

Interface-Controlled Transport and Broadband Photoresponse in ZnO photodetectors modified with Nitrogen and Phosphorus-Doped Carbon Dots

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Summary:

In this work we investigate the influence of N- and P-doped carbon dots on ZnO thin films and their applications as photodetectors. Our results indicate that aqueous deposition leads to nonuniform interfaces and asymmetric I–V behavior, while glycerol deposition gives more uniform and symmetric transport. Under illumination, conductivity increases via photogeneration and electron injection from the carbon dots, consistent with a photogating effect. The photocurrent spectrum broadens from the UV (300–500 nm) to the visible–NIR (~1100 nm) due to carbon dot absorption and interfacial states.

Keywords: ZnO; phosphorus-doped carbon dots; photogating effect; interfacial charge transfer; asymmetric transport

Introduction

ZnO is widely employed in sensing and photodetection, predominantly in the ultraviolet range due to its wide bandgap (3.37 eV) and large exciton binding energy (~60 meV) at room temperature. Incorporating nitrogen-doped and phosphorus-doped carbon dots (CDs) with ZnO offers a route to extend sensitivity into the visible and near-infrared regions [1,2]. Understanding how these carbon dots affect charge transport and interfacial properties is crucial for developing broadband photodetectors and advanced optical sensors. In this study, we investigate the impact of Nitrogen and Phosphorus-Doped carbon dots on the optical and electrical properties of thin ZnO films.

Materials and Methods

For the fabrication of the photodetectors, silicon samples with a 100nm silicon dioxide on the surface were used. A 30nm ZnO thin film was deposited on the surface of the samples using spin-coating technique. Subsequently, the ZnO layer was patterned, and aluminum electrodes were deposited on top of the ZnO layer using lift-off process. A photograph of the device is shown in figure 1. Various types of carbon dots were deposited on top of the electrodes and the ZnO film using drop-casting. CDs with two different types of doping were solvothermally synthesized by using citric acid, urea and phosphoric acid as sources of carbon, Nitrogen and Phosphorous, respectively. P-doped, N-doped and N,P-co-doped carbon dots were synthesized. Aqueous as well as glycerol solutions were used for the dispersion of the CDs

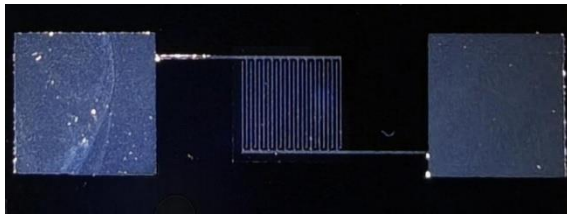


Fig. 1. Photograph of the device with the IDT electrodes.

Photocurrent measurements were carried out using a xenon (Xe) arc lamp coupled to an Oriol 7200 Monochromator for wavelength-selective excitation while photoluminescence measurements were performed using a 355 nm UV laser as the excitation source.

Results and discussion

Pristine ZnO samples show linear and symmetric current–voltage (I–V) characteristics, confirming ohmic transport. Under illumination, the photocurrent increases linearly with applied voltage, indicating classical photoconductive behavior (Fig.2).

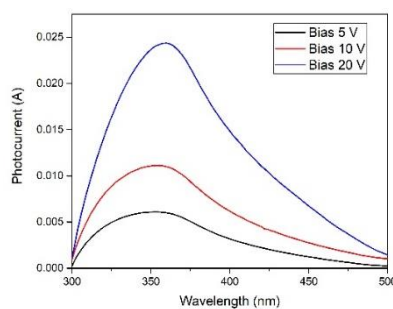


Fig. 2. Spectral dependence of photocurrents of pristine ZnO.

Following deposition of phosphorus-doped carbon dots (P-CDs) from either glycerol or aqueous dispersions, ZnO exhibits a pronounced increase in resistivity and a transition to non-ohmic transport. This behavior is attributed to interfacial charge transfer at the ZnO/P-CD interface. Electron-withdrawing surface states associated with phosphorus doping and functional groups deplete electrons from the near-surface region of ZnO, resulting in upward band bending and formation of a space-charge layer. An asymmetry in the I–V characteristics is observed after P-CD deposition, particularly for aqueous processing. This asymmetry originates from nonuniform interfacial modification of ZnO. Rapid evaporation of water leads to inhomogeneous carbon dot distribution, often with enhanced accumulation near electrode edges. These effects result in unequal band bending and trap densities at the two electrode interfaces, giving rise to asymmetric carrier

injection barriers and polarity-dependent transport. In contrast, deposition from glycerol solutions results in more symmetric I–V characteristics and photocurrent in both polarities. The higher viscosity and slower evaporation rate of glycerol promote more uniform carbon dot coverage, leading to homogeneous interfacial modification and more balanced carrier injection at both electrodes.

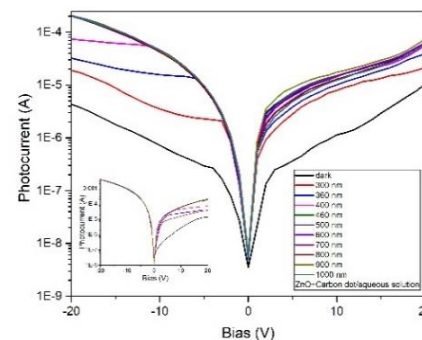


Fig. 3. Current-voltage (I–V) characteristics in dark and under illumination for deposition from glycerol solution. Inset: I–V for deposition from aqueous solution.

Under illumination in the 300–1000 nm spectral range, conductivity increases in all P-CD-modified samples. Illumination reduces the depletion region and lowers the interfacial barrier through a combination of photogenerated carriers in ZnO, photoexcitation of P-CDs, electron injection into the ZnO conduction band, and trap depopulation. This behavior is consistent with a photogating effect, where photoinduced trapped charges modulate the conductivity of the ZnO channel (Fig. 3). Detailed results for the N- as well as N,P-co-doped samples will be presented.

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