Impact of passivation layer on the subthreshold behavior of p-type CuO accumulation-mode thin-film transistors

Qi Chen[1, *], Xi Zeng[1], Denis Flandre[1]
[1]Institute of Information and Communication Technologies, Electronics and Applied Mathematics
Université Catholique de Louvain, Louvain-la-Neuve 1348, Belgium
*Corresponding author: qi.chen@uclouvain.be

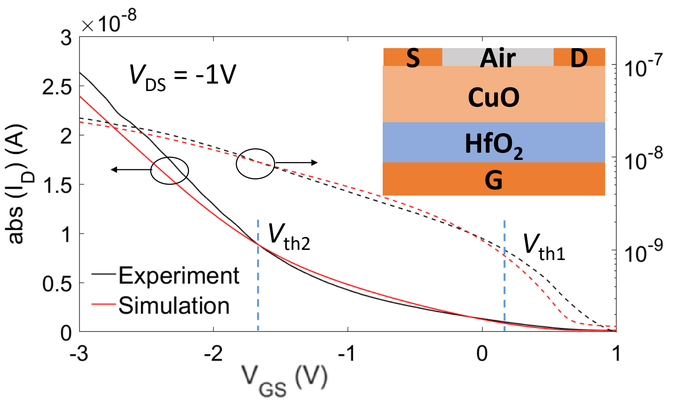
Background and Objectives

- P-type metal oxide (MO) TFTs are less studied and still featuring poor performance compared to their n-type counterparts.
- Passivation layers, such as HfO_2 and Al_2O_3, have been reported to improve the subthreshold operation of p-type MO TFTs.
- Use simulation tools to construct numerical models of p-type CuO TFT and explain the conduction mechanism in subthreshold regime.
- Investigate the impact of HfO_2 passivation layer on the subthreshold behavior of CuO TFT and further optimize the deice structure.

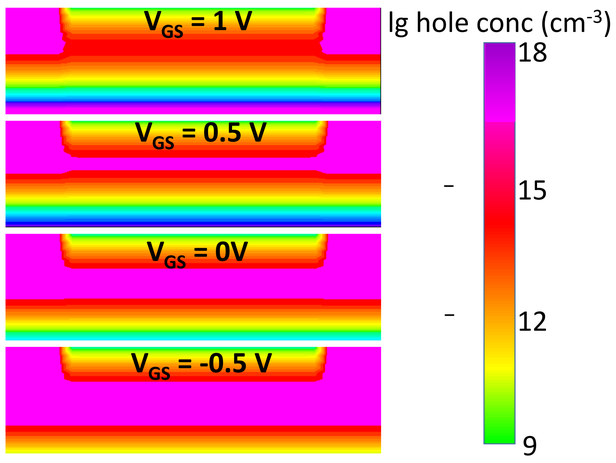
Reference structure without passivation

Table I. Process, measured [1] and Fitted device parameters used in simulations

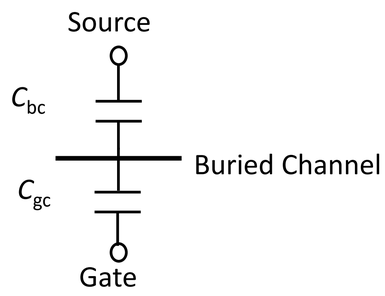
	Band Gap (eV)	Mobility ($cm^2V^{-1}s^{-1}$)	Doping Density (cm^{-3})	Interface Defect Density D_{it} ($eV^{-1}cm^{-2}$)	Thickness (nm)	W/L	Fixed Oxide Charges Q_f (cm^{-2})
Process parameters	—	—	—	—	CuO: 50 S/D: 100 HfO_2: 25	27	—
Measured parameters	1.6	6.2×10^{-4}	5×10^{17}	Back (HfO_2): 6×10^{10} Front (air): 3.57×10^{13}	—	—	Back: 9×10^{12} Front: -
Fitted parameters	1.6	6.2×10^{-4}	5×10^{17}	Back (HfO_2): 6×10^{10} Front (air): 3.57×10^{13}	CuO: 120 S/D: 100 HfO_2: 25	27	Back: 9×10^{12} Front: -



- V_{th1} is observed when a buried channel forms in the CuO film.
- V_{th2} is identified at the flat band voltage.



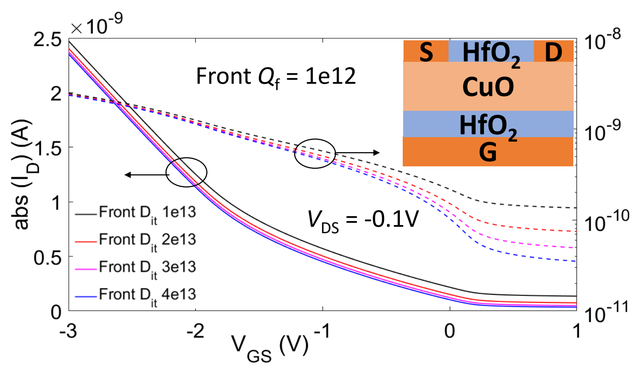
- $V_{GS} > V_{th1}$: The CuO film is fully depleted, and the current is cut-off.
- $V_{th2} < V_{GS} < V_{th1}$: A partial depletion region occurs in the CuO layer, resulting in a buried channel that enlarges for decreased V_{GS}.
- $V_{GS} < V_{th2}$: Holes are accumulated in the bottom of CuO film and thus forms an accumulation channel

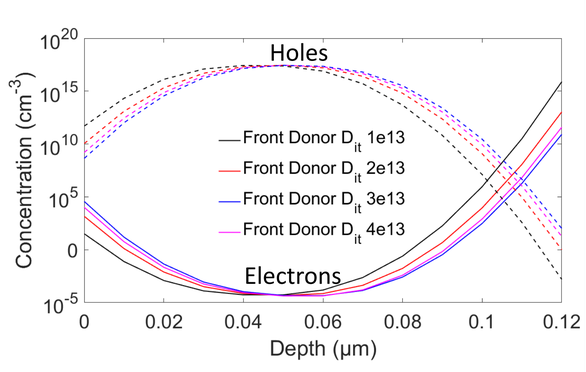


- A simplified capacitance model of the accumulation-mode CuO TFT in subthreshold operation.

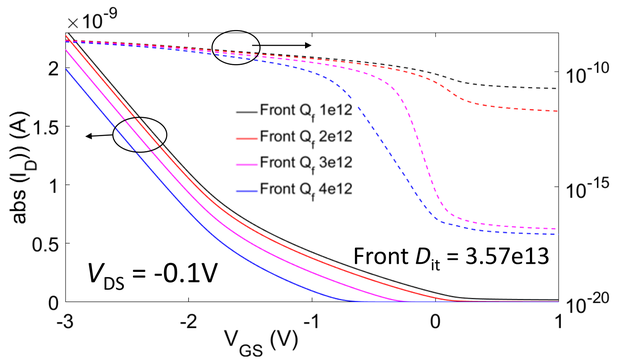
$$SS = \left(\frac{d\log(I_D)}{dV_{GS}}\right)^{-1} \cong \ln(10)\frac{kT}{q}\left(1+\frac{C_{bc}}{C_{gc}}\right)$$

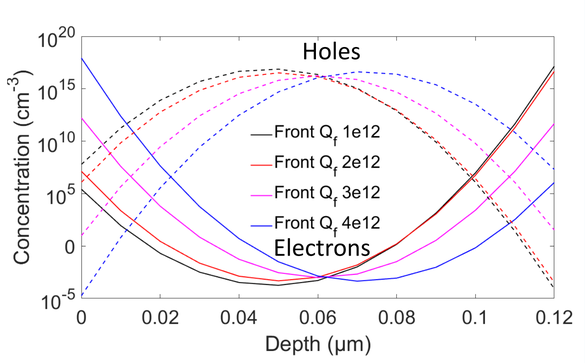
Top passivated structure with 100 nm HfO_2 passivation layer





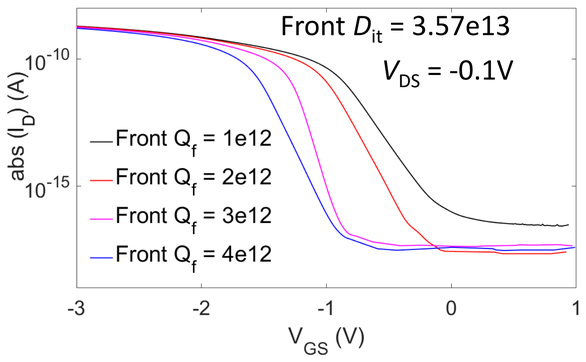
- Increased front donor D_{it} enlarges the top depletion region width and pushes the subthreshold buried channel closer to the back gate, leading to a higher C_{gc} and a smaller C_{bc}, which improves SS



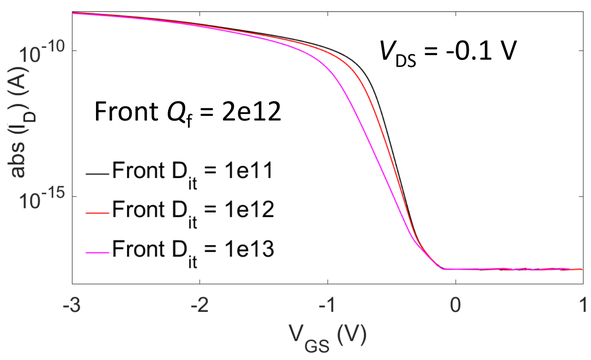


- The impact of Q_f on subthreshold behavior is similar to that of D_{it}, but more significant.
- A top inversion layer appears for Q_f larger than 3×10^{12} cm^{-2}, pinning the top surface potential, thus increasing C_{bc} and degrading SS.

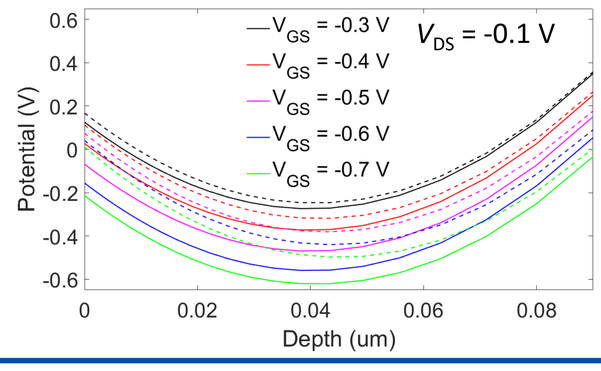
Optimized structure with 90 nm CuO film



- The effect of Q_f on subthreshold behavior is the same as the 120 nm CuO film case, while much lower off current and SS are obtained due to enhanced depletion in subthreshold regime.



- SS degrades with increased D_{it}, which is opposite to the observation in the case of 120 nm CuO film.



- With D_{it} increases from 1×10^{11} (solid lines) to 1×10^{13} eV^{-1} cm^{-2} (dashed lines), reduced control of the gate bias on the film potential occurs and leads to an increase of SS.

Table I. Device performance varying CuO thickness and front Q_f

Front Q_f (cm^{-2})	SS (mV/dec)		V_{th1} (V)		I_{on}/I_{off}	
	T_{CuO} = 90 nm	T_{CuO} = 120 nm	T_{CuO} = 90 nm	T_{CuO} = 120 nm	T_{CuO} = 90 nm	T_{CuO} = 120 nm
1×10^{12}	140	560	-0.89	0.16	1.89×10^{7}	1.8×10^{1}
2×10^{12}	110	260	-1.02	0.13	8.45×10^{7}	1.47×10^{2}
3×10^{12}	61	61	-1.28	-0.29	1.09×10^{8}	2.28×10^{7}
4×10^{12}	97	123	-1.58	-0.75	1.35×10^{8}	5.67×10^{7}

Conclusions

- The subthreshold behavior is improved by the HfO_2 passivation layer, as well as by a thinner CuO film.
- This simulation study provides guidelines to improve the p-type TFT performance and could be applied to other MO semiconductors such as Cu_2O and SnO.

References

[1]. Zeng X, Zhukova M, Faniel S, Li G, Flandre D. Room-temperature DC-sputtered p-type CuO accumulation-mode thin-film transistors gated by HfO_2. Appl Phys Lett 2022;121:133503. https://doi.org/10.1063/5.0098757.

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