PhD Open Days

Photodetectors and LEDs based on β-Ga_2O_3 membranes obtained by ion-beam-assisted exfoliation

PHD IN NUCLEAR TECHNOLOGIES AND SCIENCES

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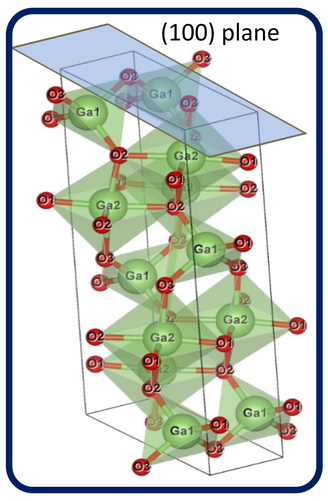
Gallium Oxide (β-Ga_2O_3)

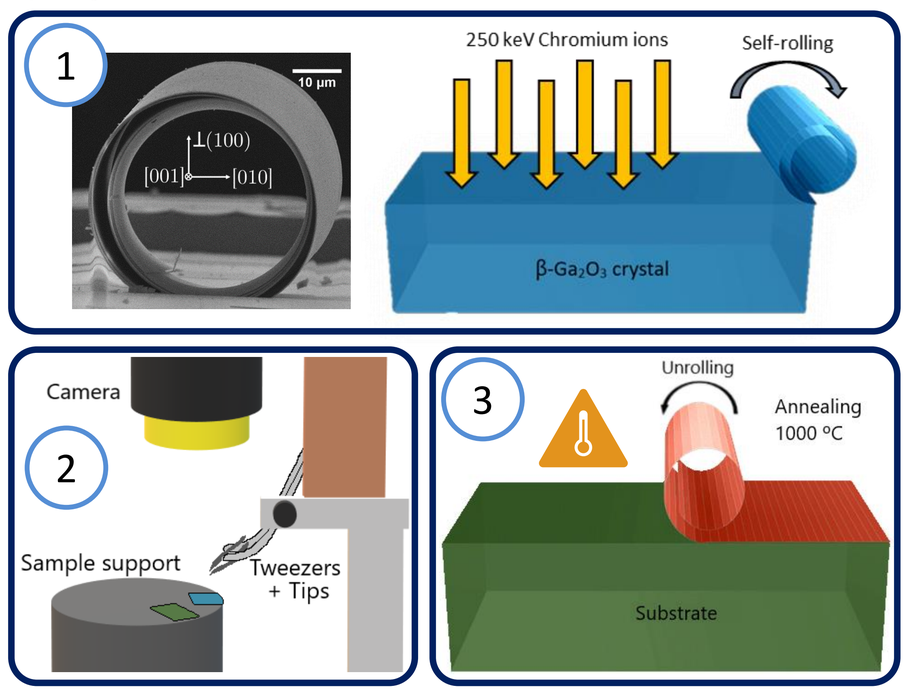


- β-Ga_2O_3 is a **semiconductor** studied for different applications, such as deep ultraviolet photodetectors;
- It has a **wide bandgap** of ~4.8 eV, naturally tuned to wavelengths **<260 nm**, making it ideal for **solar-blind optoelectronics**;
- **High responsivity** (*R*) and **detectivity** (*D**) are reported for a variety of device geometries and fabrication techniques;
- **Easy cleavage** along its (100) plane, so **mechanical exfoliation** of membranes is commonly employed;
- Low thermal conductivity and only n-type doping.

Ion-beam-induced exfoliation

- **Ion implantation** (1) (ex.: 250 keV Cr^{2+} ions), on an (100) plane oriented β-Ga_2O_3 crystal, causes a thin layer (~300 nm) to self-roll into microtubes;
- A pick-and-place technique is used to **transfer** (2) these tubes to a **substrate of choice**: transparent, p-type, high thermal conductivity, etc…;
- Rapid thermal annealing for 60 s at 900 °C in N_2 atmosphere is used to **unroll the tubes** (3) and recover the implantation defects, resulting in high crystalline quality membranes on the new substrate.

Membrane preparation



M. C. Pedro, et al., Phys. Status Solidi RRL, 20: e2500059 (2026)
D. M. Esteves, et al., Surfaces and Interfaces, 88: 109066 (2026)

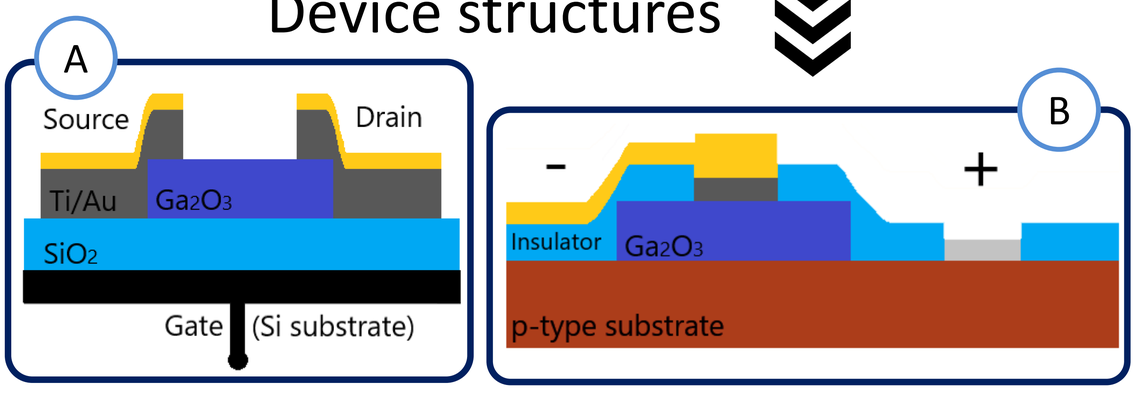
Device fabrication

The objective of this project is to use these membranes to develop several optoelectronic devices:

- Metal-semiconductor-metal **(MSM) photodetectors** and **phototransistors**, sharing structure (A), have been tested;
- **p-n heterojunctions** and **light-emitting diodes (LEDs)**, sharing structure (B), are to be developed during the PhD project.

For this, **microfabrication techniques** available at INESC MN and its clean room facilities are employed.

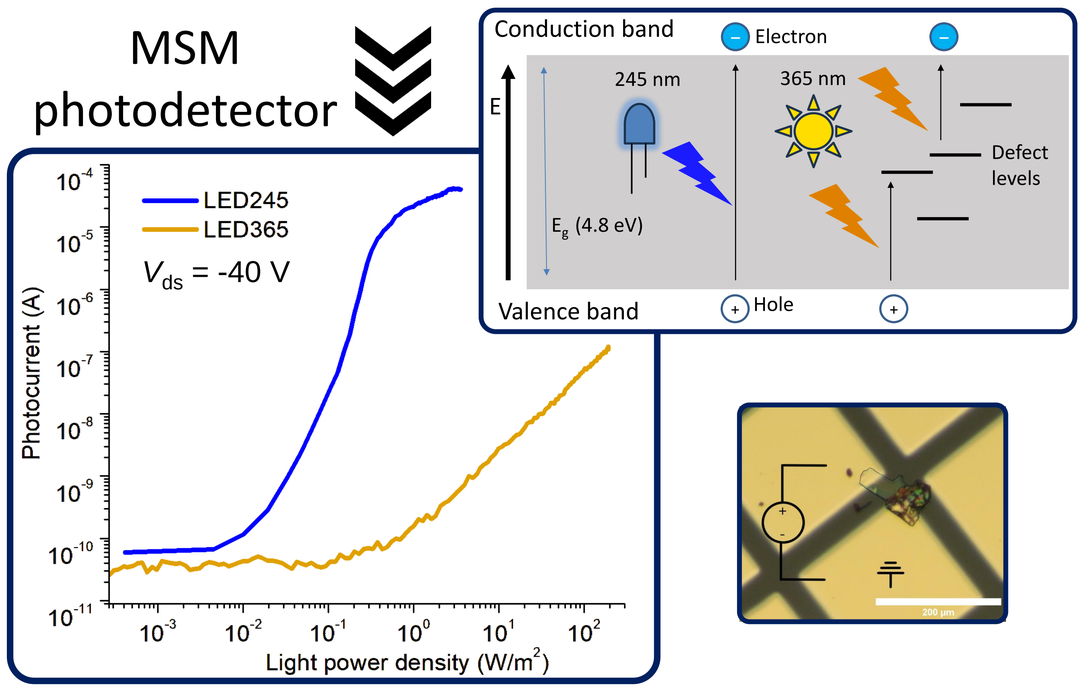
Device structures



Membrane-based MSM photodetectors

- **Under illumination** of a **245 nm** wavelength LED (5.1 eV), electrons are excited to the conduction band, resulting in an increase in current;
- **Under illumination** of a **365 nm** wavelength LED (3.4 eV), electrons can only be excited indirectly, through defect levels;
- Photocurrent is much higher, at the same power, for above-bandgap excitation, hinting at **solar-blind detection**;
- The **rejection ratio (R_{245}/R_{365}) is above 10^5**, for P_{light} = 0.7 W/m².

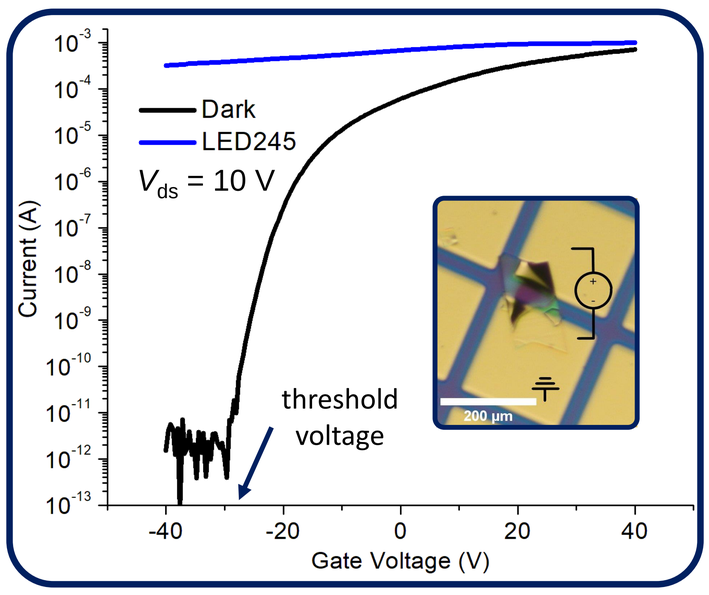
MSM photodetector



Membrane-based phototransistors

- For this phototransistor, **in the dark**, the current can be completely cut for negative gate voltages;
- This effect is much less significant under **245 nm** wavelength illumination;
- The best performance is thus obtained in this configuration, below the threshold voltage, showing **high responsivity and detectivity**.

Photo-transistor



The photoresponse can be evaluated using:

$$R = \frac{I_{photo} - I_{dark}}{SP_{light}}$$

$$D = \frac{R\sqrt{S}}{\sqrt{2qI_{dark}}}$$ (*S* is the area of the device)

Parameter	Value
R (A/W)	6.6×10^4
D (Jones)	3.8×10^{17}

Future work

- Improving or overcoming the devices' slow recovery after excitation;
- Creating **thinner phototransistors**, possibly with positive threshold voltage, so no energy is required to supress the dark current;
- Creating **p-n heterojunctions**, between n-type β-Ga_2O_3 membranes and a p-type substrate, such as Si and GaN;
- Characterisation, with **spatial resolution**, of the devices' response, to better understand its mechanisms;
- Taking advantage of the implantation step to introduce optically active ions and create **LEDs of different colours**.

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