存在的科学与技术问题



a-IGZO中存在很高的缺陷态密度，界面问题复杂！



相对而言，a-IGZO TFT技术还非常不成熟：

1. 偏压条件下的稳定性
2. 光照条件下的稳定性
3. 气氛条件下的稳定性

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南京大学的工作

- 第一部分：a-IGZO TFT制备方面的探索
- 第二部分：开展了a-IGZO TFT的载流子输运机制与界面特性研究。
- 第三部分：开展了a-IGZO TFT在偏压和光照条件下稳定性退化机制的分析研究；同时通过实验方法改善了沟道与栅氧化层之间的界面质量，显著提高了器件在偏压条件下的稳定性。

• 国内开展相关研究的其他主要单位：北京大学、华南理工大学、上海交通大学、武汉大学、湖南大学等。

• 国内开展相关产业化研究的主要企业：京东方、熊猫电子、天马微电子、龙腾光电等。

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a-IGZO TFT的制备研究

a-IGZO薄膜的淀积

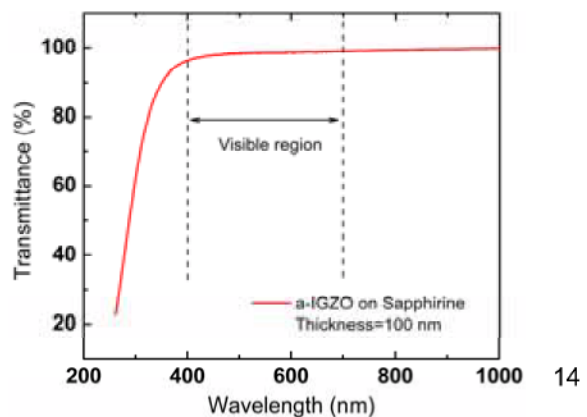
PLD



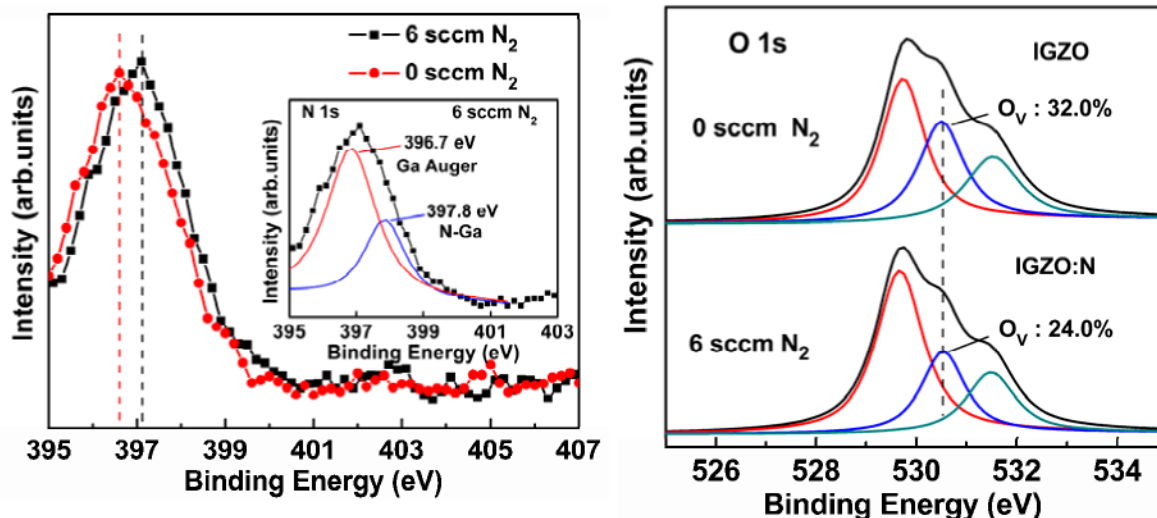
Sputtering



采用的 InGaZnO 靶材原子比为 In:Ga:Zn为 2:2:1，所获得的a-IGZO薄膜在可见光波段平均具有98%以上的透过率。

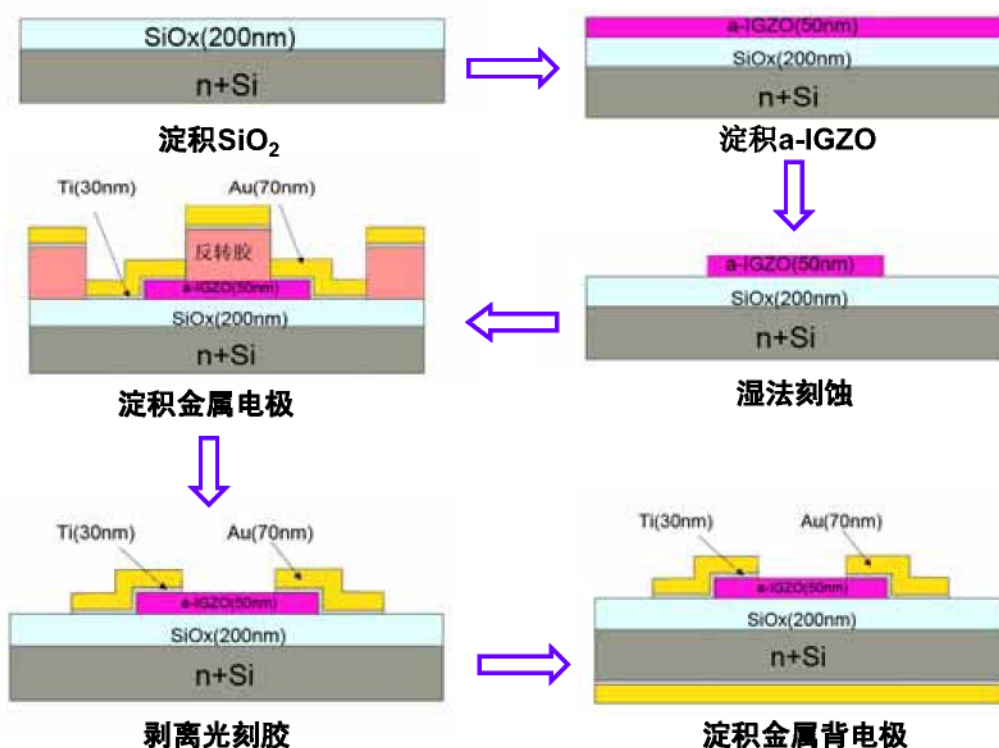


非晶IGZO:N的XPS表征

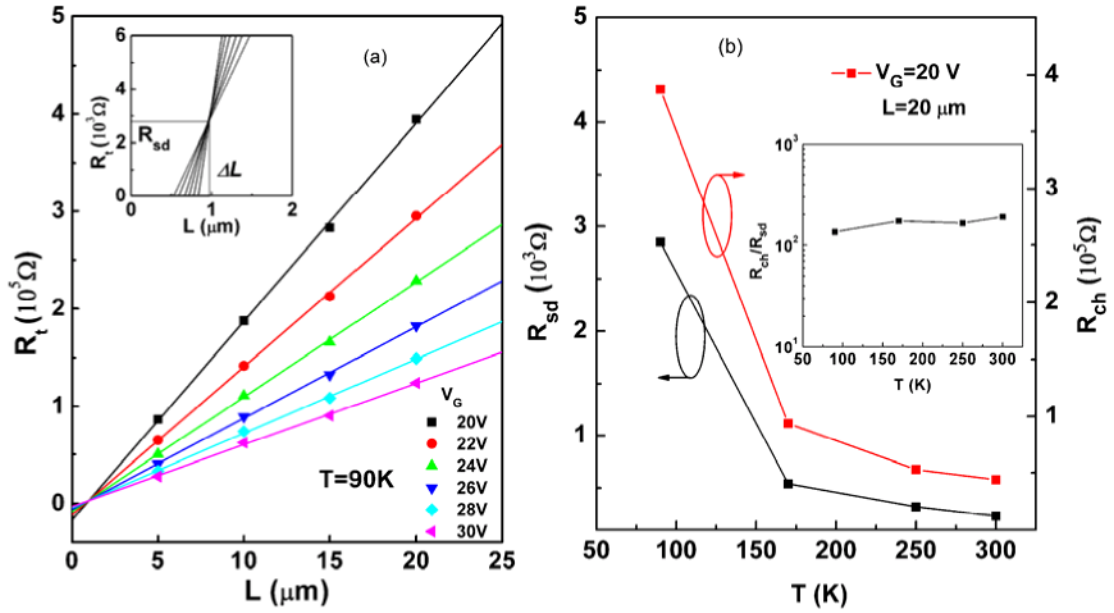


XPS测量技术不仅可以用来研究a-IGZO薄膜的化学键成键状态，还可以用来比较薄膜中特定缺陷态（如：氧空位）的相对浓度；进而从材料分析的角度上判断材料的质量和制备水平，并与潜在器件性能建立对应关系。

简化的导电硅衬底上背栅结构器件的制备过程



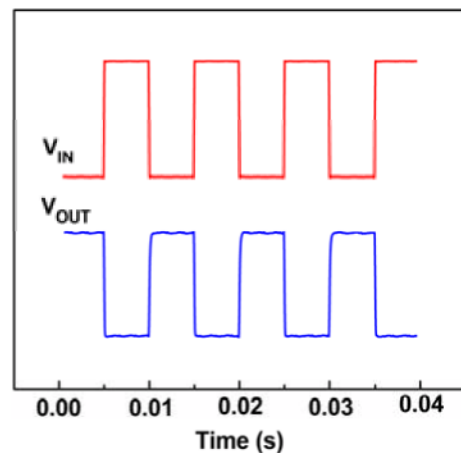
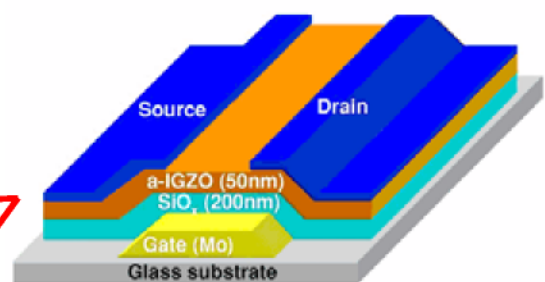
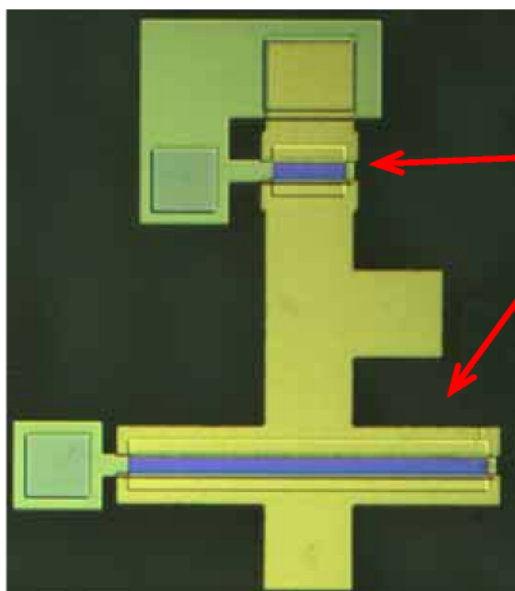
器件低接触电阻的实现



$$R_{\text{tot}} = \frac{V_{ds}}{I_{ds}} = R_{sd} + \frac{L - \Delta L}{\mu_{\text{eff}} C_{\text{ox}} W (V_{gs} - V_{th})}$$

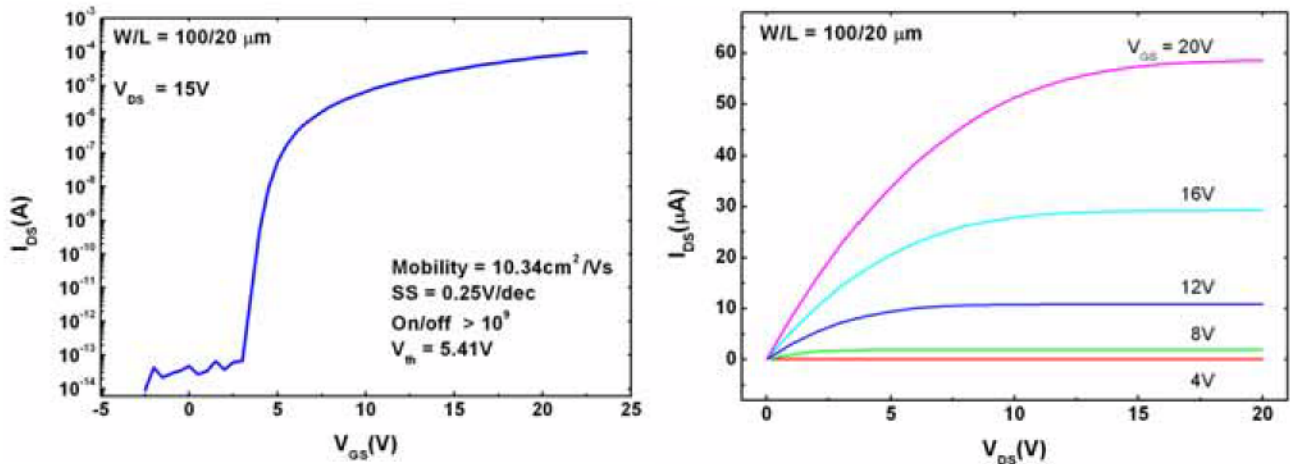
在研究的温度范围内，器件的源漏接触电阻远小于沟道电阻 ($<1\%$)

玻璃衬底上背栅结构器件与电路



研制的a-IGZO饱和负载反相器

南京大学研制的a-IGZO TFT典型器件性能指标



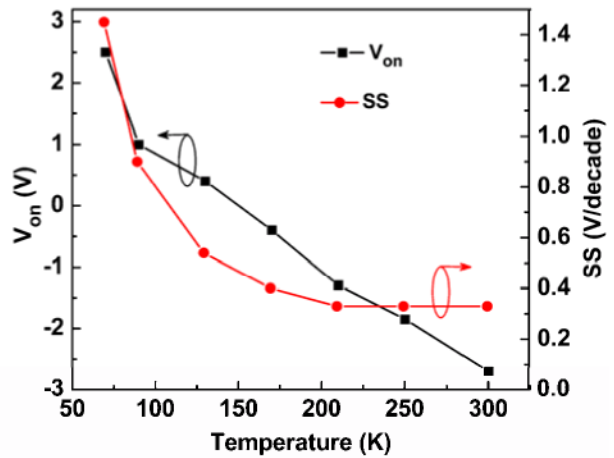
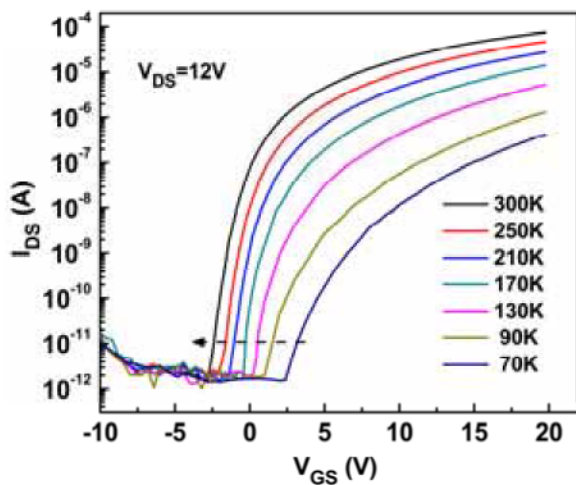
- 场电子迁移率 (field effect mobility) : **8-15 cm^2/Vs**
- 亚阈值摆幅 (sub-threshold swing) : **0.2-0.5 V**
- 开关比 (on/off ratio) : **10^8 - 10^9**
- 阈值电压: **根据实际情况可调**
- 关态漏电流: **小于1 pA**

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a-IGZO TFT的载流子输运机理与界面特性研究

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器件的变温转移特性

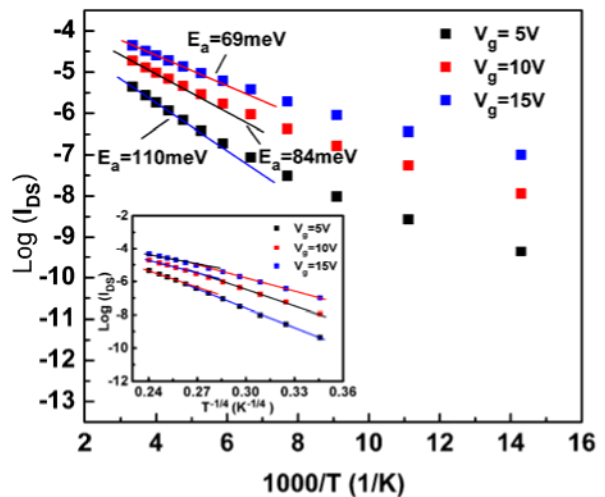
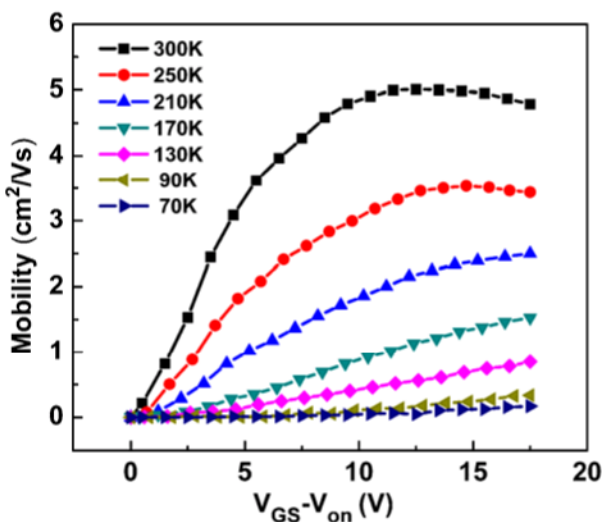


$$\Delta SS = \frac{\Delta N_t \ln(10) kT}{C_i}$$

亚阈值摆幅随温度的变化表明局域态的填充状态已经发生了变化，进一步说明a-IGZO TFT载流子的输运特性在不同温度和栅压条件也发生了改变。

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载流子输运特性分析

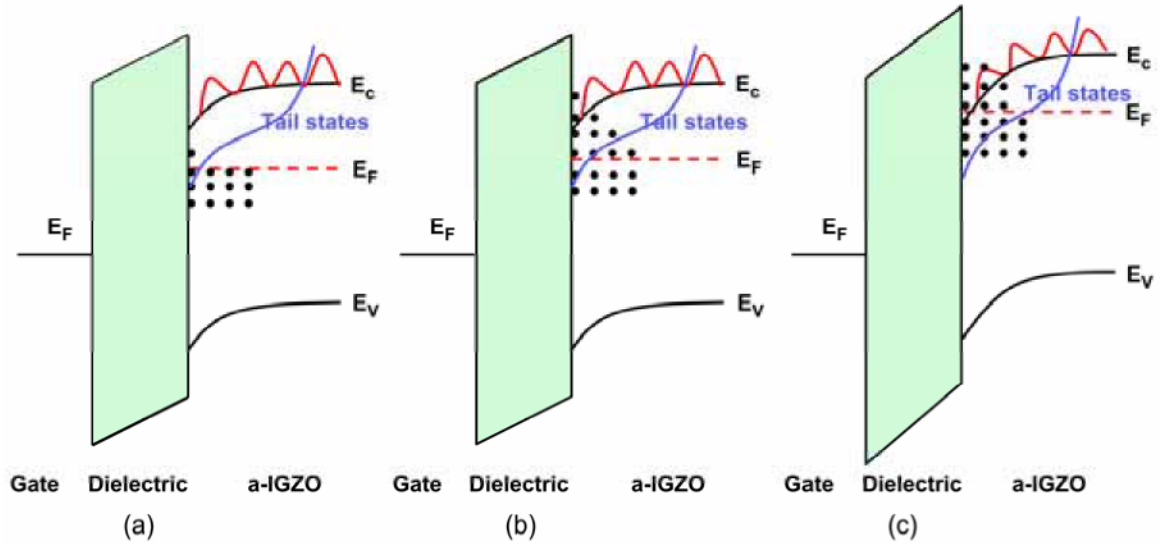


- 场效应迁移率的复杂变化趋势表明在不同的工作条件下器件载流子的输运过程具有不同的输运机制。
- 在低温范围， $\log(I_{DS})-1000/T$ 曲线偏离了原来的线性关系，表明载流子的输运机制已经发生了改变。

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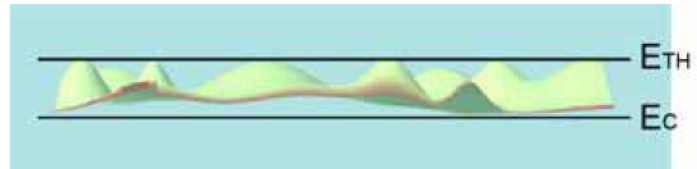
a-IGZO TFT中载流子的输运机制

• Electron

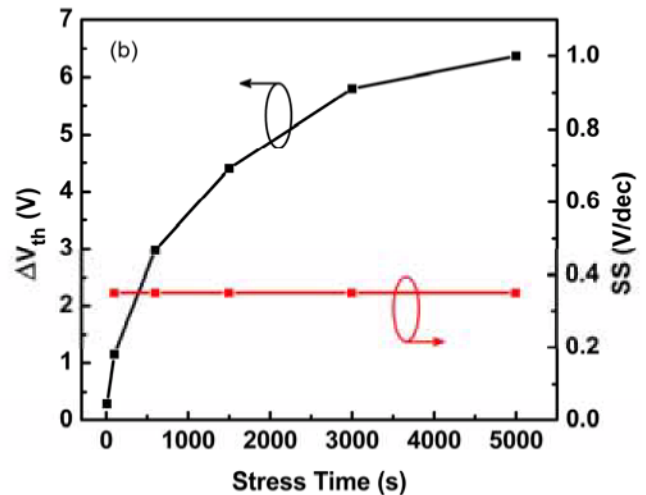
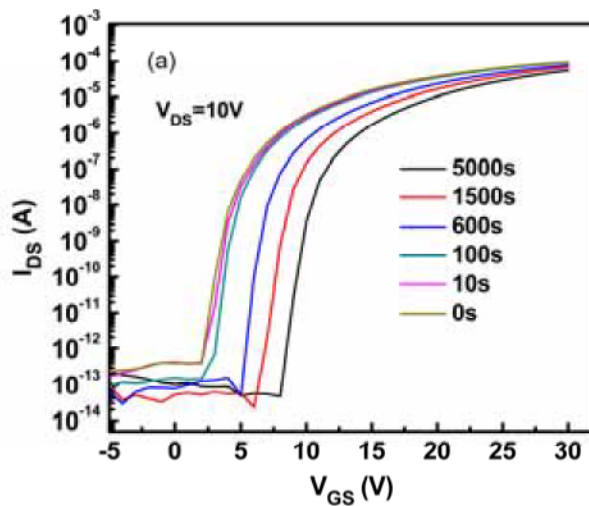


(a) 低温低栅压情况, (b) 高温相对低栅压情况, (c) 高温高栅压情况

此外, 当沟道载流子进入到带导电状态后, 又遵守渗流导电机制。



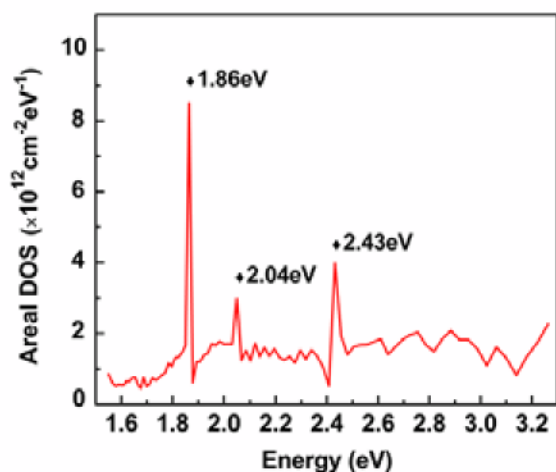
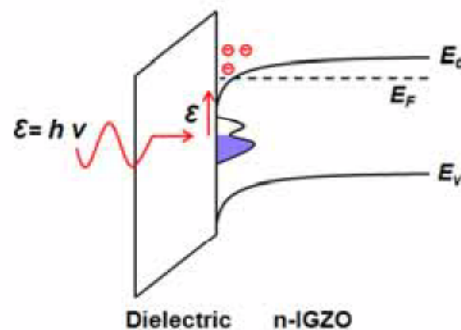
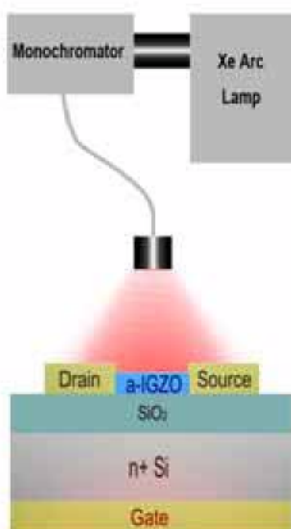
界面特性对a-IGZO TFT性能的影响



• 在正向栅极应力作用下, a-IGZO TFT 阈值电压的漂移是由于载流子被界面态捕获引起的。

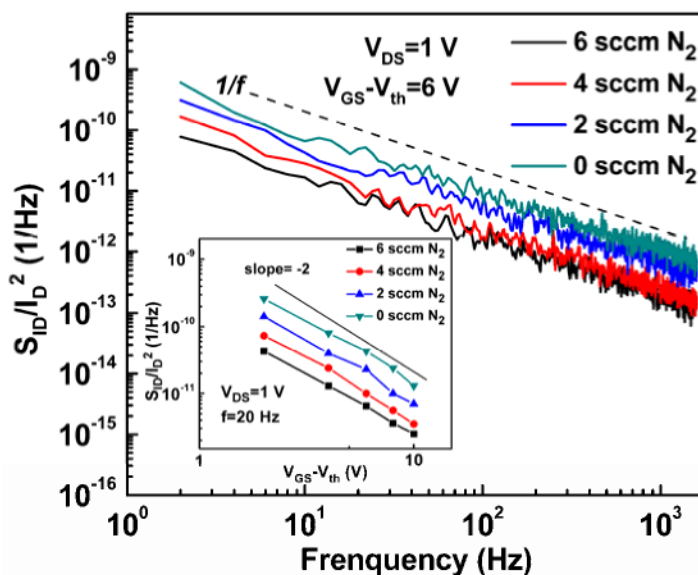
光激发电荷收集谱

PECCS技术可以表征a-IGZO TFT界面态在带隙中的具体分布，对界面质量的改善提供指导。



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1/f 低频噪声谱

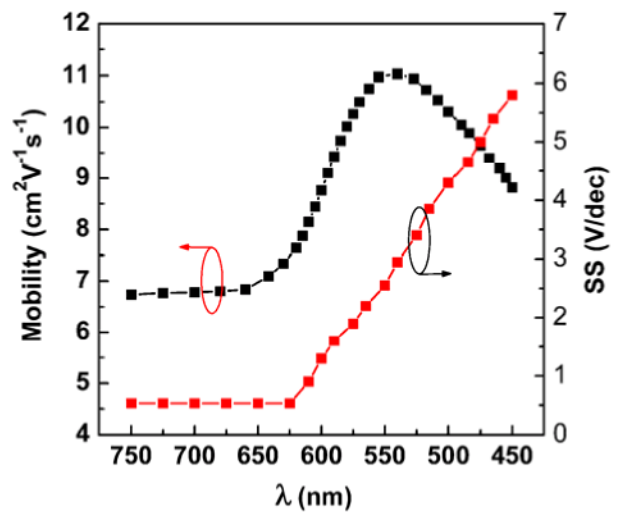
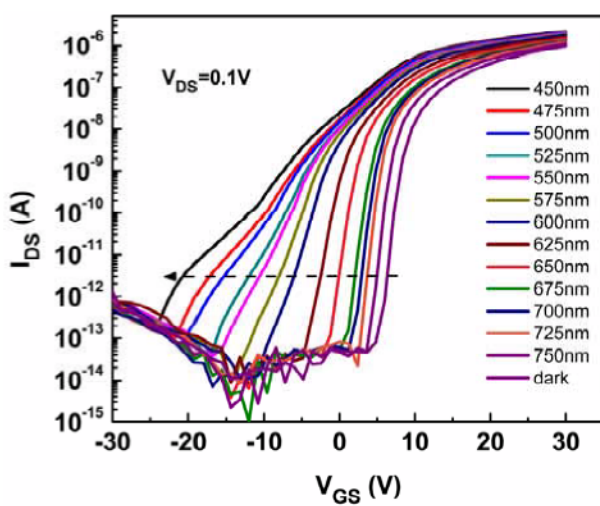


低频噪声 (low frequency noise, LFN) 是一种研究TFT缺陷特性的有效而权威的工具。1/f 噪声是由于在沟道与栅氧化层之间的界面缺陷随机的捕获和去捕获电荷过程引起电流的波动。

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a-IGZO TFT的可靠性研究

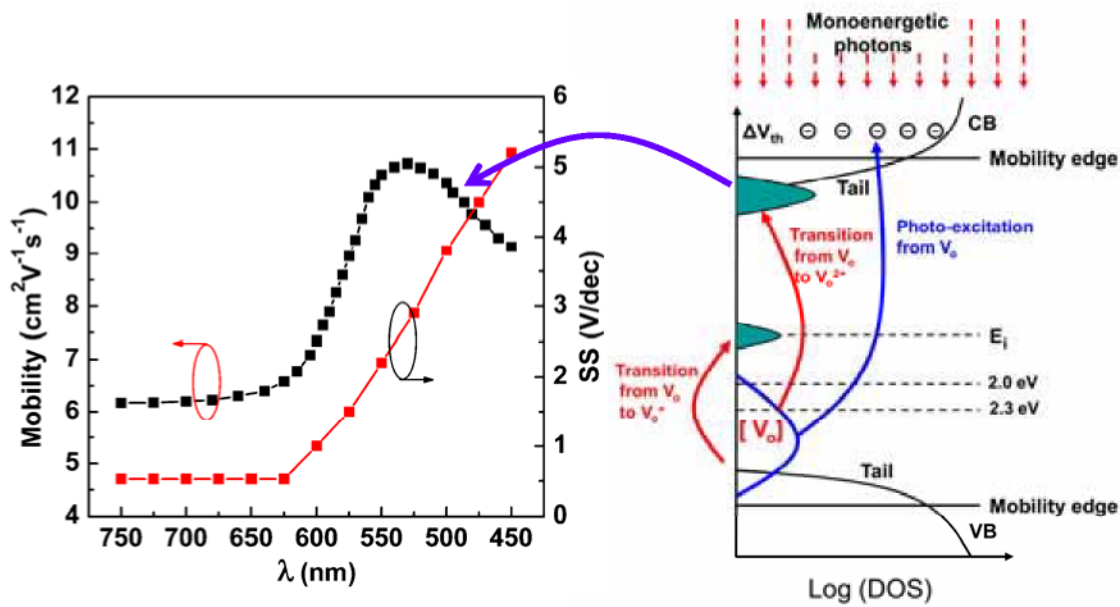
单色光照射对正向偏压后器件稳定性的影响



$$\Delta SS = \frac{\Delta N_t \ln(10)kT}{C_i}$$

当单色光的波长小于625nm时，亚阈值摆幅开始明显的增加；发现器件的场效应迁移率在特定光照条件下也发生了系统的变化。

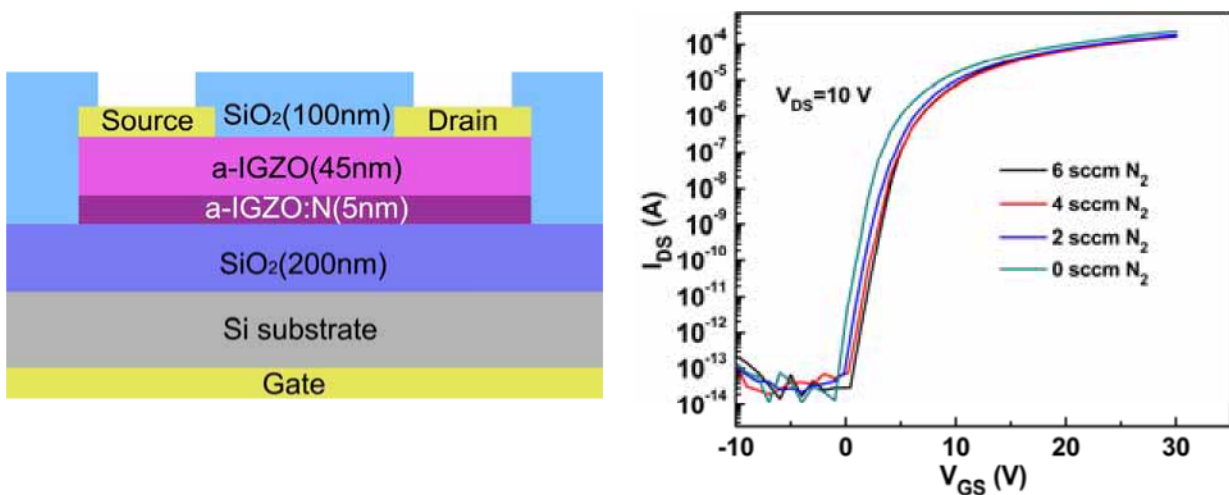
器件性能退化机制的分析



器件性能的退化是由于光照条件下在a-IGZO禁带中间和导带底产生了氧空位相关的缺陷。

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氮掺杂IGZO界面插入层对薄膜晶体管电学稳定性的影响

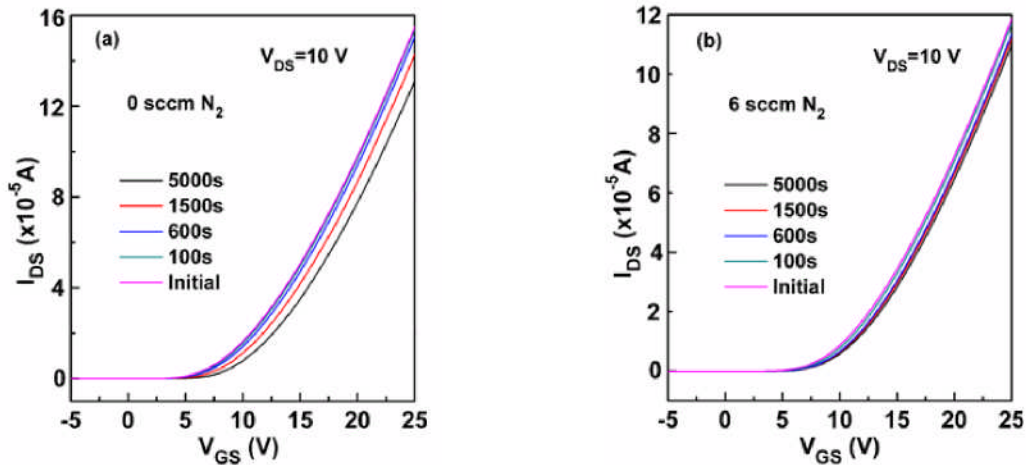


在a-IGZO:N插入层的沉积过程中，当氮气的流速从0 增加到6 sccm，发现器件的场效应迁移率、亚阈值摆幅、和开关比没有明显变化，而 TFT的阈值电压略有上升。

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界面氮掺杂IGZO器件的电学稳定性显著增强

The TFT is stressed at a high gate voltage of 20 V for a total time up to 5000 s while keeping both its source and drain electrodes grounded.



N_2 (sccm)	V_{th} (V)	μ_{FE} (cm^2/Vs)	SS (V/dec)	$I_{on/off}$	ΔV_{th} (V)
0	3.5	8.6	0.53	$>10^9$	2.2
2	4.5	8.5	0.53	$>10^9$	1.1
4	5.0	8.4	0.55	$>10^9$	0.8
6	5.2	8.6	0.55	$>10^9$	0.7

Thank you !

