Effect of silver doping on the optical properties of SiC thin films

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Abstract. In this work, pulsed laser deposition technique (PLD) with the Nd: YAG laser (1064 nm, 6 Hz, 500 mJ) had been used to prepare the pure and Ag-doped silicon carbide (SiC) films on the quartz substrates with various dopant ratios (1% wt, 3% wt, 5% wt, and 7% wt) of Ag. The optical absorbance measurements of SiC films have been studied by ultraviolet-visible spectrophotometry (UV–Vis). The optical parameters that calculated are absorbance, transmittance, reflectivity, absorption coefficient, optical energy gap, extinction coefficient, refractive index and complex dielectric constant. The results showed that the absorbance spectrum had been decreased as the doping ratio increasing. The optical energy gap was decreased from (2.62 to 2.02 eV) as the doping ratio increasing.

Keywords: Silicon carbide; Thin film; silver-doped; Optical properties.

1. Introduction
Silicon carbide films have excellent chemical and physical properties like wide band gap energy (2.3-3.2 eV), high thermal conductivity (5-7 W cm⁻¹ K⁻¹), high breakdown field (> 20 x 10⁵ V/cm), high refractive index (2.55), high mobility (1000 cm²/V.s), high resistance to corrosion and oxidation, high saturation velocity (2.2 x 10⁷ cm/s), high thermoelectric power, high thermal and chemical stability, low expansion coefficient, high elastic modulus and higher hardness etc. All these properties make it suitable for the fabrication of devices that can operate under extreme condition of temperature, frequency and power [1-3].

Silicon carbide films have been prepared by different chemical and physical methods such as hot-filament chemical vapor deposition [4], plasma-enhanced chemical vapor deposition [5], metal-organic chemical vapor deposition [6], low pressure chemical vapor deposition [7], electron beam physical vapor deposition [8], and RF magnetron sputtering [9].

The pulsed laser deposition technique can be used to prepare both polycrystalline, crystalline and amorphous films at relatively lower temperatures depending on the process parameters. In this process, both neutral and ionized species within the vapor plume can have kinetic energy in the range of (10-100 eV), which is several orders of magnitude larger than other methods. Furthermore, the kinetic energy of neutral and ionized species created during pulsed laser ablation of a SiC target in a vacuum and at high laser fluence might readily reach values over 100 eV, improving surface diffusion, nucleation, high sticking probability and chemical bonding. It also has the capacity to transfer complex stoichiometric targets to the film composition with strong adherence and a high deposition rate [10].

The chemical composition of the substrate, laser wavelength, laser fluence, target-to-substrate distance, background ambient gas, and substrate temperature all affect the quality of films created
using the PLD method. As a result, certain of these factors must be optimized in order to get the appropriate film quality. In most of the paper, crystalline SiC film has been obtained by annealing only above 950 °C [10, 11]. The main aim of this research paper is to study the optical properties of pure and Ag-doped SiC with various dopant ratios. The study of the effect of doping on the films gives a clear idea of the nature of the changes that these impurities cause in the different physical properties.

2. Experimental details
Thin layers of pure and Ag-doped silicon carbide material have been deposited on a substrate of quartz with various dopant ratios (1, 3, 5 and 7) % wt using PLD technique. The deposition process was carried out using Q-switched Nd: YAG laser with wavelength 1064 nm, pulse energy 500 mJ and laser repetition rate 6Hz. The substrates were cleaned in deionized water and ethanol before deposition. The samples were deposited under high pressure up to (10^-4 mbar) at a substrate temperature of 250 °C while the distance between the substrate and the target was (30mm). A quartz lens had been used to focus the laser beam that falls with an angle of 45 on the rotating SiC target inside the deposition chamber. The thickness of the film was measured using the optical method, Where it was found that its value is 200 nm. The optical properties of prepared thin films were studied by UV–visible spectrophotometer.

3. Results and Discussion
The study of the optical properties of the films is of great importance in finding the optical constants through which it is possible knowing the amount of the optical energy gap value according to the specific preparation conditions (pressure, temperature, thickness of the film, ... etc.) as well as we can know the other constants as absorbance and transmittance and their coefficients, as well as coefficient of extinction and dielectric coefficients, real and imaginary [12].

3.1. Absorbance Spectrum
The absorbance spectrum of a film material depends on the energy of the incident photons, the type of material and the nature of its crystal structure [13].

Figure 1 shows the absorption spectrum as a function of the wavelength (λ) of pure and doped SiC films with different ratios (1,3,5 and 7 % wt) within a range of wavelengths from (200 nm to 800 nm).

![Figure 1](image_url)  
**Figure 1** The absorbance versus the wavelength for pure and Ag-doped SiC films with various dopant ratios.
From figure 1, we note that the absorbance of the prepared films, with their two types of pure and doped, begins to increase gradually with decreasing wavelength (increasing the energy of the incident photons) until it reaches its peak and becomes quasi-sharp when the energy of the incident photons becomes equal to or greater than the value of the optical energy gap of the prepared films where the absorption edge shifts towards short wavelengths as the doping ratios change and this is attributed to the density of localized levels of the atoms of the impurity between the valence and conduction bands.

3.2. Transmittance and Reflectivity
The transmittance (T) is defined as the ratio between the intensity of the radiation passing through the film to the original intensity of the radiation falling on it and is given by the following relation [14].

\[ T = 10^{-A} \]  

(1)

Reflectivity (R) is related with absorbance (A) and transmittance, as in the following equation [15].

\[ A + R + T = 1 \]  

(2)

Figures 2 and 3 shows the transmittance and reflectivity of pure and doped SiC films as a function of the wavelength.

Figure 2 The transmittance versus the wavelength for pure and Ag-doped SiC films with various dopant ratios.

Figure 3 The reflectivity versus the wavelength for pure and Ag-doped SiC films with various dopant ratios.
From figure 2, we note that the transmittance spectrum has opposite behavior of the absorbance spectrum, where the transmittance of the films increases with the increase in the wavelength of the incident radiation on the film material. The transmittance spectrum of pure SiC films gradually increases with the increase in the impurity ratios due to the localized levels that form within the forbidden energy gap between the valence and conduction band as a result of the presence of impurity atoms. We also notice from the figure 3, an increase in the reflectivity spectrum due to the high reflectivity of silver atoms.

3.3. Absorption Coefficient

The absorption coefficient ($\alpha$) was calculated from the absorbance spectrum of the prepared films using the following relation [16]

$$\alpha = 2.303 A/t$$ (3)

where (t) represent the film thickness.

Figure 4 shows the absorption coefficient of pure and doped SiC films as a function of the wavelength. As it is clear from the figure that the absorption coefficient behaves similarly to the behavior of the absorption spectrum and this is due to the nature of the relation between them as in equation (3), where the values of the absorption coefficient increase as we approach from the ultraviolet region and this is also due to the same reason that we mentioned in the absorption spectrum.

![Figure 4](image.png)

**Figure 4** The absorption coefficient versus the wavelength for pure and Ag-doped SiC films with various dopant ratios.

3.4. Optical energy gap

The optical energy gap ($E_g$) of the pure and doped SiC films was calculated for the direct electronic transitions using the following equation [17, 18]

$$ahv = B(hv - E_g)^{1/2}$$ (4)

where $B$ is a constant depends on the nature of the material, $hv$ is the photon energy.

Figure 5 show the photon energy of prepared films as a function of the $(ahv)^2$. From the figure 5, we note a decrease in the energy gap values of the films with an increase in silver doping ratios.
This decrease in the energy gap is attributed to the fact that the higher doping results in additional levels in the energy gap due to the incorporation of impurities with energy levels close to the edge of the beam which causes a decrease in the inclination \((\alpha h\nu)^2\) with \(h\nu\) thus reducing the energy gap.

3.5. Extinction Coefficient
The extinction coefficient \((k)\) indicates the attenuation that gets of the electromagnetic wave as it passes through the medium, and its value can be found from the following equation [19].

\[
k = \frac{\alpha \lambda}{4\pi}\quad (5)
\]

Figure 6 shows the change of the extinction coefficient as a function of the wavelength of the pure and Ag-doped films. The nature of the extinction coefficient curves is almost similar to the behavior of the absorption coefficient curves due to they are related to the previous relation.
For the pure sample, we note that the values of the extinction coefficient decrease after the absorption edge. Then it increases when we approach the visible wavelengths. We also notice a decrease in the coefficient of extinction theme when increasing the noise ratios as we move towards the long mixing lengths while the extinction coefficient decrease for the impure samples, the values of with an increase in the doping ratios.

3.6. Refractive Index

The refractive index ($n$) is defined as the ratio between the speed of light in free space and its velocity in the medium and is related with film reflectivity and extinction coefficient according to the following equation [2]

$$n = \left( \frac{4R}{(R-1)^2} - k^2 \right)^{1/2} - \frac{(1+R)}{(1-R)}$$

Figure 7 shows the change of the refractive index as a function of the wavelength. We note that the nature of the refractive index curve is almost similar to the nature of the reflection curve due to its relation to the refractive index.
The refractive index of a pure sample increases as it approaches the absorption edge and then begins to gradually decrease if we get close to the visible wavelength. Increasing the doping ratios leads to an increase in the refractive index values as we approach the ultraviolet region (high energies region). This may be attributed to the increased energy levels formed in the forbidden gap, which in turn acts as scattering centers for the incident rays, increases the reflectivity and thus we see that the refractive index is increasing.

3.7. Dielectric Constant

The dielectric constant was calculated with its real ($\varepsilon_r$) and imaginary ($\varepsilon_i$) parts of the prepared films from the following relations [21]

$$\varepsilon_r = n^2 - k^2$$  \hspace{1cm} (7)

$$\varepsilon_i = 2nk$$  \hspace{1cm} (8)

Figures 8 and 9 show the real and imaginary parts of the dielectric constant of pure and doped SiC films as a function of the wavelength.

![Figure 8](image)

**Figure 8** The real part of the dielectric constant versus the wavelength for pure and Ag-doped SiC films with various dopant ratios

As shown in Figure 8, that the curves the real part of the dielectric constant has a nature almost similar to the refractive index curves. This similarity results from the dependence of calculating the values of the real part on values of ($n^2$) more than ($k^2$) because the extinction coefficient is very small compared to the refractive index.
For the imaginary part of the dielectric constant, we notice from the figure that it gradually decreases with the increase in the doping ratios for the same reason that we mentioned previously, while in the case of the pure film, its value increases when we move away from the absorption edge, and then it begins to decrease as we approach the visible region.

4. Conclusion
Study the effect of doping with silver on optical properties of SiC films prepared by the pulsed laser deposition technique. The transmittance, reflectivity, absorption coefficient, extinction coefficient, energy gap, refractive index, and real and imaginary dielectric constant were calculated. The energy gap values of the prepared films decreased significantly with the increase of the doping ratios. The addition of silver particles led to a clear decrease in both the absorption and the refractive index, while we notice an increase in the permeability spectrum in the ultraviolet region of the electromagnetic spectrum, so it can be used to work as a photodetector within this region.

5. References
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