Fabrication and Characterization of Solution Processed Colloidal ZnO Quantum Dots Based Spectrum Selective Ultraviolet Photodetectors

ABSTRACT

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By

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ABSTRACT

The key motivation of this thesis is to investigate the fabrication and characterization of some ZnO colloidal quantum dots (CQDs) based spectrum selective ultraviolet (UV) photodetectors (PDs). Devices have been fabricated either in the form of interdigitated metal-semiconductor-metal (MSM) structure using glass substrates or in the Schottky diode structure on the silicon substrates by using solution processed ZnO CQDs as the active layer the UV detectors. The spin-coated ZnO CQDs have been annealed at 450 ^{o}C for the spectrum selective applications. The spectrum selectivity has been achieved by the quantum confinement of carriers in the ZnO CQDs without using any external filter which is commonly used for silicon based spectrum selective photodetectors. The ZnO CQDs have been used in the present study due to their larger surface-to-volume ratio and better performance in terms of the responsivity, spectrum selectivity and response speed another ZnO nanostructure based UV photodetectors. The particle-size dependent electronic and optoelectronic properties of the ZnO CQDs may enable us to tune the peak detectivity wavelength of the detector by fixing the QDs size to the desired value at the time of the synthesis process. Thus the solution processed ZnO CQDs also provide the platform for low-cost low-temperature fabrication of large-area UV photodetectors with a narrowband photoresponse characteristics. An attempt has also been made to improve the photoresponse of the ZnO CQDs based MSM UV photodetector by introducing a scattering layer in the device. In this case, a layer of solution processed ZnO nanoparticles (NPs) has been deposited on the interdigitated MSM UV structure fabricated on a glass substrate and UV illumination has been provided from the back side of the device to improve its responsivity while maintaining fixed spectrum selectivity. The present thesis consists of FIVE chapters which are briefly outlined in the following:

Chapter 1 presents a brief introduction of the materials, device structures and performance parameters of the photodetectors. A detailed literature survey on various ZnO nanostructure based UV phototdetectors has been discussed. Based on the observations from the literature survey, the scopes of the present thesis have been outlined at the end of this Chapter.

Chapter 2 reports the synthesis and characterizations of ZnO CQDs prepared by hot-injection method. The transmission electron microscopy (TEM) measurements ZnO QDs have shown the average particle size of ~2.53 nm which is smaller than the Bohr's radius of ~2.87 nm for ZnO. The optical and electrical properties of Au/ZnO CQDs based Schottky UV photodiode are analyzed. For device fabrication, the thin film of ZnO CQDs is deposited on the n-Si (111) substrates using low-cost spin coating method. The gold (Au) Schottky contact electrodes are then deposited on the ZnO QDs thin film by thermal evaporation method. The responsivity and contrast ratio of the photodiode is found to be 41.17 A/W and 2.289 x 10^4 respectively at - 5 V applied bias. Further, the spectral response of the photodiode has been analyzed for the spectrum from 250 nm to 800 nm. The photodiode shows the Full Width at Half Maxima (FWHM) of 90 nm with a central wavelength of 365 nm, which indicates the UV selective response of the photodiode. In further analysis, it is observed that the rectification ratio, ideality factor and barrier height of this device are measured 2.21x10^3, 2.57 and 0.80 eV respectively. The transient response of the Schottky photodiode is found to be 73.1 ms (rise-time), and 17.85 ms (fall-time) under the illumination of UV LED for a square pulse of period 1 sec.

Chapter 3 investigates the fabrication and characterization of the spin-coated ZnO CQDs based MSM spectrum selective UV photodetector on low-cost glass substrates without using any additional absorption tuning layer. The transmission electron microscopy (TEM) measurements ZnO QDs have shown the average particle size of ~2.53 nm which is smaller than the Bohr's radius of ~2.87 nm for ZnO. The annealing of the ZnO QDs shows a shift in the energy band gap from 3.231 eV to 3.136 eV corresponding to the change in the annealing temperature from 450ºC and 600ºC at the ambient environment. The responsivity characteristics have shown a spectrum selective UV photoconductor nature with a FWHM of ~49 nm and the maximum responsivity of ~15.04 A/W at 2 V bias voltage and ~360 nm operating wavelength. The response time and recovery time were measured as 7.2 s and ~18.5 s respectively.

Chapter 4 investigates the photoresponsivity and spectrum selectivity of ZnO NPs coated Ag/ZnO CQDs/Ag interdigitated MSM photodetectors of Chapter-3 under front and back illuminations. It is shown that the ZnO NPs film coated over the interdigitated MSM photodetector acts as a filter layer to enhance the spectrum selectivity at the cost of reduced responsivity of the detector under front illumination. However, the same NPs

layer acts as a scattering medium to enhance the responsivity at the cost by maintaining the fixed selectivity of the detector under back illumination condition. The measured responsivity under front illumination is 6 A/W with a FWHM of ~25 nm whereas it is increased to 20 A/W with a FWHM of ~49 nm under back illumination at an applied bias of 2 V. Thus, the ZnO NPs layer can be used to optimize the photoresponse characteristics of the ZnO CQDs based MSM photodetector by changing the direction of illumination on the device.

Chapter 5 has been devoted to summarize the major findings of the works presented in various chapters of the thesis. Finally, some future scopes of research in the related area of the thesis are outlined at the end of this Chapter.

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List of Journal Publications Related to the Thesis

1. **Yogesh Kumar**, Hemant Kumar, Gopal Rawat, Chandan Kumar, Bhola Nath Pal, and Satyabrata Jit, "Spectrum Selectivity and Responsivity of ZnO Nanoparticles Coated Ag/ZnO QDs/Ag UV Photodetectors", ***IEEE Photonics Technology Letters***, 30 (12), 1147-1150, 2018.

2. **Yogesh Kumar**, Hemant Kumar, Gopal Rawat, Chandan Kumar, Anand Sharma, Bhola Nath Pal, and Satyabrata Jit, "Colloidal ZnO Quantum Dots Based Spectrum Selective Ultraviolet Photodetectors." ***IEEE Photonics Technology Letters***, 29(4):361–364, 2017.

3. **Yogesh Kumar**, Hemant Kumar, Bratindranath Mukherjee, Gopal Rawat, Chandan Kumar, Bhola Nath Pal, and Satyabrata Jit, "Visible-blind Au / ZnO Quantum dots based Highly Sensitive and Spectrum Selective", ***IEEE Transactions on Electron Devices***, 64 (7), 2017