Fabrication of ZnO Thin Film Transistors Using Pulsed Laser Deposition

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High electron mobility makes ZnO thin film transistors (TFTs) a possible alternative to silicon-based TFTs for driving liquid crystal displays and organic light emitting diode displays. Moreover, optical transparency in the visible light region and low deposition temperature make ZnO TFTs a suitable component of flexible and transparent future LED displays. We report the fabrication and characterization of low temperature processed ZnO-based TFTs on glass substrates. ZnO channels were grown by pulsed laser deposition method (PLD) without heating. In addition to the conventional ZnO TFTs composed of metal electrodes, Al-doped ZnO films were evaluated as ohmic and gate electrodes for realizing fully transparent TFTs. High dielectric constant HfO_2 was used for the gate insulator layer in order to improve the transfer characteristics. This presentation investigates the effects that changing the deposition method and the growth conditions of HfO_2 gate insulator has on the electrical characteristics of TFT. The former is a comparison of the electron beam evaporation and PLD, the latter is a comparison of the atmosphere with or without oxygen gas. We examine the transfer characteristics, transconductance and on/off ratio of ZnO TFTs with these different types of HfO_2 gate insulators in order to determine the optimal deposition conditions.

Fabrication of ZnO Thin Film Transistors Using Pulsed Laser Deposition

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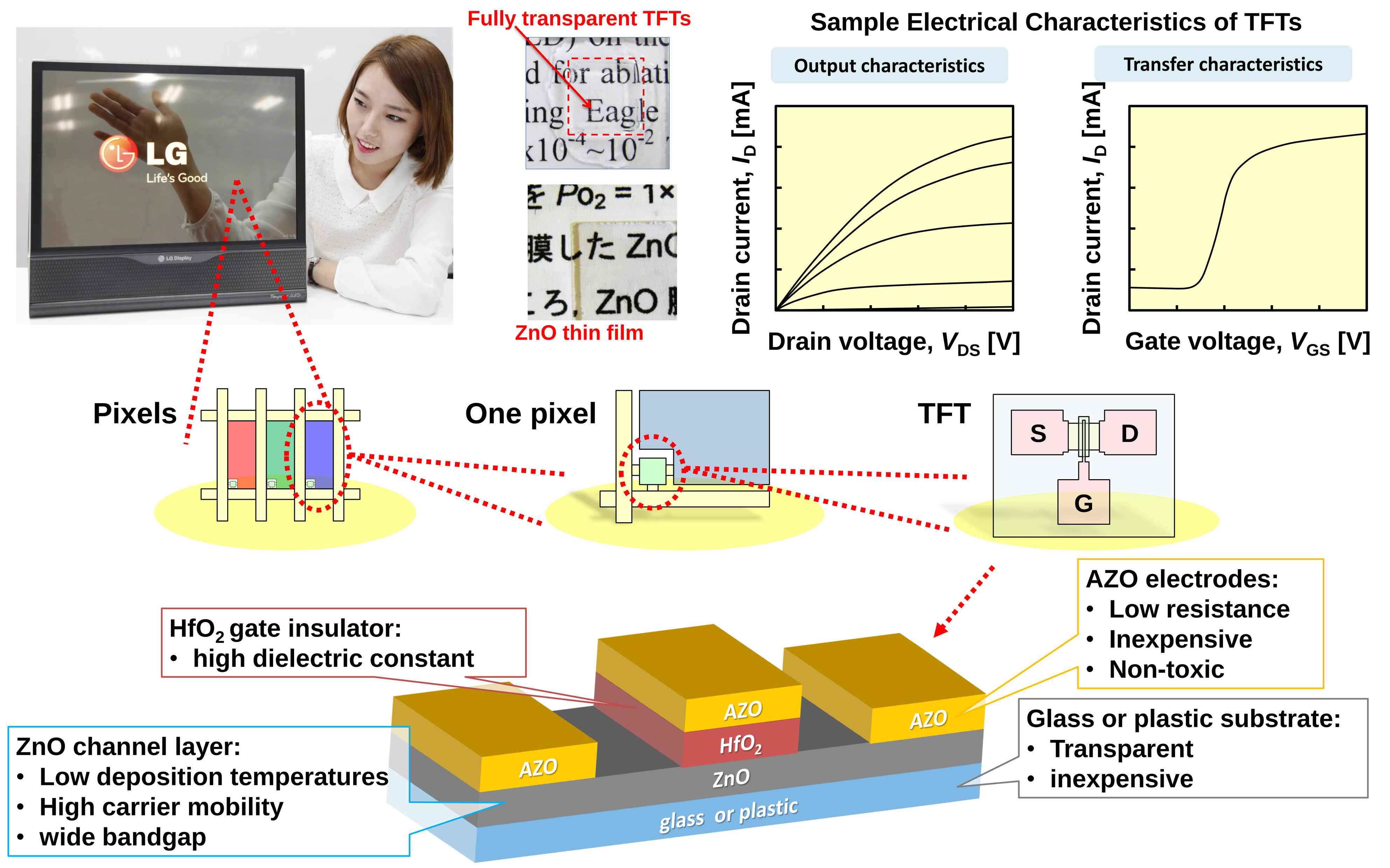
ZnO Thin Film Transistors (TFTs)



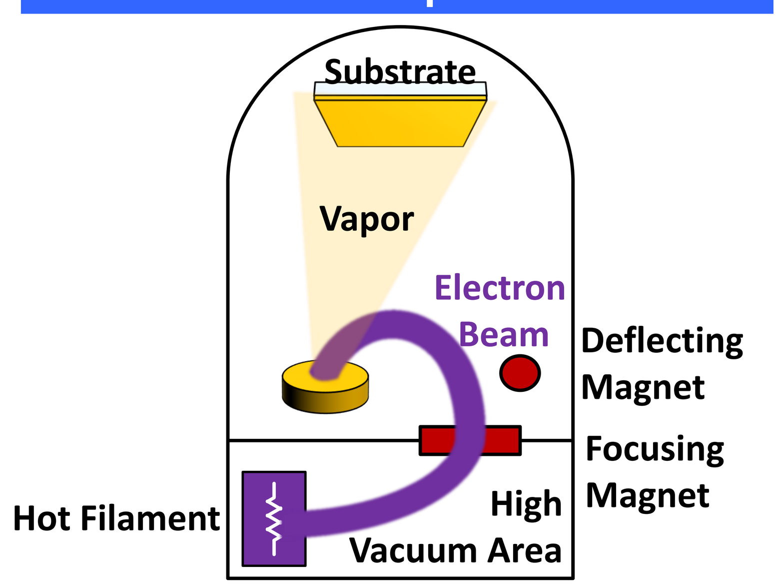
TFTs are commonly used in liquid crystal displays (LCDs). A TFT switches a pixel on/off controlling the color of display. Transparent and flexible LCDs can be made with clear ZnO TFTs. ZnO TFTs are a cheaper TFTs without Indium-based transparent electrodes since they do not use rare earth metals.

Goal: fabricate and characterize ZnO-based TFTs at low temperature on glass substrates, while changing the deposition method and the conditions of HfO_2 gate insulator formation. Fabricate transparent TFT without use of Indium.

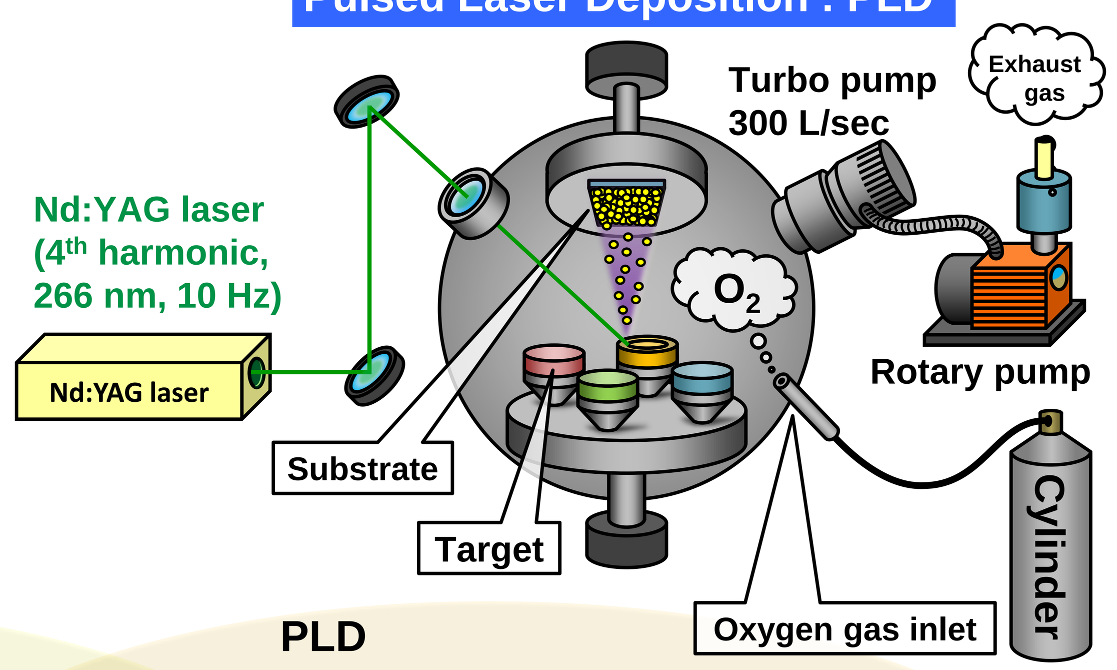
Pulsed Laser Deposition & Electron Beam Evaporation

Two types of deposition methods were used for forming the gate insulator:

Electron Beam Evaporation : EBE



Pulsed Laser Deposition : PLD



EBE
- heated filament emits an electron beam directed by a magnet
- electron beam hits the target causing heat and vaporization that condenses on the substrate surface
- **no O_2 pressure**
- **High temperature**

- **Low contamination**

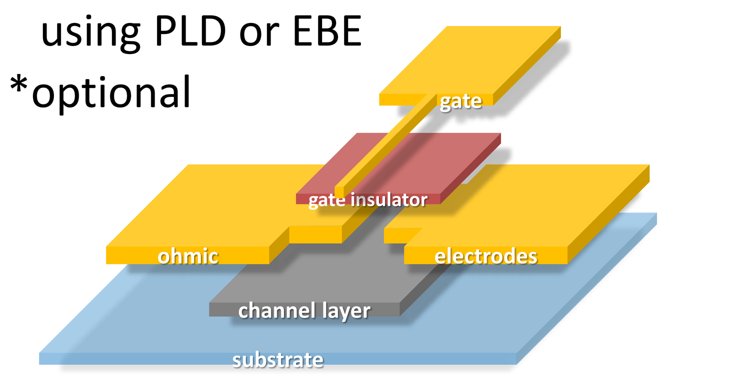
PLD
- alloy targets are struck by a pulsed, focused laser
- the atoms and ions are ablated from the target and are deposited onto the substrate
- **Wide range of O_2 partial pressures**
- **Room temperature**

TFT Fabrication

Fabrication Sequence:

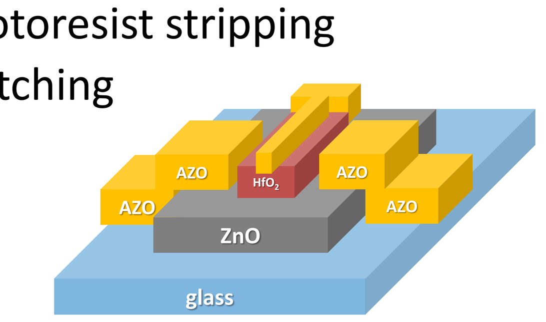
1. Channel layer deposition:
   ZnO on Eagle XG glass using PLD
2. Ohmic electrodes formation:
   Photolithography & Liftoff
   + AZO or Ti/Au Ohmic electrode using PLD or EBE
3. Annealing *: heating to decrease resistance of ohmic contact
4. Gate Insulator:
   Photolithography & Liftoff
   + HfO_2 using PLD or EBE
5. Gate electrode:
   Photolithography & Liftoff
   + AZO or Ti/Au gate electrode using PLD or EBE

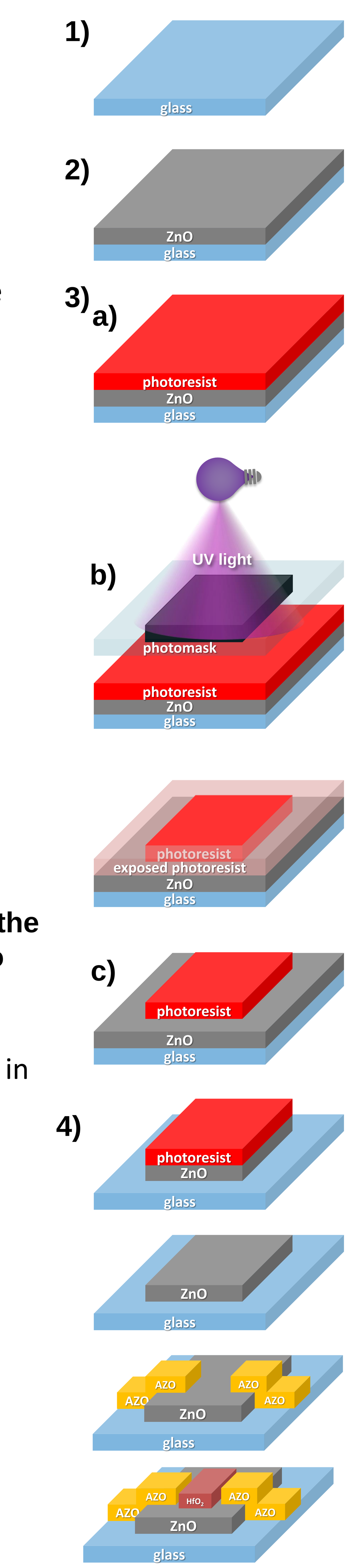
*optional



Photolithography:
*** for each fabrication step above, the following patterning steps need to be taken**

1) Cleaning
   - With acetone and isopropanol in ultrasonic cleaner
2) Thin Film Deposition
   - PLD or EBE
3) Photolithography
   a. Photoresist coating
   b. Exposure
   c. Development
   d. Photoresist stripping
4) Wet Etching





Electrical Properties of TFTs

Growth conditions of ZnO channel

Target	ZnO
Growth atmosphere	O_2
O_2 Partial Pressure[Torr]	1.94 x 10^{-2}
Laser Power [mJ/pulse]	30
Target – Sub. Distance[mm]	40
Film Thickness [nm]	41

As-grown ZnO Electrical Properties

van der Pauw measurement @ R.T.

Electron Mobility [cm^2/Vs]	2.8
Sheet Carrier Density [cm^{-2}]	2.8 x 10^{12}

Formation Process of Fabricated Devices

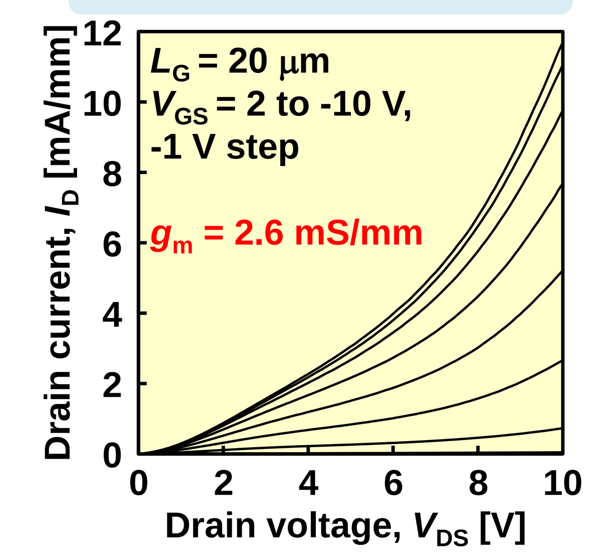
Sample	Ohmic Electrode	Gate Insulator	Gate Electrode
A	Ti/Au	EB-HfO_2	Ti/Au
B*		PLD-HfO_2 (without O_2)	
C*		PLD-HfO_2 (with O_2)	
D*	AZO	EB-HfO_2	AZO
E*		PLD-HfO_2 (without O_2)	
F*		PLD-HfO_2 (with O_2)	

Even though AZO electrodes yield desirable transparency, they have low drain current due to high contact resistance. Therefore, Ti/Au electrodes were used in order to measure better electrical characteristics of ZnO TFTs.

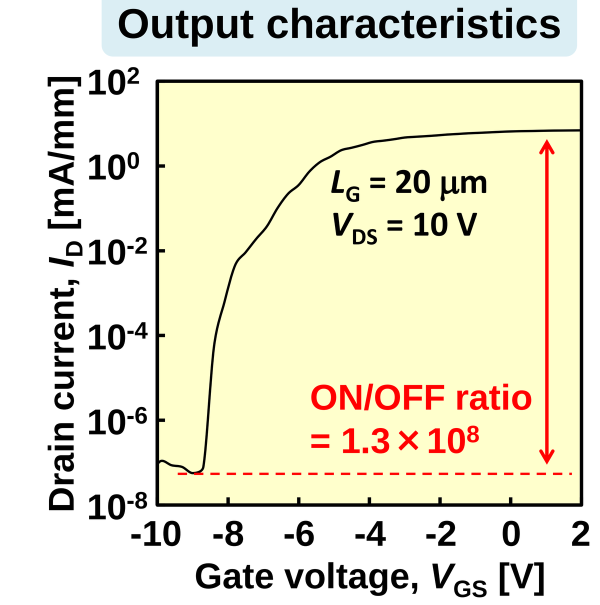
* Process problem caused the TFT to not function

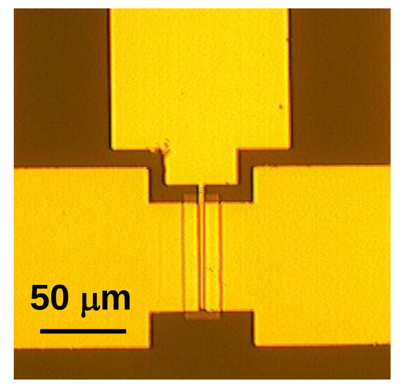
ZnO TFT with Ti/Au electrodes & gate insulator deposited by EBE (Sample A)

Transfer characteristics



Output characteristics



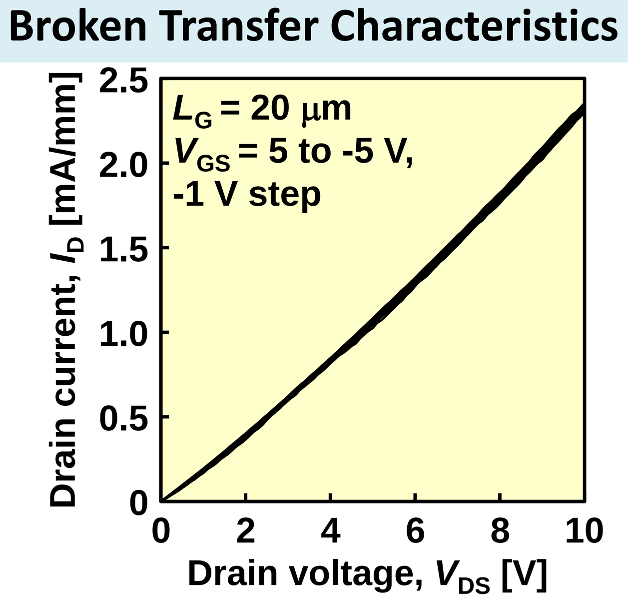


functional TFT
- all features present and working

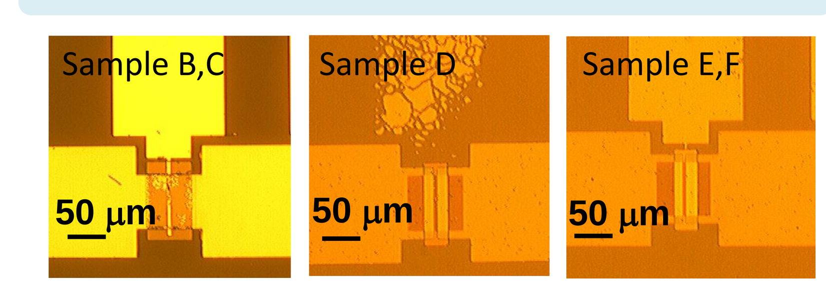
- Transconductance g_m = 2.6 mS/mm and an ON/OFF ratio = 1.3 x 10^8
- There is significant scope to continue to improve Ohmic contact resistance.

Other devices(Non-functional due to process troubles: Sample B-F)

Broken Transfer Characteristics



Photos of Broken Devices



-cracked gate insulator layer due to problem with PLD deposition conditions (increased surface temperature?)
-dissolved gate electrode due to insufficient time for development of photoresist
Further process optimizations for stable fabrications of TFTs are needed.

Conclusions

- **A functional ZnO TFT with Ti/Au electrodes was obtained with using PLD to grow channel layer, Ohmic electrodes and gate electrodes, as well as EBE to grow the gate insulator.**
- **Further investigation needs to be done to optimize the deposition conditions of PLD and determine the fabrication process for ZnO TFTs with gate insulator grown by PLD and for ZnO TFTs with AZO electrodes.**
- **Transparent TFTs were fabricated without the use of rare earth metals creating a relatively cheap and non-toxic transistors.**

References

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Acknowledgments

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