Electrolyte-gated transistor based on metal-oxide nanoparticles

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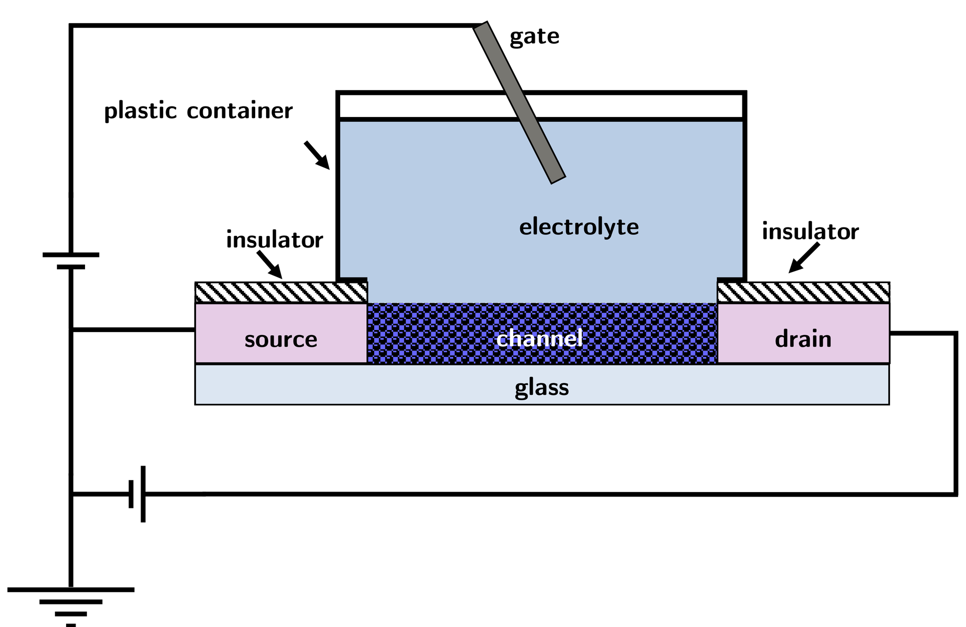
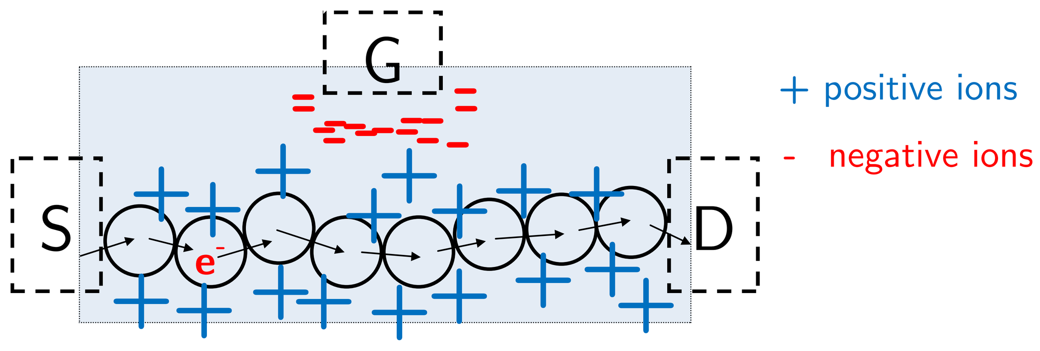
Introduction

Transistors are increasingly used as biosensing elements in several applications, ranging from clinical diagnostics to water and food monitoring. The sensitivity of such sensors requires the use of transistors with high gain that can be operated in aqueous environment, such as physiological conditions, soils or marine environment. Here we present electrolyte-gated transistors (EGTs) based on intrinsic or Al-doped ZnO nanoparticles, which work with an aqueous electrolyte in direct contact with the channel layer. As such, these transistors could be easily integrated in bio-sensor devices, given the intrinsic stability and non-toxicity of metal oxides.

Device structure



Working principle

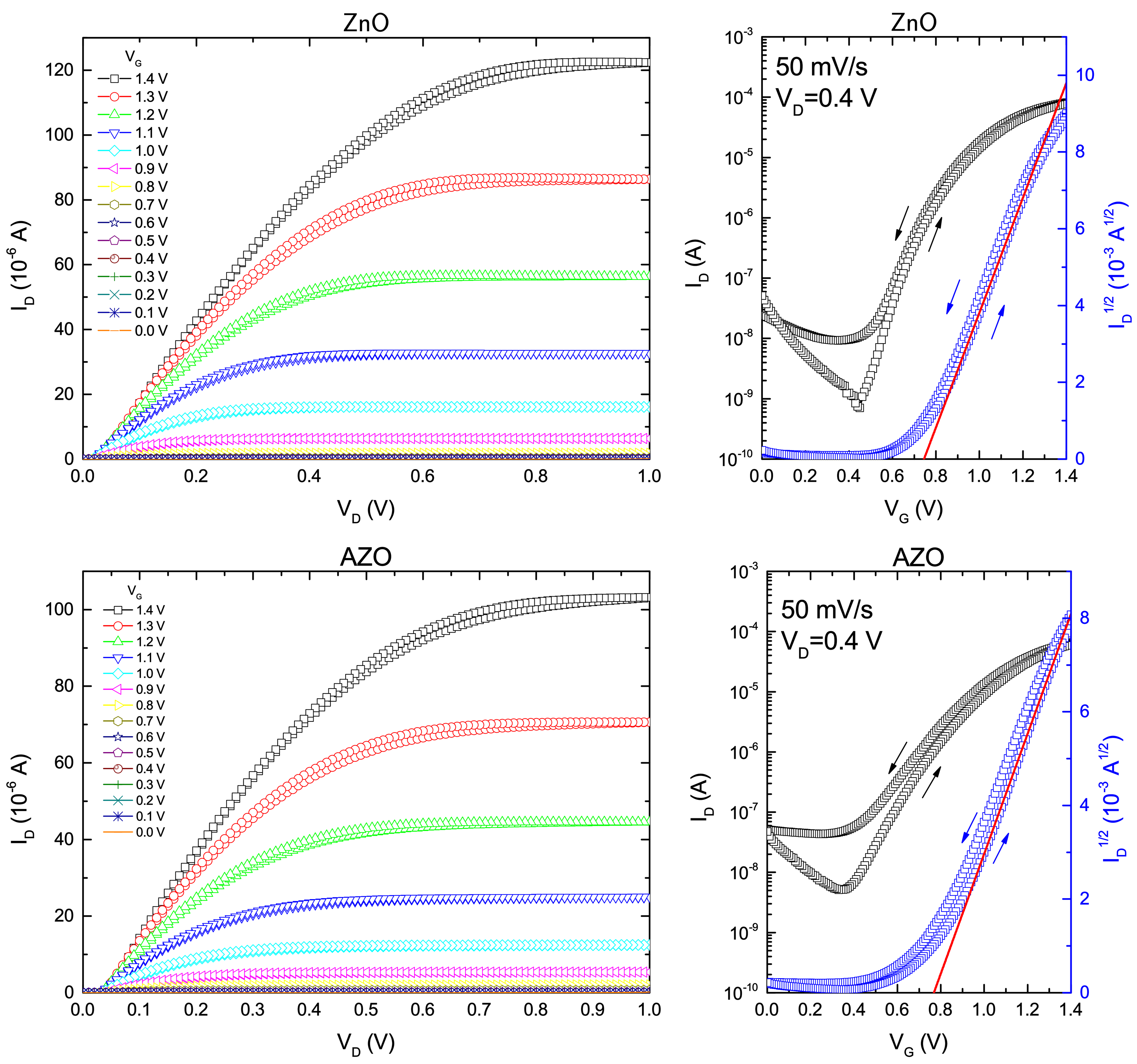


The nanostructured morphology of the channel results in a large surface area in contact with the electrolyte. When a gate bias V_g is applied, positive ions accumulate at the metal oxide NPs interface inducing accumulation of negative mobile charges, which can be displaced through the applied drain voltage V_D.

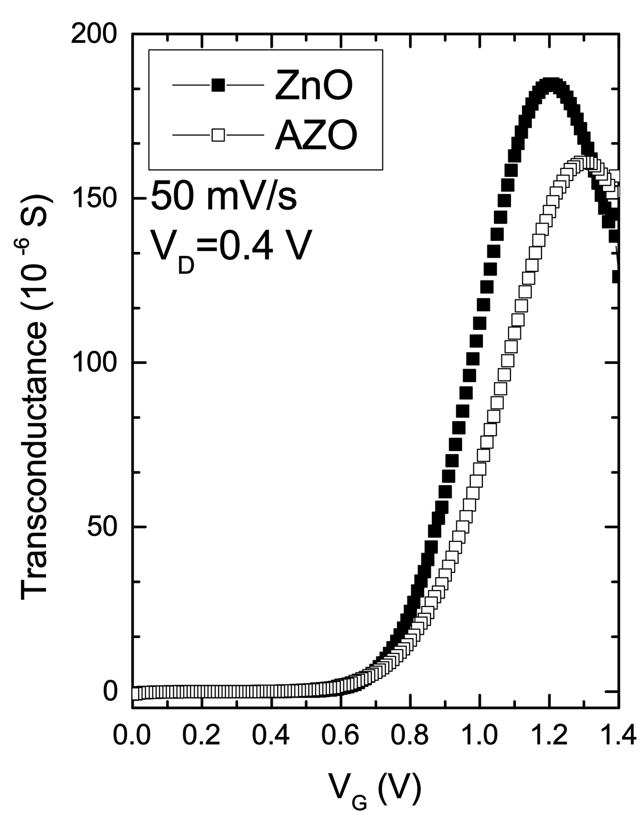
Experimental details

- *Source/drain*: pre-patterned ITO (80-90 nm) (on glass).
- *Gate*: Ag/AgCl pellet.
- *Channel*: ZnO or AZO nanoparticles (12-15 nm Ø, in 2-propanol);
  - *thickness*: 110 nm (spin coating);
  - W/L = 800 μm/200 μm = 40.
  - *Annealing*: 120 minutes, 150 °C.
- *Insulator*: polystyrene, 130 nm (spin coating).
- *Insulator etching*: shadow mask + plasma cleaner/etcher.
- *Electrolyte*: phosphate buffered saline.

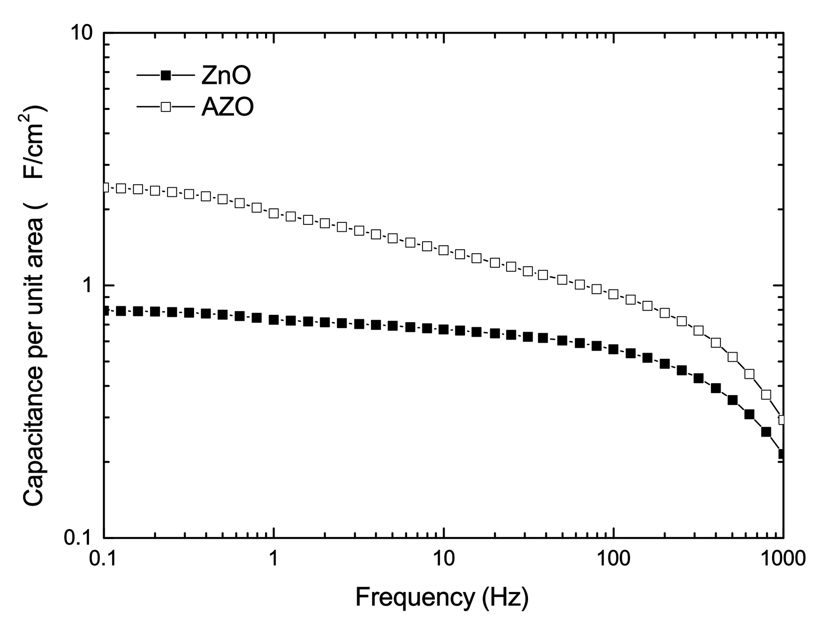
Experimental results



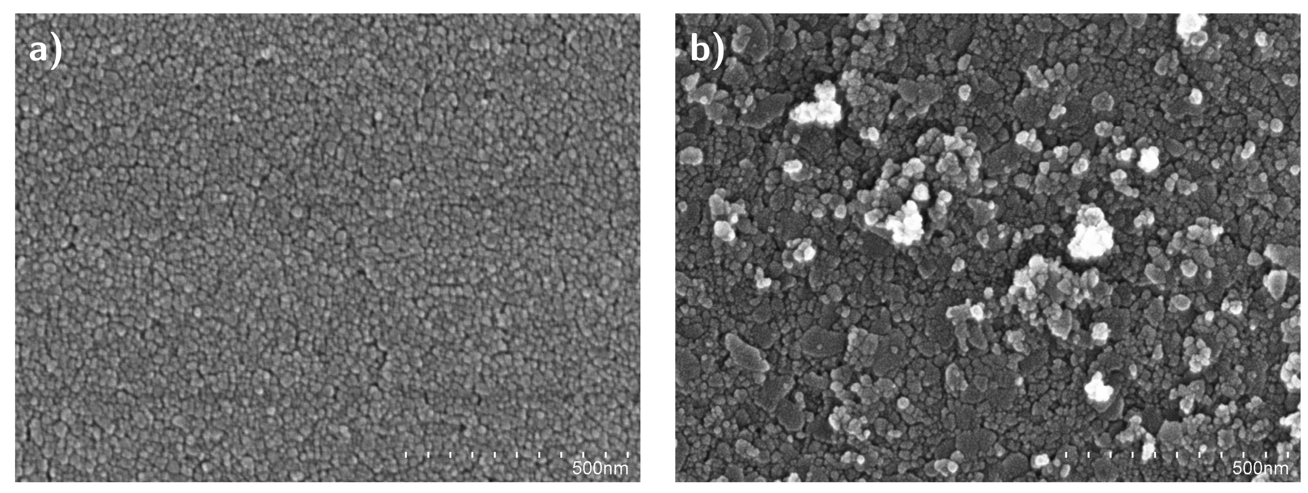
Output (left) and transfer characteristics (right) for the ZnO/AZO transistor.



Transconductance (g_m) curves for the devices under examination.



Capacitance as a function of frequency for the ZnO and AZO nanoparticles layers (by impedance spectroscopy).



SEM images of the a) ZnO and b) AZO nanoparticles layer after the annealing (120 minutes, 150 °C).

These transistors can operate at low gate voltage (V_G): a significant modulation of the drain current (I_D) is achieved for $V_G < 1.4$ V and drain voltage (V_D) in the range of 0-1 V.

The hysteresis in the transfer characteristic is attributed to trap filling phenomena.

	on/off	turn-on [V]	threshold [V]	transconductance [μS]	capacitance (@1 Hz) [μF/cm^2]	mobility (sat.) [cm^2/Vs]
ZnO	10^5	0.45	0.74	185 (1.2 V)	8.12	1.66
AZO	10^4	0.35	0.77	161 (1.3 V)	21.36	0.60

The ZnO transistor shows higher on/off ratio and higher maximum transconductance, at a lower gate voltage. The AZO device, however, has a significantly lower turn-on voltage and higher *off current*, most likely due to a lower injection barrier from the ITO contacts to the channel material.

The e^- mobility in ZnO is found to be 3 times higher compared to AZO. This can be due to the more homogeneous morphology (as revealed by SEM) which would facilitate the charge transport between adjacent particles. On the other side, the AZO films show a relatively rough morphology, which results in a higher capacitance per unit area.

Conclusions

We demonstrated electrolyte gated FETs based on solution processed metal oxide nanoparticles such as ZnO and AZO. The intrinsically nanostructured morphology and the environmental stability of metal oxides allows for low voltage functioning (0-1 V) in aqueous electrolytes. Moreover, the electrolyte gating directly results in high current modulation and thus in high device transconductance. In particular, low turn-on voltage (< 0.5 V), high on/off ratio (10^4-10^5) and transconductance in the range of 0.2 mS. These characteristics make the devices very promising candidate as sensors in application such as diagnostics, water and environmental monitoring, where stable performances in aqueous environment is required.

References

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