Preparation and Characterization of Silicon Carbide by Pulse Laser Deposition as Heterojunction Solar Cell

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Abstract

Silicon Carbide (SiC) thin film nanostructures were prepared by using the pulse laser deposition technique at room temperature with varying lasing energies to optimize the quality of the films. Structural properties of the prepared films were identified by X-Ray diffraction patterns, atomic force microscopy, UV-visible spectroscopy, and the current-voltage characteristic curve. The results showed that good quality silicon carbide films can be prepared by pulse laser deposition technique on silicon p-Si (111). The X-Ray diffraction of the prepared films showed an amorphous structure that turned into polycrystalline when annealed to 400oC. It can be seen from I-V characteristics of SiC/Si solar cell that the photocurrent density increased with increasing bias voltage. Moreover, the study showed that the higher falling factor was (0.46) and efficiency was (3.46).

Key Words: Silicon Carbide, Pulse Laser Deposition, Solar Cell, Nanostructures, Heterojunction Solar Cell.

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Introduction

One of most important non-oxide ceramics is silicon carbide, which has properties that qualify it to work in harsh environments such as high temperature and high corrosion effects. Thus, it can be utilized in a variety of industrial applications (Matovic *et al.*, 2014) (National and Recherche, 2008). SiC was first synthesized by Acheson (1892) using what is called Acheson process. It can also be synthesized by different methods such as chemical vapour deposition (CVD) (Brütsch, 1985), direct combustion (Mukasyan *et al.*, 2013), detonation (Langenderfer *et al.*, 2019), carbothermal reduction (Martin, Ecke and Müller, 1998), physical vapour deposition (PVD) (Yi *et al.*, 2007), sol-gel (Raman, Bahl and Dhawan, 1995), liquid phase sintering (LPS) (Van Dijen and Mayer, 1996), and pulsed laser deposition (PLD).

SiC properties are affected by the preparation method used, including PLD (Casady and Johnson, 1996). Many studies investigated the properties of SiC; however, the beginning of interest in the electrical properties of SiC thin films was in the 1970s (Abderrazak and Hadj Hmi, 2011). Soto et al. deposited SiC and SiC_xN_y films using PLD technique by KeF excimer laser under Ar and N_2 atmospheres. They investigated the influence of pressure on the bonding and concentration of atoms and optical properties (Soto *et al.*, 1998). The structural, optical and morphological properties of SiC films on Si(100) substrates using PLD method at different temperatures were investigated in (Katharria *et al.*, 2018), the prepared films showed a nanostructured formation.

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SiC thin films on Si (100) and (111) substrates were prepared using PLD, optical and morphological properties were investigated as well (Gusev, Ryndya and Zenkevich, 2014). 3C–SiC nanowires were prepared using carbothermal reduction technique combined with two-stage temperature program (Shen *et al.*, 2019). C-SiC films on Mg (100) substrates at 800°C were deposited.
Moreover, the structural, Raman scattering, and I-V characteristics of the prepared films were investigated (Paneerselvam *et al.*, 2019). The optical and morphological properties of SiC aerogels with higher specific area were prepared by carbothermal reduction technique. The SiC nanowires prepared by vapor-solid technique for Al_2O_3, which appeared on the surface of the aerogels were (30-90) nm (Zirakjou and Mehrdad, 2020).
This study focused on the preparation and evaluation of SiC nanostructure thin films as solar cells using PLD technique at room temperature (RT). To the best knowledge of the authors, the silicon carbide thin films were not previously prepared via laser pulse deposition technique with 1064 nm of wavelength.

Methodology

PLD technique is used to deposit SiC thin films as shown in figure (1), where this technique consists of vacuum chamber evacuated to pressure (10^{-3} mbar) and Q-switched Nd:YAG laser. The incident Nd:YAG laser beam at (600 mJ to 900 mJ), comes through a window and focused on the surface of the SiC target with an angle of 45°. P-type Si (111) substrate is placed in front of the target, and its surface is parallel to it. A suitable gap is kept between the substrate and the target, so that the substrate holder does not impede the incident laser beam. The films were deposited on glass and Si substrates at RT. Nd:YAG laser with (1064 nm) wavelength, (pulse width 10 ns), and repetition frequency (6 Hz) for 1500 laser pulses was used as a deposition technique. Next the prepared films were annealed at 400°C for one hour to complete the crystalline of films.

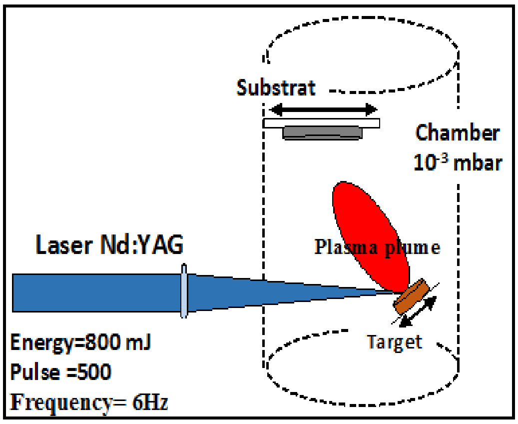


Figure 1. Diagram of PLD system using Nd: YAG

Results and Discussion

Structural properties

At 600 mJ of lasing energy, the prepared films have an amorphous structure, and they became polycrystalline structures at (700, 800, and 900 mJ) when annealed at 400°C as shown in figure (2). The peaks located at (35.61^0, 41.42^0 and 60.10^0) of X-Ray diffraction (XRD) belonged to the (111), (200) and (220) planes for cubic SiC structure, which was identical to standard card number (JCPDS 96-900-8857). These results are in good agreement with (Vyshnyakova *et al.*, 2006). Peaks intensity increased with increasing lasing energy i.e. increasing the crystallinity is related to the increase in the laser energy and heat of plasma plume (Itina *et al.*, 2002). Crystalline size (calculated using Scherrer's formula) increased with increasing lasing energy. Crystalline size was (8.6 - 11.5) nm, (8.8 - 13.3) nm and (9.4 – 15.3) nm for (700, 800, and 900) mJ respectively. Table (1) shows the structural parameters for SiC thin films.

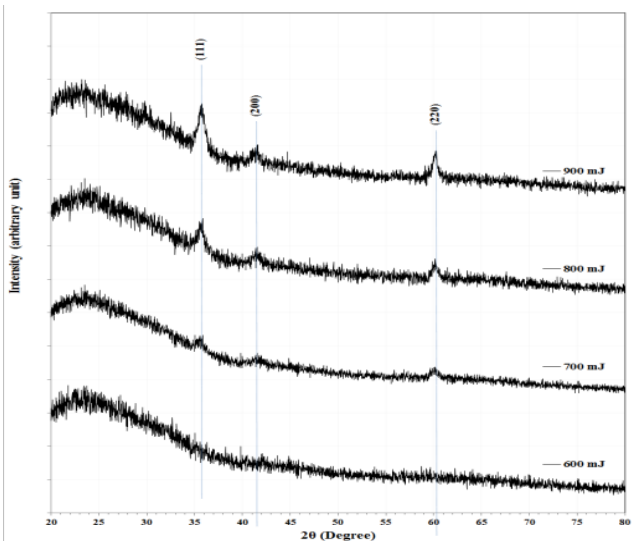


Figure 2. XRD pattern of the prepared SiC thin films at different laser energies

Table 1. Structural parameters of the prepared SiC thin films with laser energies

Energy (mJ)	2θ(°)	FWHM (°)	d_{hkl} Exp.(Å)	G.S (nm)	Lattice Phase	Hkl	card No.
600	Amorphous						
	35.6100	0.970	2.5191	8.6		(111)	
700	41.4200	0.930	2.1782	9.1		(200)	
	60.1000	0.800	1.5383	11.5		(220)	
	35.6500	0.950	2.5164	8.8		(111)	
800	41.4800	0.910	2.1752	9.3	Cubic	(200)	96-900-8857
	60.1500	0.690	1.5371	13.3		(220)	
	35.7000	0.890	2.5130	9.4		(111)	
900	41.5000	0.870	2.1742	9.8		(200)	
	60.1400	0.600	1.5373	15.3		(220)	

Morphological properties

Figure (3) illustrates atomic force microscopy (AFM) images and their granularity accumulation distribution for pure SiC thin films deposited by laser pulses on Si substrate using three laser energies (700, 800, and 900) mJ. For AFM parameters, the average diameter increased from 62.50 nm to 84.41 nm, while the average roughness decreased from 15.1 nm to 4.56 nm at 700 mJ and 900 mJ lasing energies respectively.

Table (2) illustrates that these results are in good agreement with (Vispute *et al.*, 2000).

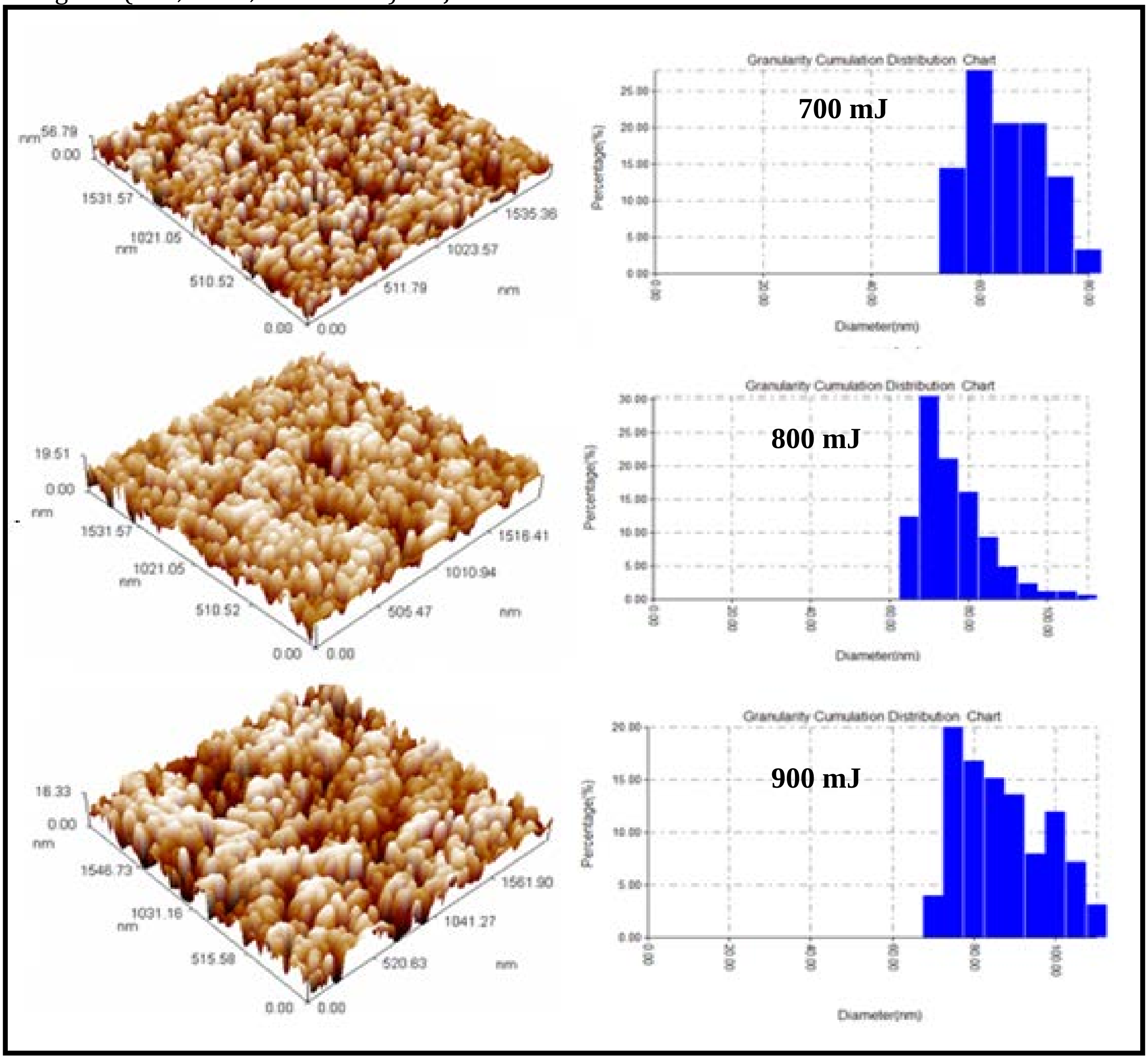


Figure 3. 3D AFM images and their granularity accumulation distribution for the prepared SiC thin films by different laser energies

Table 2. AFM parameters of the prepared SiC thin films by different laser energies

Laser energy (mJ)	No. of pulse	Average Diameter (nm)	Roughness Ave. (nm)
700	1500	62.50	15.1
800	1500	73.48	4.36
900	1500	84.41	4.56

Optical properties

Optical properties of the deposited films on glass substrates were measured using UV-Visible absorption spectrum analysis within the wavelength (300 to 1000) nm.

Figure (4) shows the transmittance spectra for SiC deposited thin films on glass substrates employing various laser energies (700, 800, and 900) mJ. In general, the prepared films achieved the highest transmittance intensity at the visible region of the spectrum; greater than 90% (i.e. the absorbed spectrum was the least) with prepared films by 800 mJ. The reduction in the transmittance of the prepared films by 700 mJ probably occurred due to increasing its reflectivity, which is related to surface smoothness as shown in AFM image analysis above.

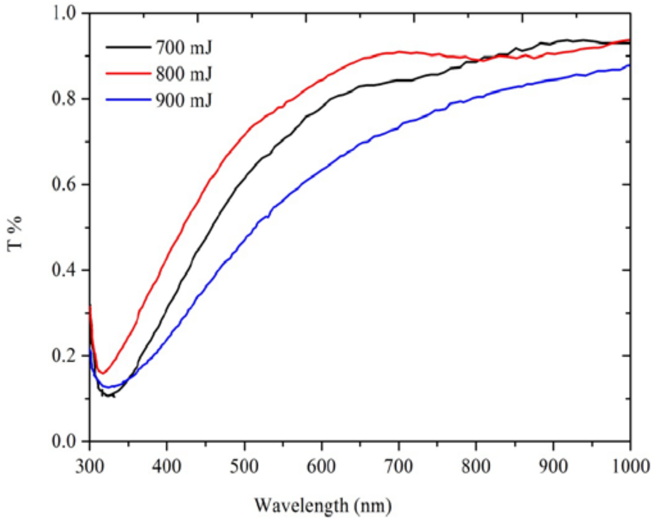


Figure 4: The variation of transmittance as a function of wavelength for prepared SiC thin films on glass substrates with different lasing energies

Energy gap (E_g) values for the deposited SiC films on glass substrates have been determined using Tauc formula as follows.

$$(\alpha h\nu)^n = A(h\nu - E_g) \qquad (1)$$

Where A is constant, h is Plank's constant, ν is the frequency of incident photon, α is the absorption coefficient, $h\nu$ refers to the incident photon energy and $n = 2$ to direct transmission (Rzaij *et al.*, 2018). Energy gap decreased from 3.17 eV to 2.81 eV at RT for different lasing energies and the reduction of grain size led to increase energy gap due to the quantum confinement of electrons (Quinten, 2011), as shown in figure (5). This result is consistent with previous researches such as (Khashan, Ismail and Mahdi, 2018) and (Dey and Khare, 2016)

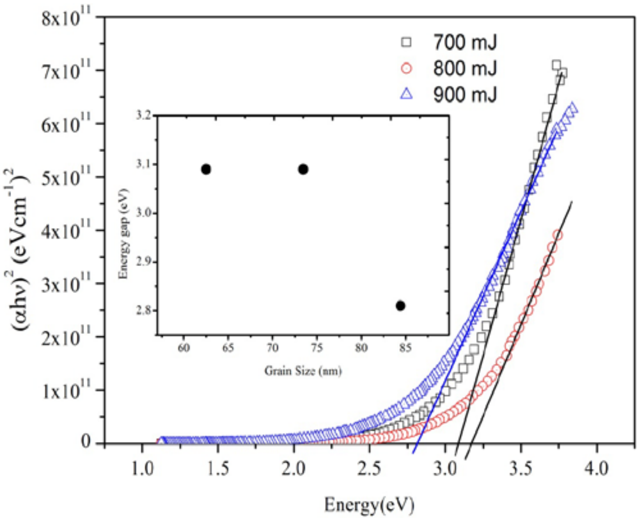
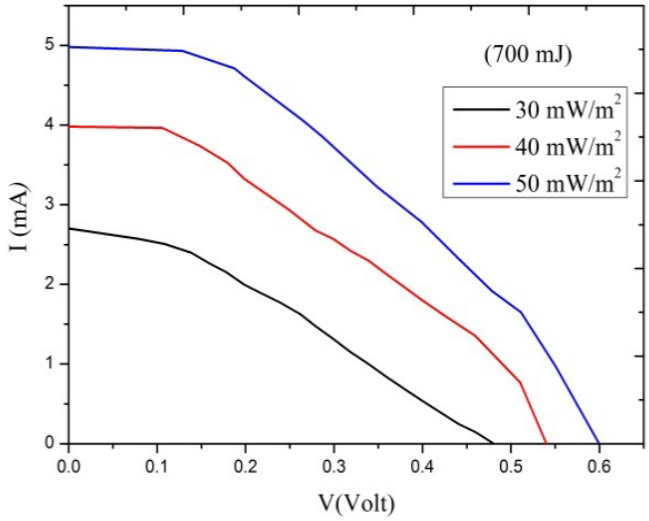


Figure 5. The variation of $(\alpha h\nu)^2$ versus photon energy for the prepared SiC thin films on glass substrates with different laser energies

I-V Characteristics

To evaluate the quality of a solar cell device, in addition to its electrical behavior; current-voltage (I-V) measurements were performed. I-V characteristics of the prepared SiC/p-Si solar cell at different laser energies $(700, 800, and\ 900)\ mJ$ under $(30, 40, and\ 50)\ mW/cm^2$ of the illumination powers with the forward applied voltage are shown in figure (6). Increase of energy gap led to reducing light absorption in the upper layer (SiC), which increased the intensity of the incident light on the Si layer. Photocurrent density increased due to the absorbed light, which generated charge carriers in the conduction band of the lower layer (Si) (Ramizy *et al.*, 2011). Furthermore, increase in photocurrent density, enhancement films crystallinity, and reduction in grain boundaries led to the increase of the charge carriers.

Solar cell parameters such as the dark voltage (V_o), short circuit current (I_{sc}), falling factor $(F.F)$, and the solar cell efficiency (η) were calculated from figure (6). Based on calculations, η was reported to increase proportionally with illumination powers in all prepared cells. The optimized values were noticed in the produced cell at 800 mJ of laser energy, η was (2.69, 3.24, and 3.46) % for $(30, 40, \text{and } 50)\ \mathrm{mW/cm^2}$ of illumination powers respectively. Also, η changed according to the change in the energy gap of SiC layers as shown in table (3), which illustrates the optimum condition.



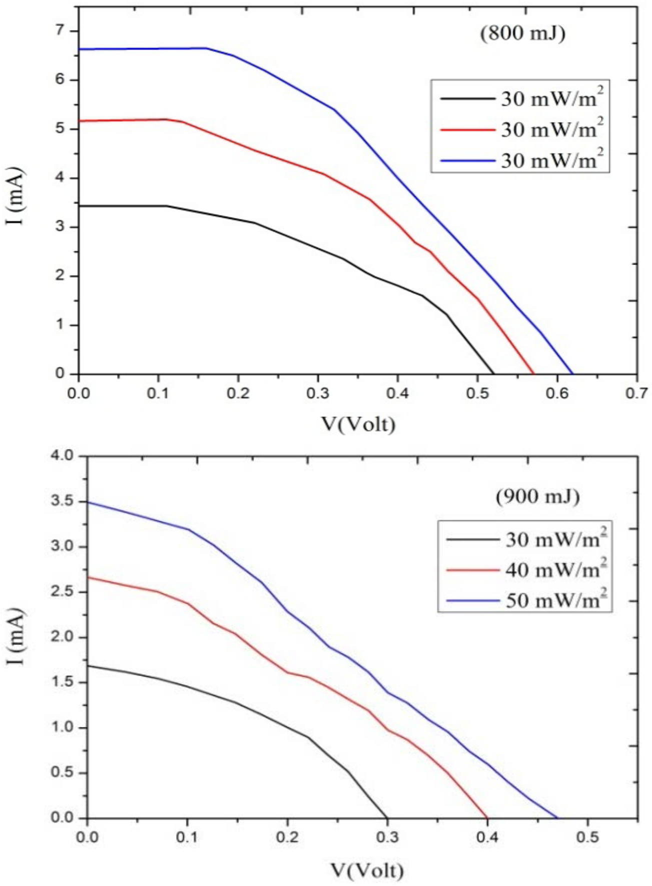


Figure 6. I-V Characteristics for SiC/p-Si heterojunction solar cell at (700, 800, and 900) mJ laser energy at different falling intensities

Table 3. The solar cells parameters

Laser energy (mJ)	Eg (eV)	Light intensity mW/cm^2	I_{sc} (mA)	I_m (mA)	V_{oc} (V)	$V_m (V)$	$F.F$	$\eta\%$
700	3.13	30.00	2.70	1.60	0.48	0.28	0.35	1.49
		40.00	4.00	2.30	0.54	0.34	0.36	1.96
		50.00	5.00	3.00	0.60	0.38	0.38	2.28
800	3.17	30.00	3.40	2.60	0.52	0.31	0.46	2.69
		40.00	5.20	3.60	0.57	0.36	0.44	3.24
		50.00	6.60	4.80	0.62	0.36	0.42	3.46
900	2.81	30.00	1.70	1.00	0.30	0.20	0.39	0.67
		40.00	2.70	1.40	0.40	0.25	0.32	0.88
		50.00	3.50	1.52	0.47	0.28	0.26	0.85

Conclusion

SiC nanostructure thin films were successfully prepared using PLD technique at room temperature on p-Si substrates. SiC films showed a polycrystalline structure after being annealed. Because of SiC high melting point, it requires high laser energy to deposit its crystalline films. The grain size increased and energy gap decreased with increasing laser energy. Despite their poor efficiency, the prepared cells can be improved by enhancing SiC layer via doping it with other elements that improve both the concentration of charge carriers and energy gap.

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