Boosting the Electrical Performances of Solution-Based High-κ Multilayer Dielectrics at Low Temperature and Their Application in Electronic Structures

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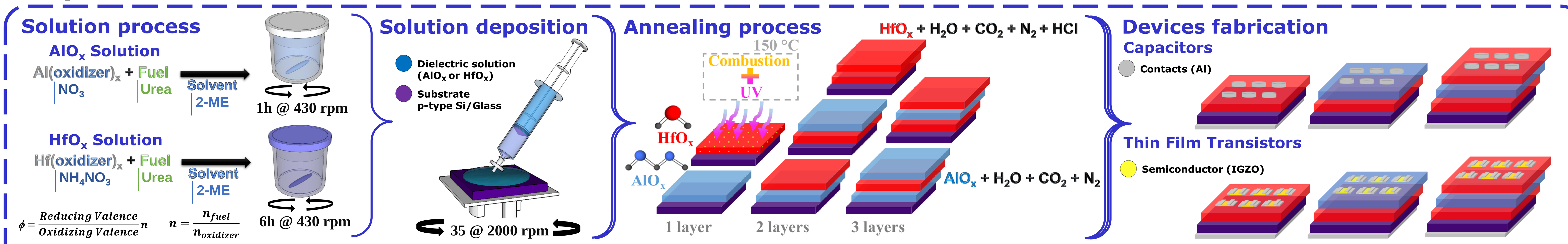
Introduction

In the last decade solution-based dielectric oxides have been widely studied in electronic applications enabling the use of low cost processing technologies and devices improvement. The most promising are the high-κ dielectrics, like aluminum (AlO_x) and hafnium oxide (HfO_x), that allow an easier trap filing in the semiconductor and the use of low operation voltage. However, in the case of HfO_x usually is needed a high temperature to induce a uniform and condensed film, which limits its applications in flexible electronics. This paper describes how to obtain HfO_x dielectric thin films and the effect of their implementation in multilayer dielectrics (MLD) at low temperatures (150 °C) to apply in thin film transistors (TFTs) using the alliance between solution combustion synthesis (SCS) and ultraviolet (UV) treatment. In the case of SCS an oxidizer (nitrates) and a fuel (urea, citric acid) are added to the precursor solution. During the annealing process a exothermic reaction occurs, resulting in a reduction of the external heat required for the film formation; the remove of organic solvents and film densification. By using a DUV treatment the films are exposed to high-energy photons which causes the cleavage of alkoxy groups, active metals, and oxygen atoms to simplify M−O−M network formation. After less than 10 min of UV irradiation, the polymeric chains break into smaller fragments, which induces degradation, leading to removal of oxygen, carbon and improving the film densification. The combination of these methods improves the reliability of the nanoscale film morphology, composition of metal oxides and stability over time. [1–3]

Experimental Section

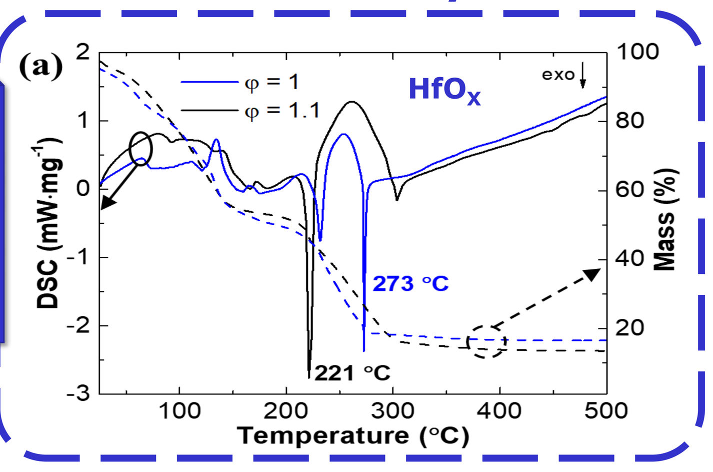


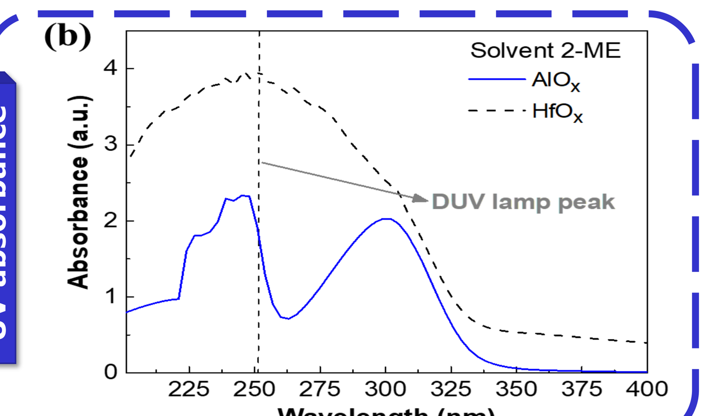
Variables

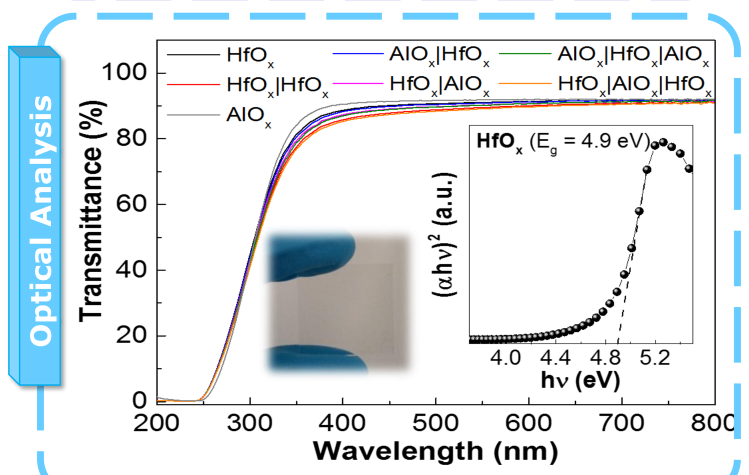
:: Metal ion concentration: c = 0.1, 0.15 to 0.2 M (AlO_x) and c = 0.1 M (HfO_x) :: Fuel/oxidizer ratio: ϕ = 1 (AlO_x and HfO_x solutions) and ϕ = 1.1 (HfO_x solution) :: Dielectric annealing time: 30 min for each layer

Results

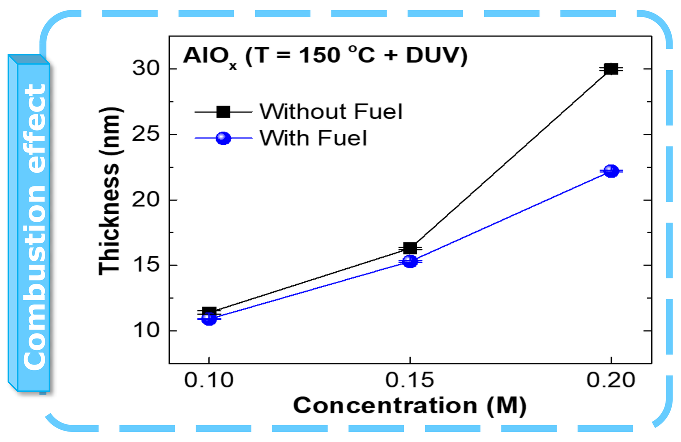
Solution analysis

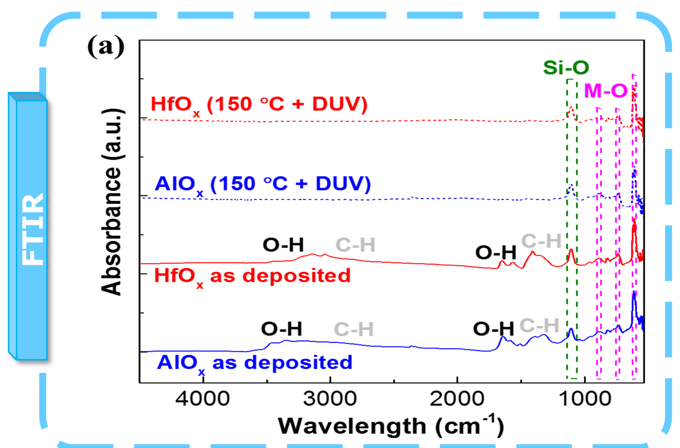


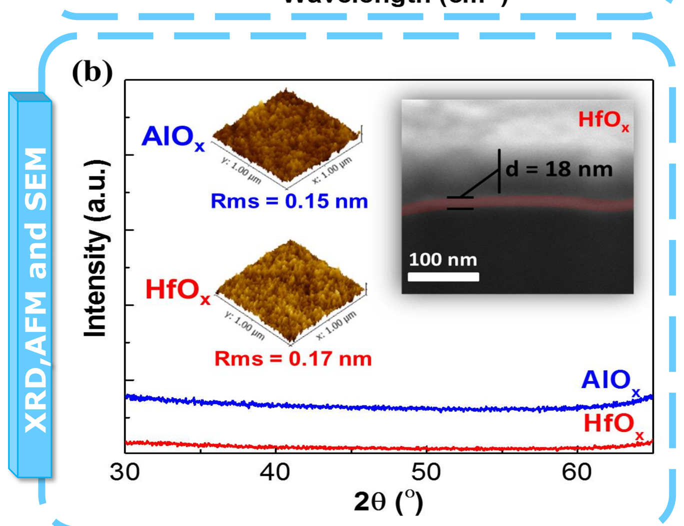




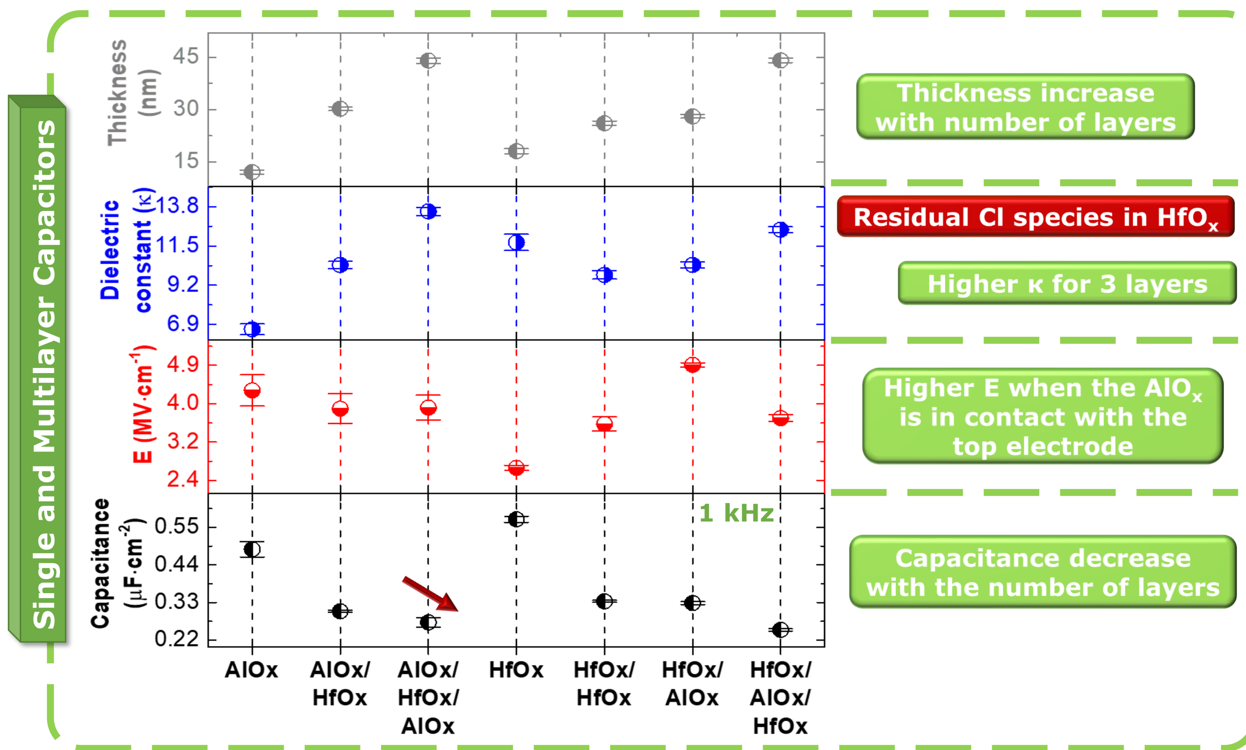
Film Characterization

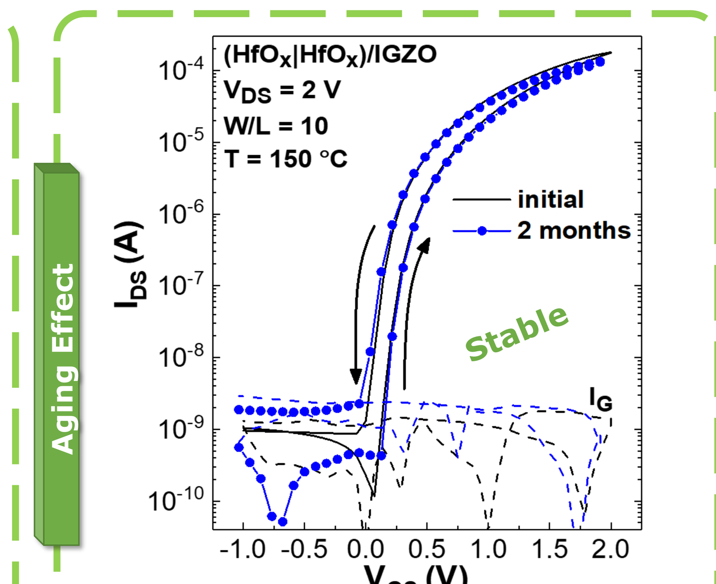




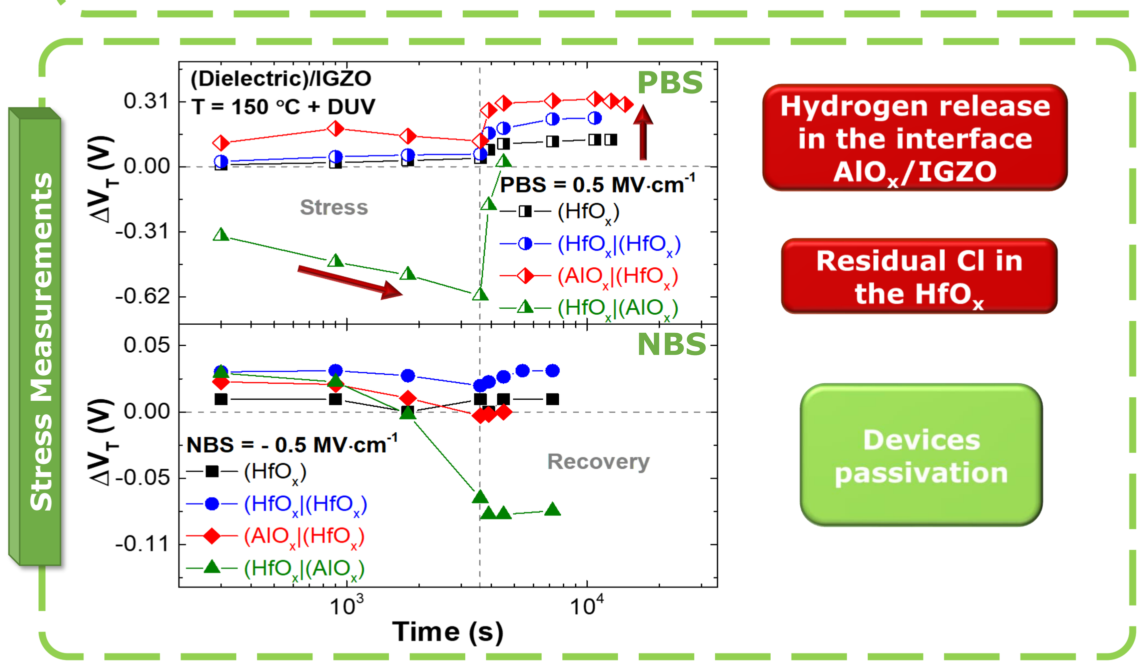


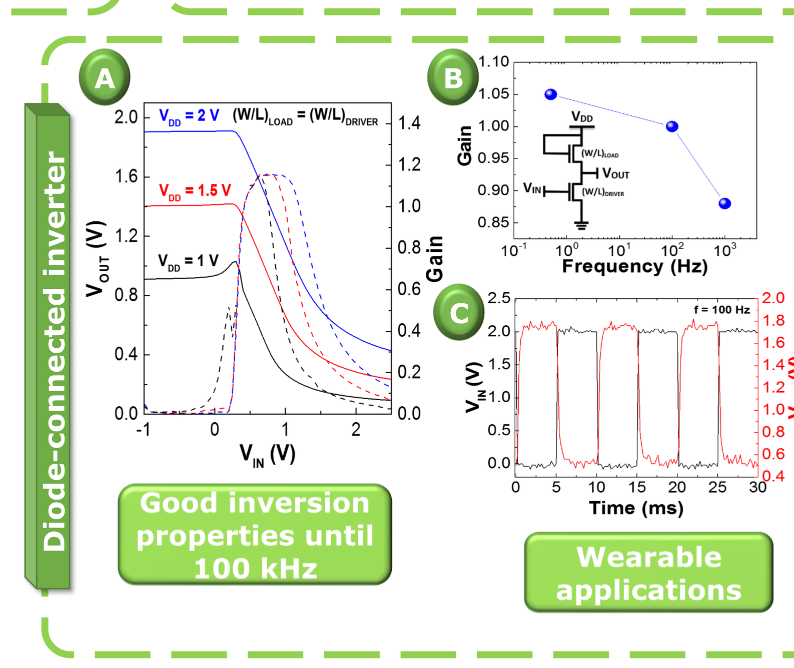
Electrical Characterization

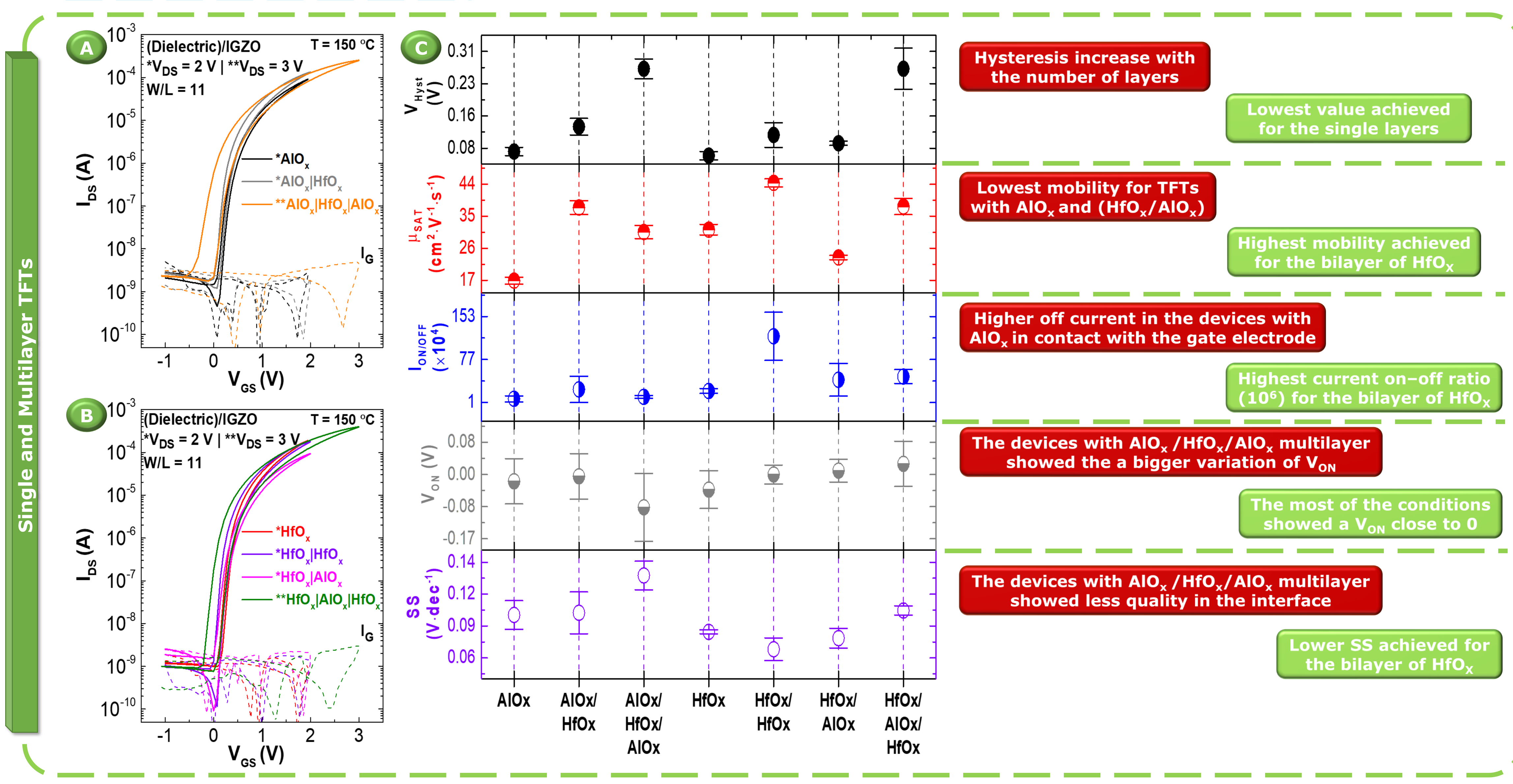




Aging	SS (V dec⁻¹)	μ_{SAT} ($cm^2 V^{-1} s^{-1}$)	$I_{ON/OFF}$	V_{ON} (V)
initial	0.061	43.94	1.5×10^6	0.07
2 months	0.068	35.8	3.0×10^5	0.12







State-of-the-art

Year	TFT (Dielec/ Semic)	T (°C)	SS (V dec⁻¹)	μ_{SAT} ($cm^2 V^{-1} s^{-1}$)	$I_{ON/OFF}$	V_{ON} (V)	V_G range (V)
2012	(HfO_x |AlO_x)/ ZTO	400	0.12	3.8	10^5	0.4	-2 to 3
	(AlO_x |HfO_x)/ ZTO		0.16	1.2		-0.2	
2012	(HfO_x)/ ZTO	300	0.11	1.1	10^7	0.2	- 5 to 5
2013	(HfO_x)/ ZnO	150	----	1.2	10^6	2	- 10 to 20
2015	(HfO_x)/ HIZO	500	1.1	3.6	10^4	-0.1	- 5 to 10
2015	(HfO_x)/ ZnO	380	----	42±1.4	10^7	-0.4	- 1 to 6
2015	(HfO_x)/ IZO	300	0.72	25.7	10^6	1.5	- 1 to 5
		200	1.32	6.2	10^3	0.8	
2017	(HfO_x)/ ZTO	350	0.07	13.2	10^8	- 0.1	- 1 to 2
Present study [3]	(HfO_x)/ IGZO	150	0.082±0.002	31.2±1.4	10^5	-0.04±0.05	-1 to 2
	(HfO_x |HfO_x)/ IGZO		0.066±0.010	43.9±1.1	10^6	0±0.03	-1 to 2
	(HfO_x |AlO_x)/ IGZO		0.076±0.009	23.6±0.6	10^5	0.01±0.03	-1 to 2
	(HfO_x|AlO_x|HfO_x) /IGZO		0.101±0.004	37.5±2.2		0.03±0.06	-1 to 3
	(AlO_x |HfO_x)/ IGZO		0.099±0.019	37.2±1.9		-0.01±0.06	-1 to 2
	(AlO_x|HfO_x|AlO_x)/ IGZO		0.133±0.013	30.5±1.8		-0.09±0.09	-1 to 3

Conclusions

- ✓ The single layers and multilayers exhibited the elimination of all the residual organics, a small surface roughness (< 1.2 nm) and a high breakdown voltage (> 2.7 MV·cm⁻¹).
- ✓ The resulting MLD/IGZO TFTs presented a high performance at a low operation voltage (< 3 V), with high saturation mobility (43.9 ± 1.1 cm²·V⁻¹·s⁻¹), a small subthreshold slope (0.066 ± 0.010 V·dec⁻¹), current ratio of 10^6, and a good stability after 2 months. To our knowledge, the results achieved surpass the state-of-the-art.
- ✓ Finally, we demonstrated a low-voltage diode-connected inverter using (MLD)/IGZO TFTs working at a switching speed of 100 Hz with a maximum gain of 1 at 2 V.

References

[1] R. Branquinho et al, *InTech*, Ch. 15, Oct. 2016.
[2] E. Carlos et al, *ACS Appl. Mater. Interfaces*, vol. 8, no. 45, pp. 31100–8, Oct. 2016.
[3] E. Carlos et al, *ACS Appl. Mater. Interfaces*, *accepted*, Nov. 2017.

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Acknowledgments

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