UV detectors based on zinc-oxide thin films

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Introduction

UV spectral range is strategic in several fields both for human operations and for environmental monitoring.
UV detection is exploited essentially by silicon photodiodes and photomultiplier devices, but silicon are limited by 1.2 eV energy gap at room temperature, that means a low quantum efficiency in the deep UV.
New technology, based on wide band gap materials, allows to produce high performance UV photodectors: f.e. zinc oxide has a band gap of 3.4 eV and a large excitation binding energy of 60 meV at room temperature.
Istituto Nazionale di RIcerca Metrologica is involved in the activity on the ZnO UV detector development related to the Joint Research Project (EMRP ENV03).
This work shows ZnO photodectors starting from both realised at INRIM and commercial films characterized at several voltage biases and at different wavelengths.

Fabrication

The UV sensible films have been realized following two methods:

(1) ZnO thin film with thickness ranging from 100 nm to 300 nm, deposited at INRIM, by electron gun technique, starting from commercial powder (Alfa Aesar 99.999%), on sapphire substrates (either 1-102 or 0001 oriented). After deposition at room temperature the film was annealed in air at temperature of 500°C for 30 minutes, to reduce the oxygen deficiency and to improve the film homogeneity.

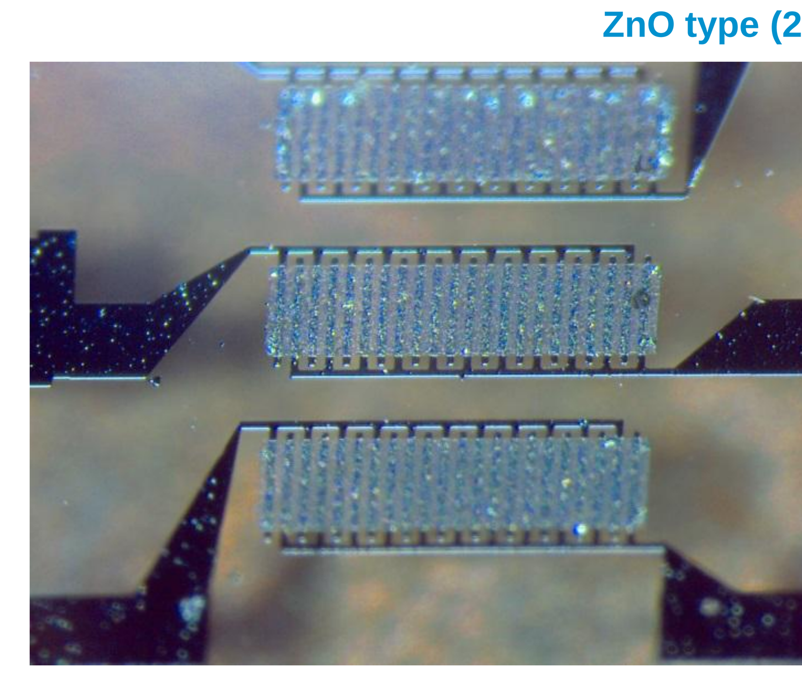
(2) Commercial high-quality ZnO epitaxial film on sapphire substrates.

To reduce the detector dark currents to the order of μA, an oxidation process has been carried out to both samples.

The photodetectors have been developed on both films, (1) and (2), and consist of two intergitated contact electrodes of aluminum fabricated through standard lithography and etching.

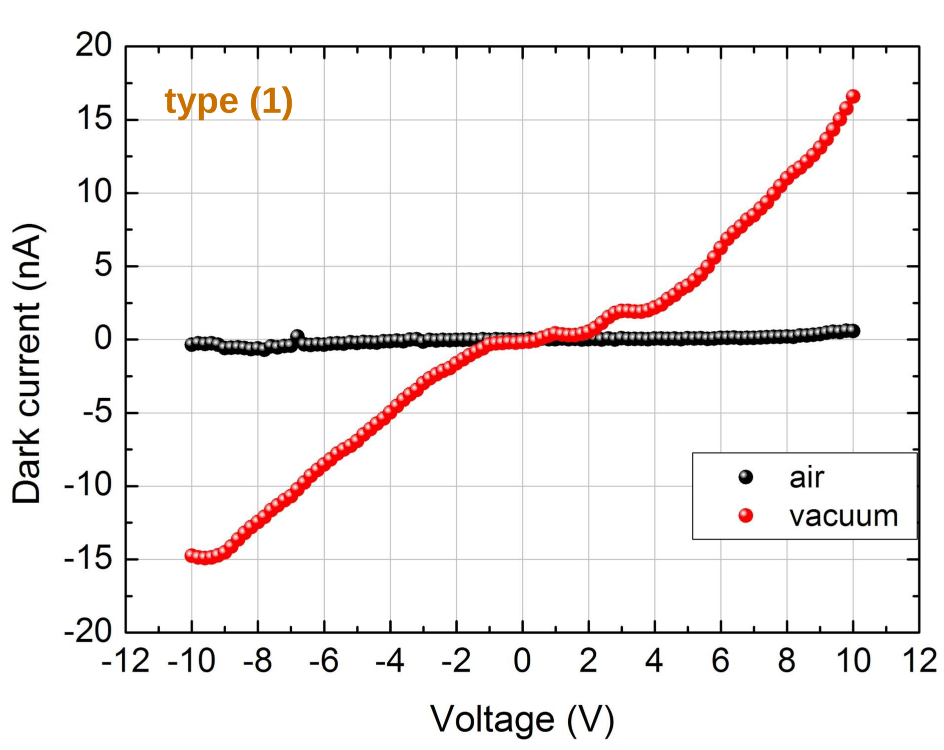
Detector area is 530 μm × 120 μm.
The contact are 8 μm wide, 154 μm long and separated one from each other of 15 μm.

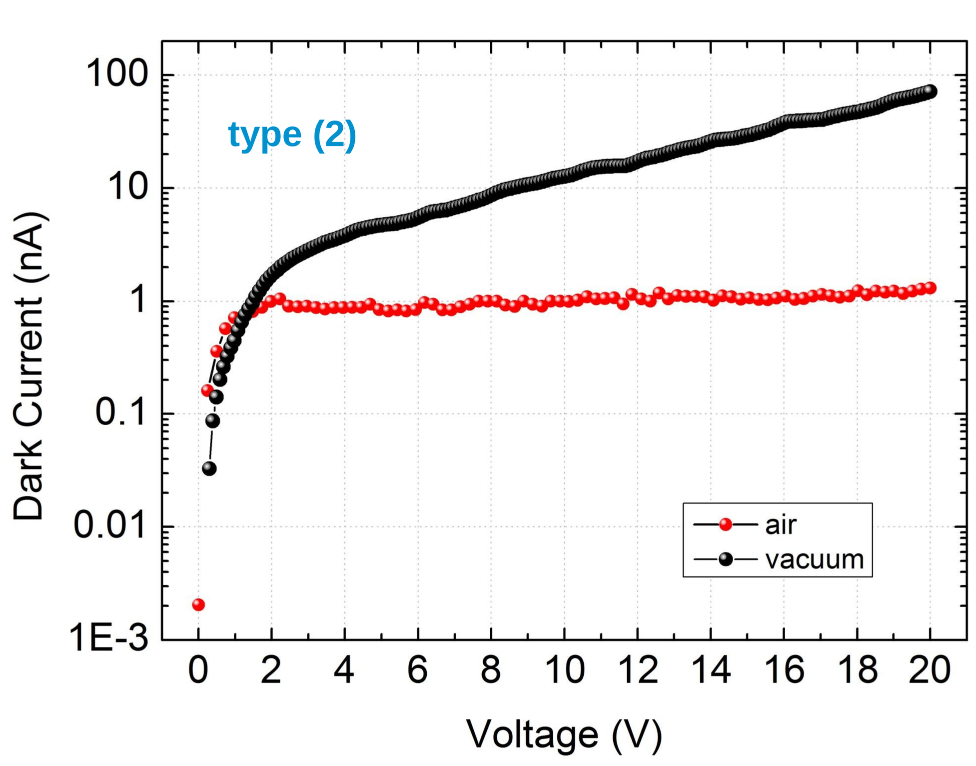
ZnO type (2)



I-V charactesistics

Dark ambient IV characteristics of ZnO detectors, in air (black line) compared with in vacuum data (red line). Note the different voltage range and log scale for type 2 detector (right). All data are acquired at room temperature.





For both samples, dark currents in air are lower than in vacuum, as expected from literature.

When the ZnO films are exposed to air, oxygen adsorption on the surface takes place resulting in the extraction of free electrons from ZnO: this creates a depletion of electrons.

The negative oxygen ions are not free carriers and cannot contribute to the conductivity of the film, inducing a low conductive surface.

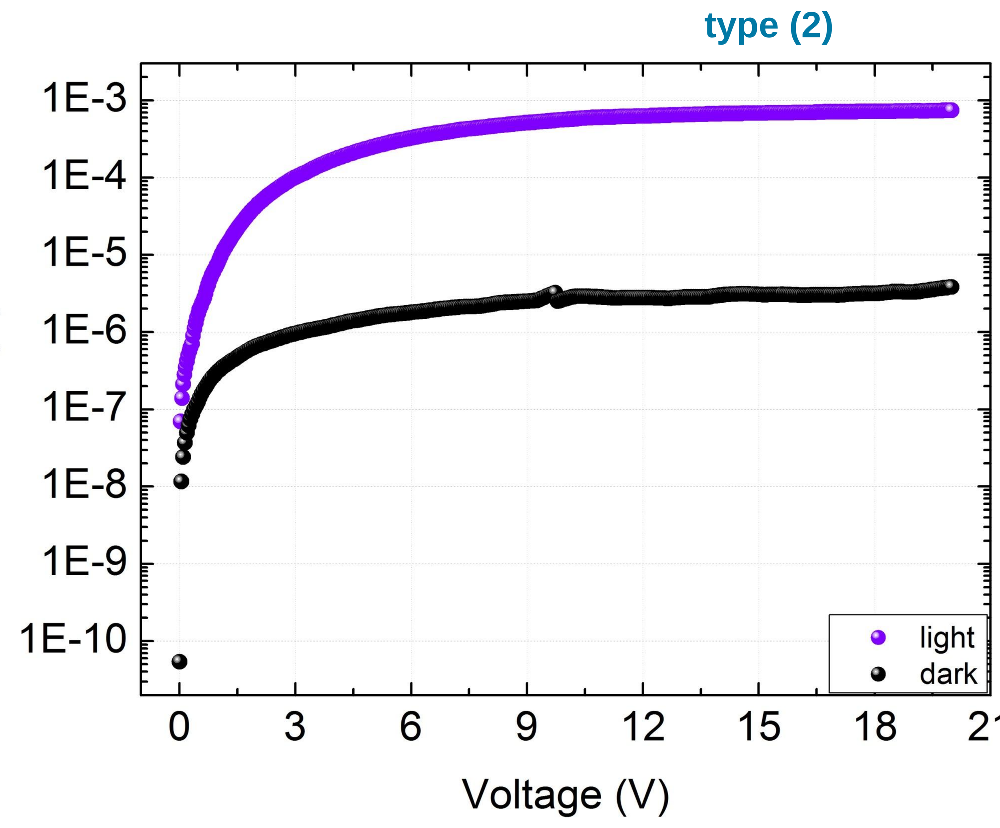
Top figure: ZnO type (1) detector.

Bottom figure: ZnO type (2) detector.

Dark and illuminated I-V characteristics of ZnO type (2) sensor at room temperature in vacuum.

I-V curves in vacuum have been acquired to compare the behavior under dark ambient (black dots) and under UV light exposition (violet dots).

The UV light source is an LED at 365 nm of wavelength with an estimated incident power of about 15 nW.



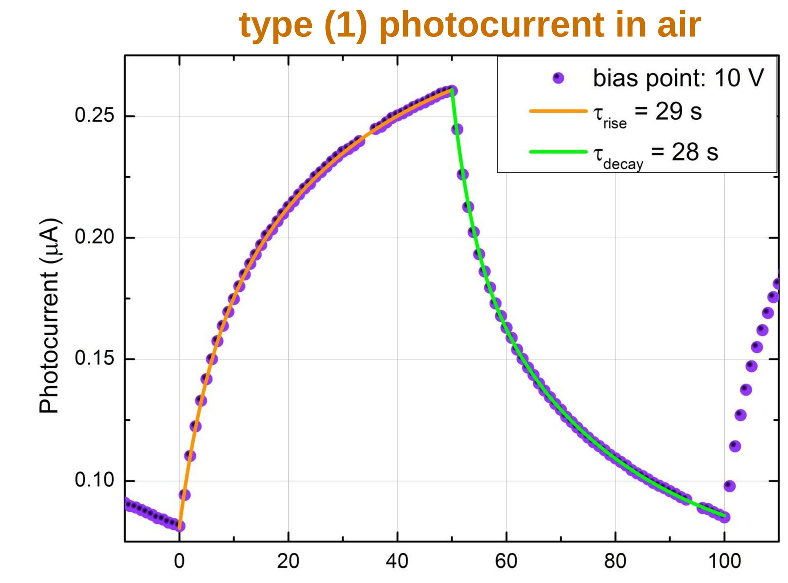
Photoresponse

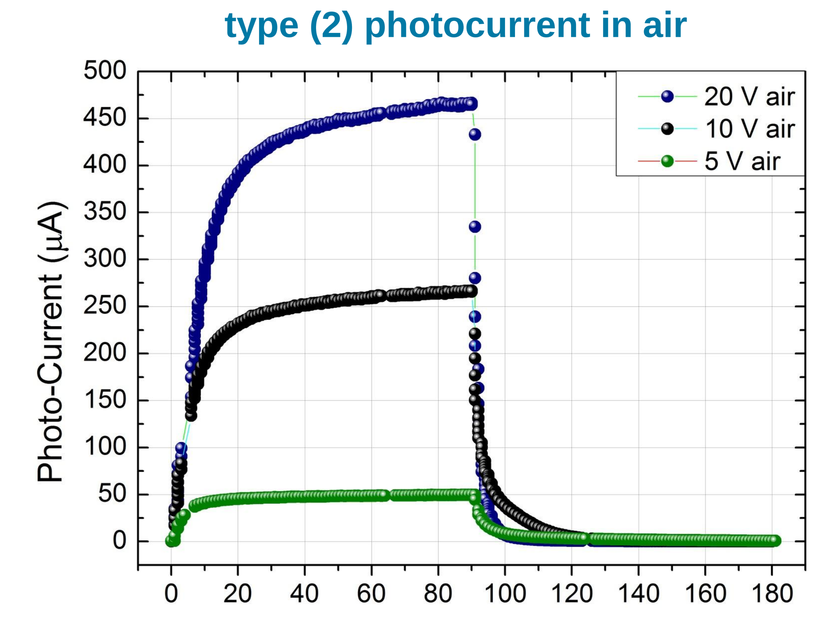
A comparison of the photocurrent biasing the detectors at different voltage points and illuminating them at 365 nm.

Type (1) detector, in air
pulse duration: 50 s
sample bias point: 10V

From the fit
rise time constant: 29 s
decay time constant: 28 s

Estimated responsivity: 15 A/W

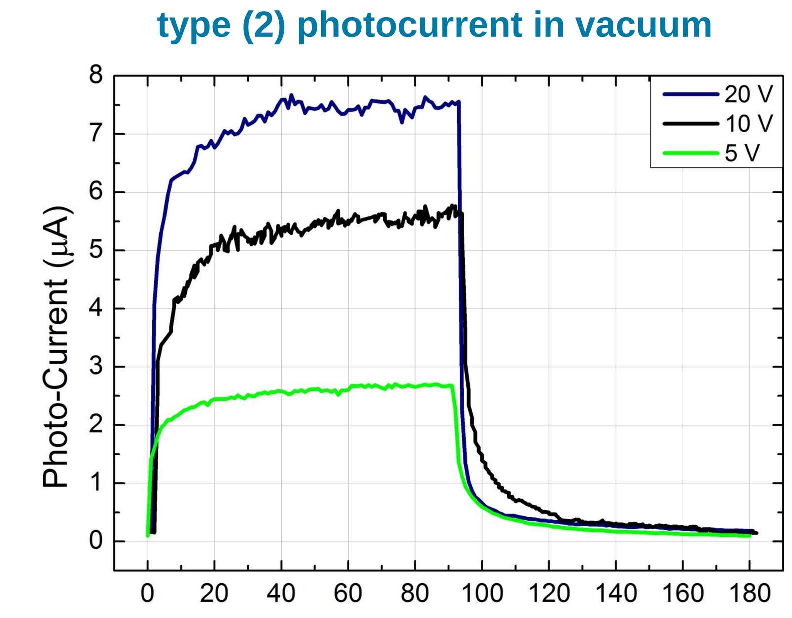


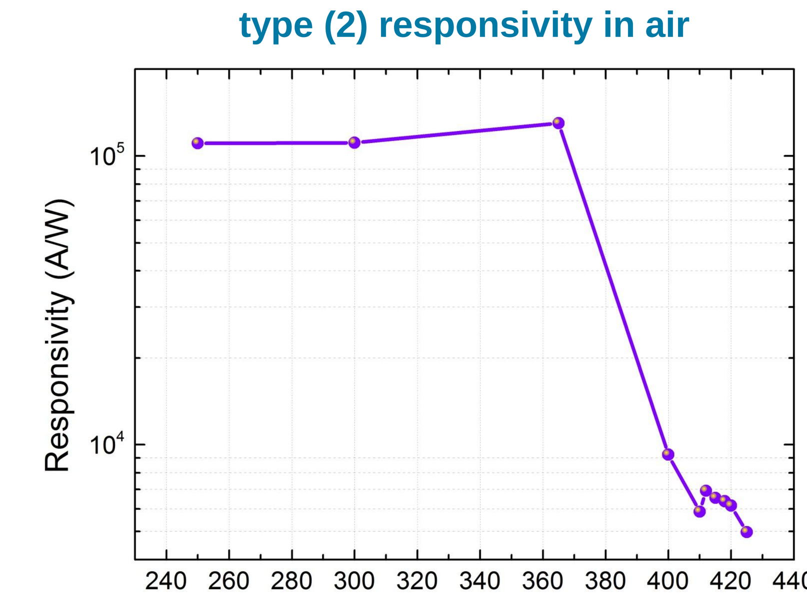


Type (2) detector. Study of the photo-response at different bias points: 5 V, 10 V and 20 V

Pulse duration: 90 s.
At 10 V, the rise time constants are 41 s, in air, and 12 s, in vacuum.
The decay time constants are 10 s in air and 13 s in vacuum.

Responsivity vs. wavelength, biasing the sample at 10 V, in air.





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Conclusion

UV photodetectors based on evaporated ZnO films (INRIM-type (1)) and epitaxial films (commercial-type (2)) have been fabricated. A solar blind responsivity up to 10^5 A/W has been measured on type (2) detectors. For both detectors slow time constant has been observed on the order of tens of seconds. High responsivity could allow to work with higher modulation signals without reaching the saturation values of the photocurrent.