Fabrication and Study Properties of ZnO/SiC Quantum Dots

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Abstract. In this research, heterojunction was developed by using SiC quantum dots. High-quality n-ZnO film on commercial p-SiC quantum dots has been prepared based on utilizing pulse laser deposition technique and spin coating under the pressure of \(10^{-5}\) mbar, deposited at room temperature on a substrate of glass at various values of the thickness (113.3 and 160) nm, respectively. Then, annealed for two hours at 450 °C. ZnO/SiC QDs were described by the estimation of XRD and FE-SEM. XRD estimation uncovered that the SiC QDs prepared by spin coating with dye were hexagonal structure. The pulse laser deposition PLD method used to make ready ZnO thin film was hexagonal wurtzite with high-quality polycrystalline. UV-Visible spectrophotometer utilized in the range of (200 -800) nm to determine spectral absorbance, transmittance, and energy gap of heterojunction. The optical properties results showed that the transmittance was (98 and 87)% for ZnO film and SiC, respectively. The pure ZnO thin film allowed a direct energy gap (Eg) that was 3.8 eV, while SiC QDs were 2.65 eV direct energy gap.

Keywords. Silicon carbide quantum dots, Optical properties, Tandem.

1. Introduction

In recent years, the growing global renewable energy crisis and the quest for environmental infection treatment have become a critical affair, so it is essential to develop different effective strategies to solve these problems [1]. Solar cells (SCs) have become an effective solution to energy problems that provide safe and stable energy [2]. Due to their favorite energy obstetrics applications, SCs have gained considerable attention in the modern age [3]. A broad range of SC technologies is currently being developed and researched. These contain, as exposed in Figure 1, bulk heterojunction (BHJ), hybrid organic-inorganic SCs, and nanocrystalline (QDs) [4]. Due to its wide and direct 3.4 eV bandgap, hexagonal wurtzite structure, as shown in Figure 2, and high exciton binding energy of 60 meV at RT [5-7]. ZnO is a promising semiconductor material for optoelectronic applications in the ultraviolet (UV) range. An alternative approach to using the excellent optical properties of ZnO is to use p / n-heterojunctions that are easy to realize by increasing n-type ZnO on acceptable p-type semiconductors such as Al\(_2\)O\(_3\), GaN, GaAs, Si, and SiC [8-10]. Amid these materials, SiC attracts excessive interest because it is, of course, a p-type semiconductor with Eg = 3.0 eV (for 6H-SiC). It has been exposed that zinc oxide and SiC can create high-quality interfaces that promise to apply this material combination to different optoelectronic tools, such as LED, photodetectors, and SCs [11]. Several techniques were used to prepare ZnO thin films, such as sputtering, sol-gel, thermal oxidation, spin coating, evaporation, CVD,
Compared with other approaches, the pulse laser deposition technique allows the growth of high-quality films of oxide materials at moderately low substrate temperatures. In addition, the method provides the creation of multilayers that are suitable for different crystalline compositions. This is due to the high energy in the ablated particles' laser-generated plasma plume [14-15].

Attractive requests in optoelectronics and microelectronics are given by silicon carbide (SiC), a wide bandgap semiconductor with excellent thermal conductivity, high saturated electron drift speed, high electric field breakdown, and high chemical constancy [17-18]. The SiC system has the advantages of high temperature, frequency, and chemically aggressive environment activity. In the spectrum from green to ultraviolet light, SiC nanostructures can be tuned in size to emit light [19]. Besides, photoluminescence performance in SiC nanocrystals is significantly improved by some orders of greatness associated with that of bulk material [20]. Very recently, the applicability of quantum dots SiC to fluorescence imaging of genetic living cells was shown by Botsoa et al.[21]. Recently, Reboredo et al. [22] examined SiC nanoparticles up to 3 nm in diameter and showed that the structure and termination of the surface play a dominant role in determining optical gaps and thermodynamic stability. The current research has studied quantum dots' effect on the structural, morphological, and optical properties of the fabricated films formed by solar cells.

2. Experimental details

Thin film of ZnO on glass and wafer silicon substrate was prepared by the pulsed laser deposition technique. Zinc oxide powder was pressed under a 7 tons press to form disk-shaped with dimensions of (2.5, 0.5) cm, respectively. Then, it was dry at 150 °C and 1 hr. inside a vacuum oven compatible. Before deposition, the glass substrate was cleaned by rinsed in distilled water to eliminate all oil or dust on the surface and dried by cold air. ZnO target previously obtained was used to produce a thin film on a substrate by PLD method (Nd: YAG laser wavelength 1064 nm), the width of the pulse is 10 ns, rate of repetition 6 Hz, this operates at 120 mJ to ablade the goal. Power supply, pressure, and temperature for deposition are (220 v, 250 °C, 10⁻⁵ mPa), respectively. After that, annealing thin film at 450 °C for 2 hr. The distance was 3.5 cm between the substrate and the target. The target is necessary to rotate during the deposition to achieve uniform deposition. Quantum dots of SiC on glass substrate was prepared by spin
coating technique. After that, annealing thin film at 450 °C for 2 hr. The target is necessary to rotate during the deposition to achieve uniform deposition.

2.1. Method of spin coating

Samples were ready by incomes of a spin coating technique. The silicon carbide was dissolved in a 20:80 ratio (SiC: Dye) dye by magnetic stirrer at 50 °C. At room temperature, the perfect solution was dropped onto glass-based via a pipette. The solution was coated on glass substrates with an angular rotation rate of 2500 rpm for 1 min. At a flow rate of 20 sccm (cm³/min) at 450 °C for 2 hr., the samples were put in a tube furnace under the N₂ stream.

3. Results and discussion

3.1. XRD results

The ZnO film XRD spectrum strengthened with protruding reversal planes at 450°C is shown in Figure 3. The XRD spectrum peaks agree to those from the JCPDS data of the ZnO patterns (PDF, Card No: 36-1451), with a structure of hexagonal wurtzite. No other impurities peaks observed in the XRD diffractograms revealed that the crystalline ZnO formed well for all samples. Thin-film deposited on a glass substrate with a thickness equal to 113.3 nm by pulse laser deposition method at room temperature. The crystallite size of the pure ZnO film was calculated using the Debye-Scherrer formula according to Equation (1) below [23]. The results are listed in Table 1.

\[ D = \frac{0.94\lambda}{\beta \cos \theta} \]  

Where; D crystallite size, \( \lambda \) =1.54059 Å, \( \beta \) broadening of diffraction line, and \( \theta \) angle of diffraction.

The EDS spectrum of thin-film ZnO at the required process parameters indicates that the film contains 64.3% O and 35.7% Zn (mass fraction), the structure of the thin film is expected to be crystal. Lower incorporation of nano-particles in thin films can be ascribed to the smaller size of the particles.
Table 1. The obtained result of the XRD for pure ZnO thin film.

| No. | Peak 2θ (deg) | d (Å) | FWHM (DEG) | The crystallite size (nm) |
|-----|---------------|-------|------------|--------------------------|
| 13  | 36.2123       | 2.47861 | 0.27110    | 31.01                    |
| 2   | 31.7216       | 2.81850 | 0.28730    | 29.169                   |
| 9   | 34.3735       | 2.60688 | 0.29000    | 28.95                    |

Figure 4 shows that the XRD patterns of SiC NPs prepared by spin coating with dye and heat-treated at 450 °C for 2 hours on a glass substrate at thickness 160 nm. Peaks of XRD were recorded between (20°-80°), with values for 2θ of 34°, 35.7°, 38.7°, 60°, and 73.6° corresponding to (101), (102), (103), (110) and (203) planes, obtaining hexagonal SiC, according to JCPDS card number 00-029-1128. This result was similar to research [24]. The EDS spectrum of SiC QDs at the required process parameters indicates that the film contains 18.57% C and 48.58% Si. The structure of the film is expected to be amorphous.

Figure 4. XRD for SiC NPs at thickness 160 nm.

3.2. FE-SEM

The morphologies of the generated ZnO particles prepared by pulsed laser deposition technique at 450 °C was analyzed using FE-SEM. Figure 5 shows an image at a magnification of 60 Kx for the ready ZnO NPs. The image shows that the nanoparticle's shape is almost spherical and having a hexagonal wurtzite structure. The thicknesses of ZnO films were measured by Spectroscopic Ellipsometry. The thickness of the prepared films was 113.3 nm for PLD. Figure 6 shows FE-SEM patterns of SiC QDs prepared by spin coating with dye and heat-treated at 450 °C for 2 hours on a glass substrate at thickness 160 nm. Notice all of the SiC QDs are form a nearly monosized structure with semi-spherical morphology, at diameters of approximately 3 to 10 nm. Furthermore, the grains are not separated from each other. In other words, the produced formed agglomeration.
3.3. Optical measurements

The pure ZnO and SiC quantum dots' optical characters were investigated using the spectrophotometer defined by (JAPAN 1800 UV-Visible) for wavelength range (200-800) nm. Analyzing the absorbance spectrum can be used for determining some of the optical properties, such as transmittance ($T_\lambda$) and the optical energy gap ($E_g$). Figure 7 shows the absorbance scale as a function of the wavelength (200-800) nm for ZnO film. The ZnO spectrum showed that film has a high reply in the UV region, and reductions exponentially as the wavelength in the visible region increases while the glass spectrum in the visible region is transparent. This means that when passing through the thin film, the released photons from this film will not undergo any absorption. Except for the wavelength of 364 nm, where there is a slight absorption peak. Optical properties are mainly influenced by the microscopic structure and distribution of NPs size.
From Figure 8, it can be observed that the spectra of absorbance in terms of the SiC QDs wavelength at thickness 160 nm and temperature of annealing equal to 450 °C, we noted that the absorbance decreased with increasing the wavelength. Physically this means that the falling photon could not excite the electron and transfer it from the valency pack into the conduction beam because the energy electron value is higher than the energy of the falling photon. Also, the QDs structure will exhibit a high impact of quantum confinement with its size less than its radius of exciton Bohr. The size distribution of the SiC QDs was homogeneous in the size of 3-10 nm. The SiC nanostructures' size could be adjusted for emitting the light within the green light range to ultraviolet one, while the bulk SiC was a wide bandgap material having 2.4 eV. Additionally, the photoluminescence efficiency in the SiC nanocrystals is substantially enhanced by many times compared to bulk counterparts [19].

The ZnO film transmission spectrum deposited on glass substrates at a range of (200-800) nm is shown in Figure 9. At room temperature, all the calculations are carried out. As can be observed, the sample's average optical transmission in the visible range is 98 percent. Furthermore, it is important to remember that the film has an acceptable thickness of 113.3 nm, leading to a good optical quality of the ZnO materials, provided that it is in good agreement with the literature article [25]. Figure 10 demonstrates the transmittance spectra of SiC QDs prepared by spin coating with dye and heat-treated at 450 °C for 2 hours.
on a glass substrate at thickness 160 nm. We notice silicon carbide quantum dots have 87% of the optical transmission. In other words, it increased optical transmittance with wavelength and decreased with the decrease of grain size, which could probably be due to increased crystallization.

Figure 9. The transmittance of ZnO thin film. Figure 10. The transmittance of SiC QDs.

The curve can be fitted with a straight line very well for a higher energy range. From Figure 11, it is clear that the direct energy gap of ZnO film (3.8) eV. It is evident from Figure 12 that the direct energy gap of SiC QDs (2.65) eV., as the thickness 160 nm at room temperature. The increase of the energy gap is attributed to the decrease of grain size and disorder in the material, which means allowing secondary excitation levels inside the energy gap, which leads to increasing the width gap. The density decreasing of localized states inside the energy gap causes the increase of the optical energy gap.

Figure 11. The energy gap of ZnO thin. Figure 12. The energy gap of SiC QDs.
4. Conclusions
The XRD analysis of ZnO/SiC films points out that it has more quality polycrystalline with exhibited (101) and (102) for ZnO film and SiC QDs, respectively. Small crystallite size that calculated from FE-SEM. The size of 3-10 nm in diameter for SiC QDs, while the average grain size for ZnO film was 48.8 nm, making the films' surface more interactive with the incident photons, leading to a more efficient solar cell. The results of the OP showed that the T is 98% for ZnO film at thickness 113.3 nm, whereas the transmittance is 87% for quantum dots at thickness 160 nm, the work of these films extra suitable for SC manufacture. Intrinsic similarities exist among the optical structural and morphological properties of films of ZnO/SiC, which are essential for the future analysis and application of the solar cells and thin films of TCO.

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