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Ultraporous Electron-Depleted ZnO Nanoparticle Networks for Highly Sensitive Portable Visible-Blind UV Photodetectors

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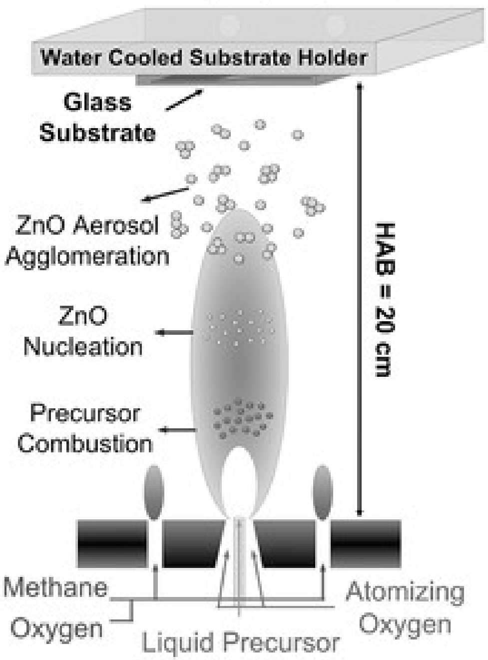
Portable visible-blind photodetectors have a wide range of application including UV dosage monitoring for skin cancer films featuring an I_{UV}/I_{dark} of 4.6×10^3 at 10 V under a UV light intensity of 0.45 mW cm^{-2}.[5] Despite these significant



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Depanjan Sarkar

Introduction

Why UV photodetector?

Portable visible-blind photodetectors have a wide range of applications:
UV dosage monitoring for skin cancer prevention
Flame and missile launch detection
Optical communication
Astronomy

Si-based photodetectors, relying on n-p type semiconductor homojunction technology, are the most established commercial solution for measurement of ultraviolet light.

But these devices have some drawbacks like high operation voltage, requirement of longpass filters to block low energy photons and cooling systems to reduce noise. Hence these are not suitable for portable or wearable technologies.

We need materials like TiO_2 and ZnO, which are inherently visible-blind and can detect low concentration of ultraviolet light by a different mechanism, namely, photogenerated variations in the concentration of surface states.

Introduction (Cont'd.)

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Among highly performing materials, zinc oxide is a promising transparent metal oxide with a room temperature bandgap of 3.37 eV that matches well the lower edge of the visible light spectrum.

Nano- and microstructured ZnO photodetectors have been produced by several methods such as RF magnetron sputtering, sol-gel, chemical vapor deposition, and pulsed laser deposition demonstrating significant improvement over bulk equivalents.

Few recent studies show that further optimization of morphology and composition of ZnO surface structures achieve a very high I_{UV} / I_{dark} ratio.

Till now, among the highest response to moderate UV light intensities has been achieved by electrospun ZnO-SnO_2 nanofibers films featuring an I_{UV} / I_{dark} of 4.6×10^3 at 10 V under a UV light intensity of 0.45 mW cm^{-2}.

Although the I_{UV} / I_{dark} ratio was high the photocurrent reach at a maximum value of 35 nA at a bias of 2.4 V.
This is quite low and makes them incompatible with integrated CMOS (complementary metal-oxide semiconductor) micro-circuitry utilized in state-of-the-art portable devices such as smartphones, watches, and security devices.

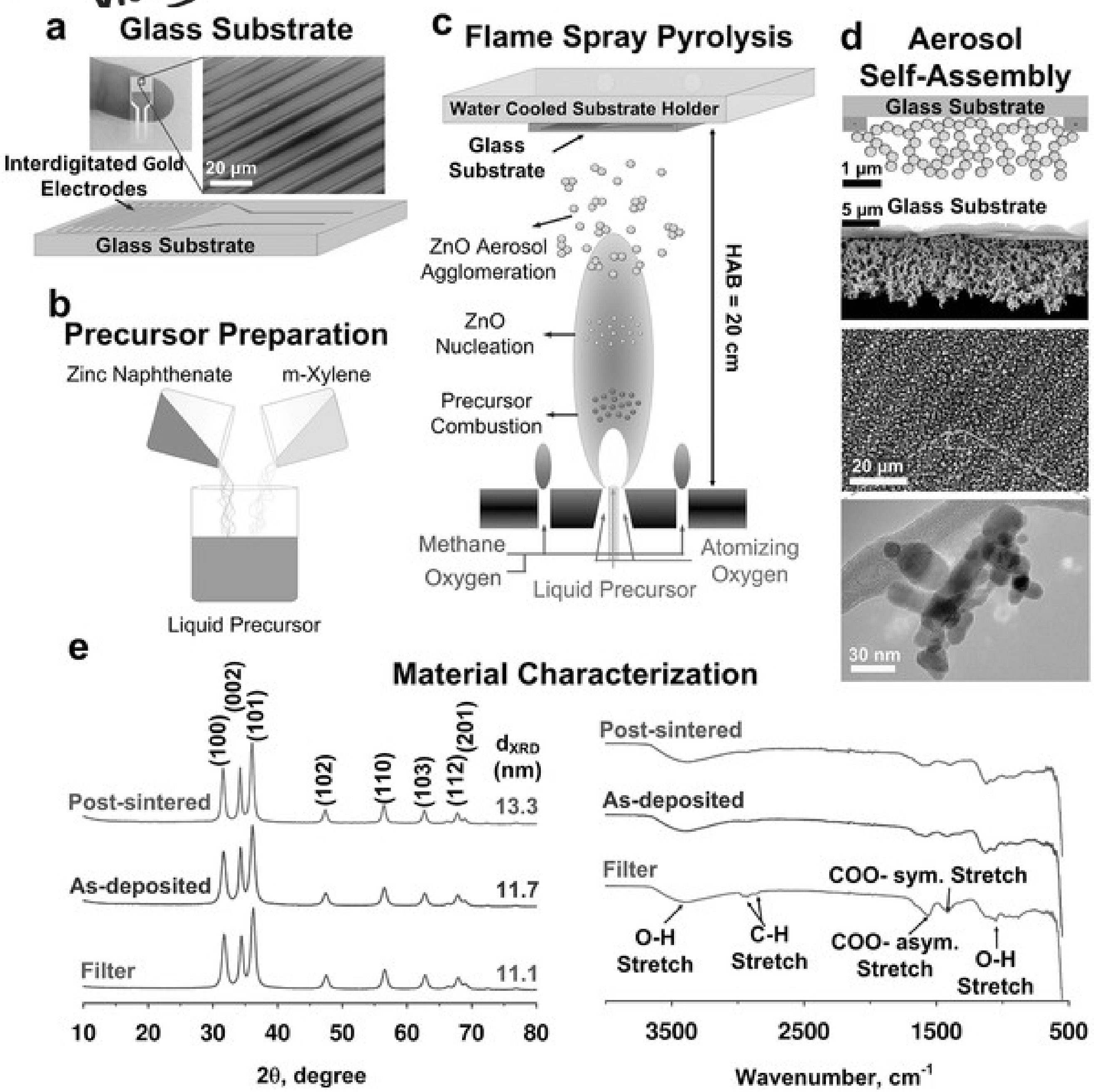
In this paper

Here, they report a novel hierarchical morphology for UV photodetectors that results in excellent selectivity, record high mA photocurrents to very low ultraviolet light intensities and nA dark currents.

They demonstrate a rapid (≤100 s) one-step synthesis and self-assembly of transparent ultraporous films composed of electron-depleted crystalline ZnO nanoparticles on low-cost glass substrates.

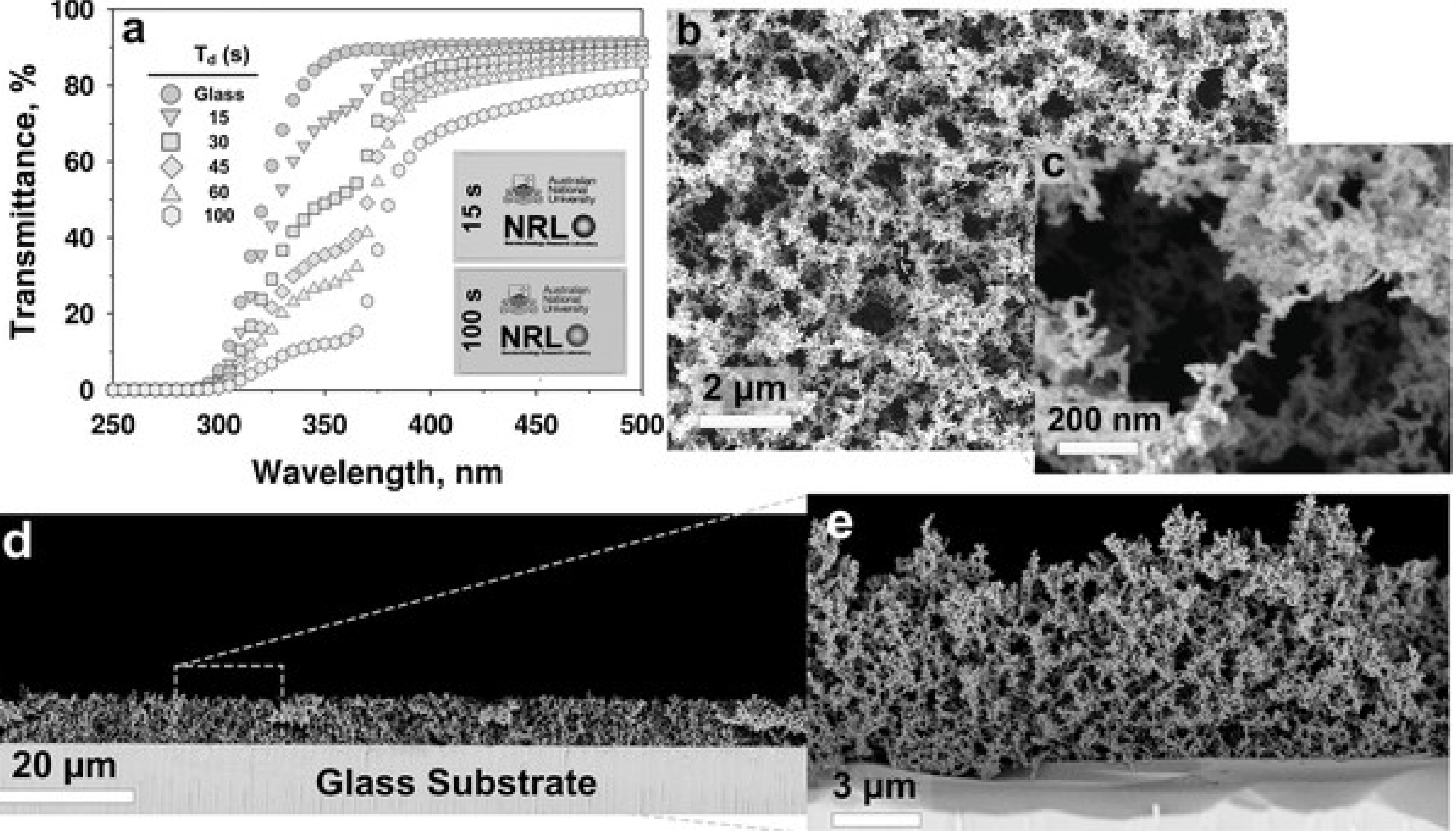
Characterization of the photodetector performance is pursued at very low light intensity (0.1 mW cm^{-2}) resulting in the highest (3.4×10^5) I_{UV} / I_{dark} so far reported.

Results and discussion



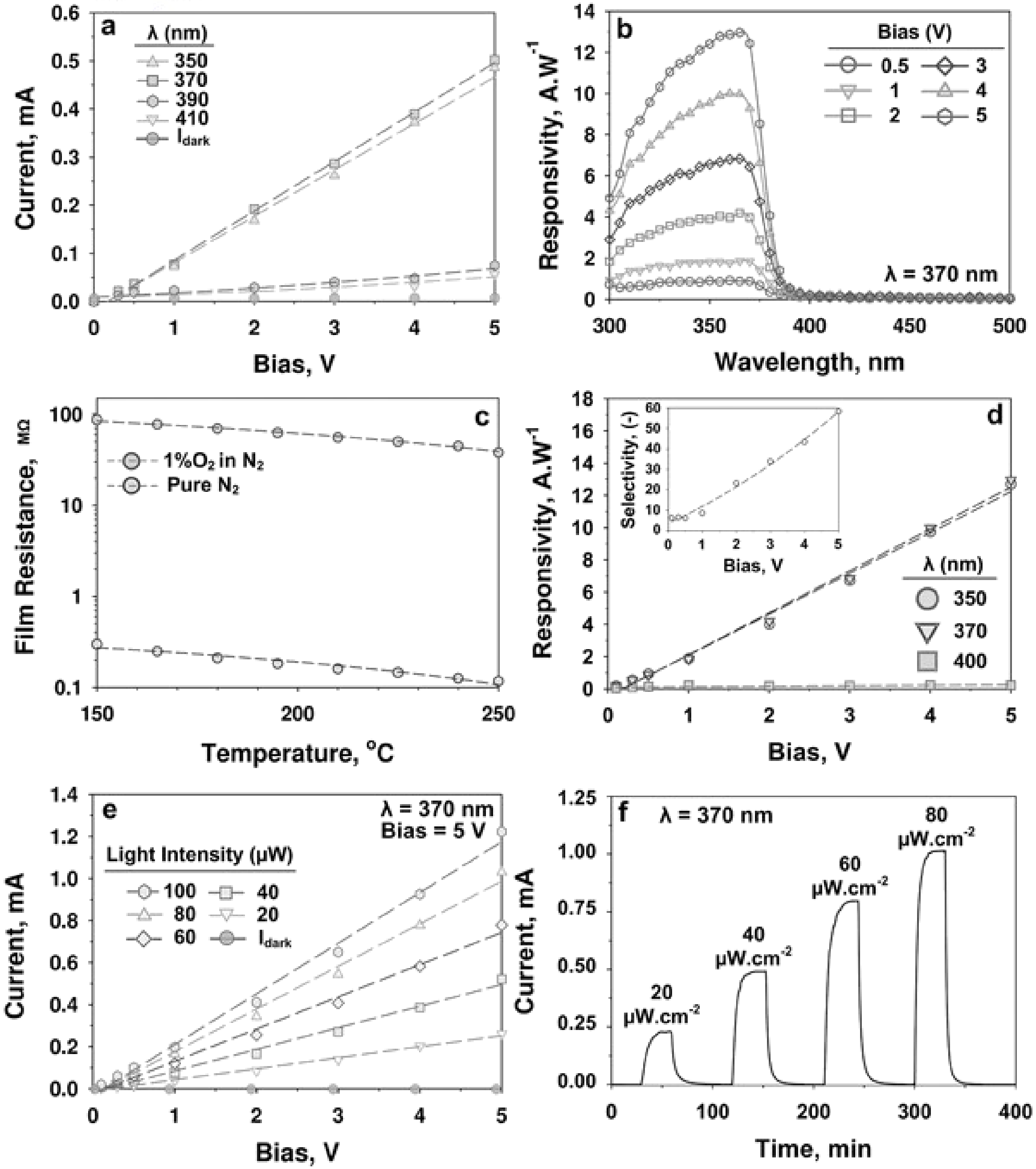
Schematics of a) a photodetector substrate and b,c) flame spray pyrolysis synthesis and aerosol self-assembly of d) ultraporous films made of electron-depleted ZnO nanoparticles at 20 cm height above the burner. e) The XRD patterns and FTIR spectra of the ZnO particles collected on the filters and substrate before and after sintering.

Results and discussion (Cont'd.)



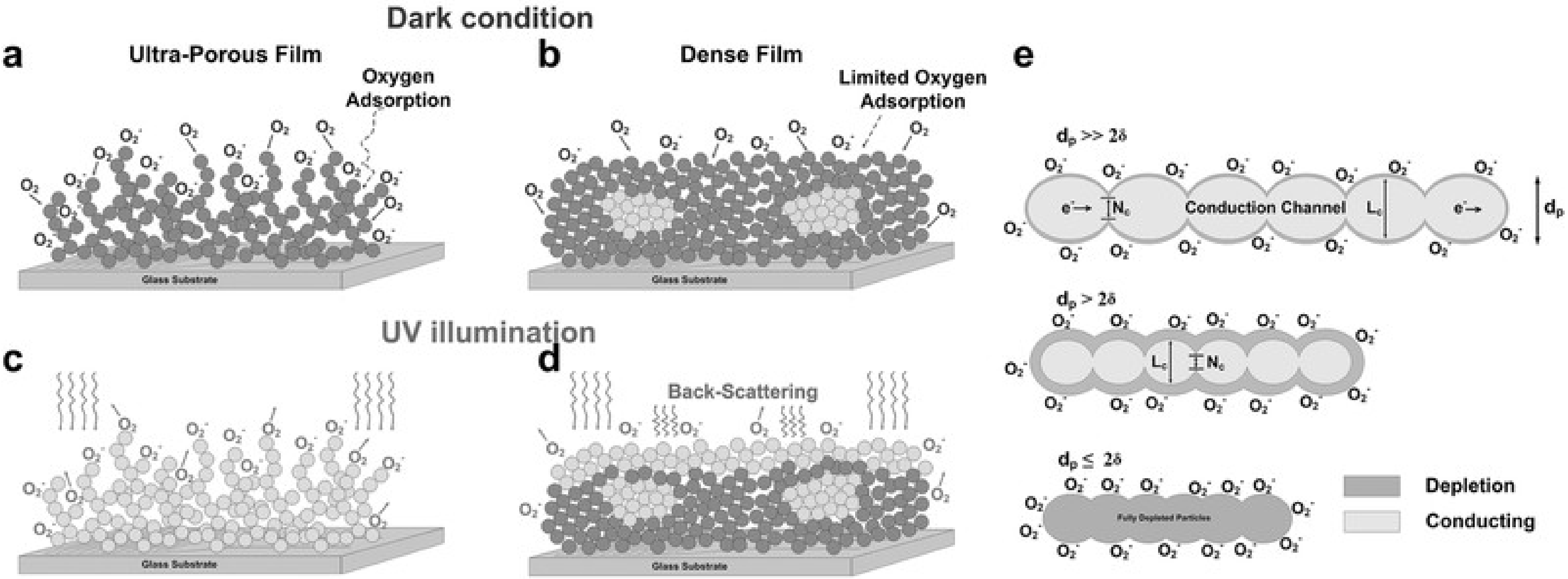
Optical transmittance spectra of ultraporous ZnO films, Inset: Optical images of ZnO films deposited for 15 and 100 s on glass substrates placed over a printed paper. SEM images of an exemplary film deposited for 100 s on a glass substrate reveal a highly porous and uniform (b,c) top surface and (d,e) cross-section.

Results and discussion (Cont'd.)



a) *I–V* characteristics and b) responsivity of the ZnO ultraporous photodetectors as a function of the applied light and bias. c) Film resistance in N_2 as a function of the temperature and O_2 content. d) Photodetector responsivity as function of applied bias at a wavelength of 350, 370, and 400 nm and (inset) I_{370}/I_{400} UV-visible selectivity. e) Photocurrent as a function of applied bias and inset, light intensity demonstrating mA currents at low light intensities of 100 μW. f) Time-dependent photodetector response to alternating exposure to increasing light intensity at a bias of 5 V and a wavelength of 370 nm.

Results and discussion (Cont'd.)



Schematic model of the photoresponse mechanisms of ZnO nanoparticle films based on the adsorption and desorption of molecular oxygen in a,c) ultraporous and b,d) dense films. e) As a function of the ratio between the particle diameter (d_p) and the Debye length (δ), three photodetection mechanisms are expected. Particle size larger than twice the Debye length of ZnO leads to grain boundary or surface controlled responses with limited photo- to dark-current ratios, whereas particle size smaller than twice the Debye length leads to fully depleted nanostructures with an on/off switching behavior.

Conclusion

They have developed a novel structural design for CMOS-compatible visible-blind photodetectors featuring ultrahigh milliampere photocurrents, very low dark currents, very low UV intensity detection limit, and low operation voltages.

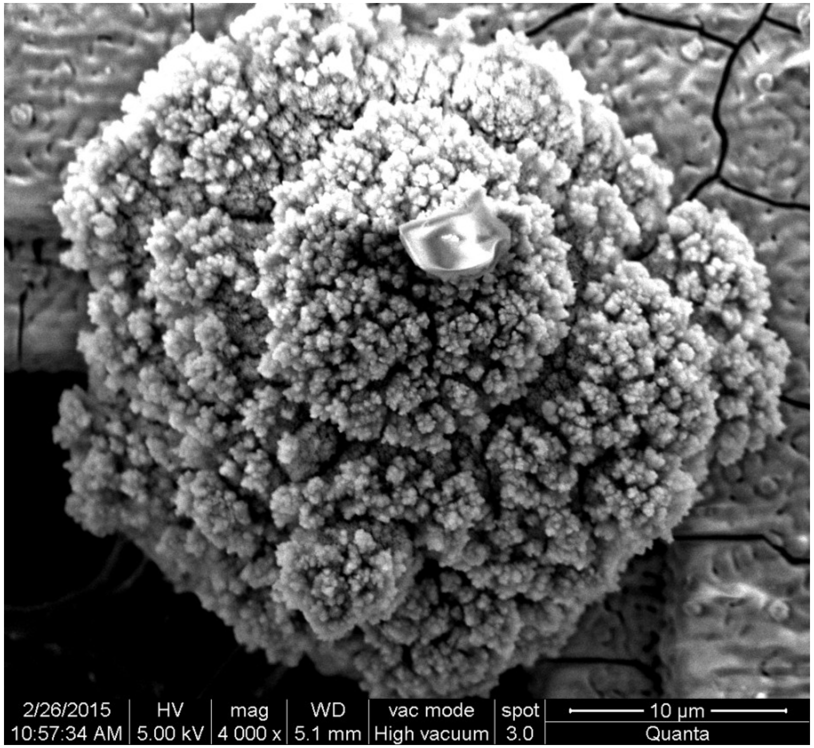
This excellent performance was attributed to the high film porosity and electron-depleted composition of these nanoparticle networks.

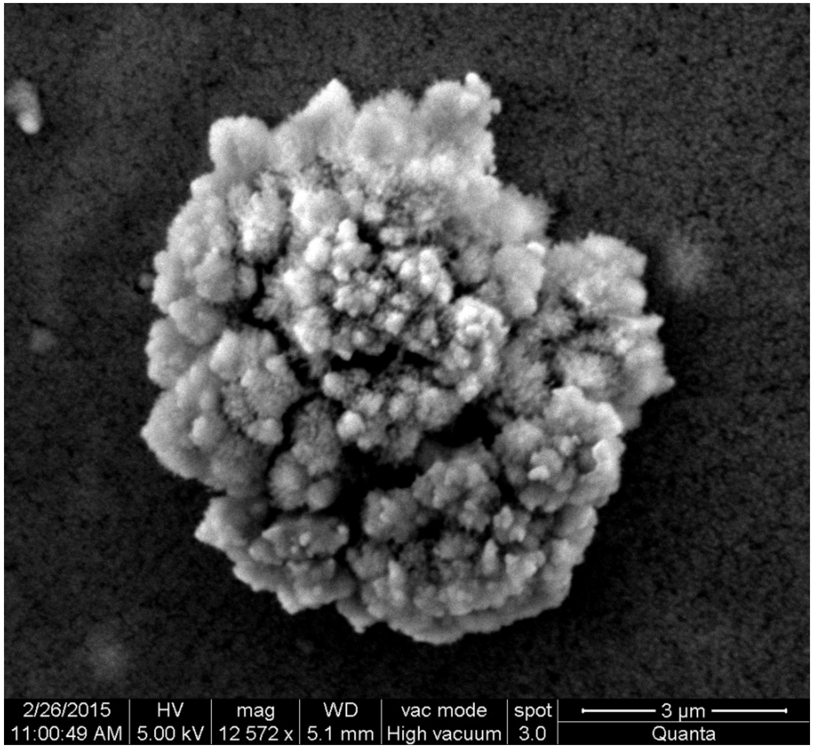
Decreasing the primary particle size below twice the ZnO Debye length and providing ultraporous film morphology enhanced adsorption/desorption of oxygen molecules from the nanoparticle surface and facilitated the penetration of UV light into the lowest film layers resulting in an on/off switching behavior to UV light exposure.

They have demonstrated a flexible and low-cost platform technology for the rapid fabrication and integration of ultraporous electrondepleted nanoparticle photodetectors in micro machinable circuitry.

Future directions:

Porous metaloxide formation using soft landing of electrosprayed ions on various substrate, under ambient conditions





Thin flims of ZnO or other metaloxides can be made on any conducting surface.
ITO-coated glass slides, ITO-coated PET sheets, etc.

Thank you