DOI:10.26565/2312-4334-2025-2-41 ISSN 2312-4334

STRUCTURAL CHARACTERISTICS AND OPTICAL PROPERTIES OF SiC THIN FILMS PRODUCED BY THE RF-PVD METHOD

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Received November 14, 2024; revised December 19, 2024; revised April 4, 2025; accepted April 12, 2025

We studied the silicon carbide semiconductor compound, which is widely used as the most characteristic material in the preparation of semiconductors. In the radio frequency (RF) mode of the magnetron sputtering device, 300-400 nm thick SiC thin films were formed in an Ar environment as a reactive gas in a vacuum of 10^{-4} Torr. In the radio frequency mode, a power of 240 W with a frequency of 100 kHz and D=70% were used. The maximum sputtering speed of the magnetron was 50 Å/s. A circular silicon carbide (SiC) target with a diameter of 76.2 mm and a compound content of (99.9%) was used. X-ray analysis of the obtained films was performed on an XRD-6100 device and the Miller indices were determined. In addition, the optical parameters of the thin films were determined. FTIR spectroscopic analysis showed a relative decrease in the transmission spectrum in the far-IR region from 13.1% to 8.9% with increasing SiC film thickness in the range of 480-400 cm^{-1}. Characteristic peaks associated with Si-C and C≡C vibrations were also detected. A characteristic Si-C stretching absorption was observed at a wave number of 780 cm^{-1}, where the IR absorption was 88.7%. At a wave number of 2180 cm^{-1}, it corresponds to a triple covalent bond of C≡C. The results showed that the optical and electrical properties of SiC films can be easily tuned by changing the Si and C concentrations in the coating for the same film thickness.
Keywords: *Magnetron sputtering; Silicon carbide; X-ray phase analysis; Transmission spectrum; Refractive index; FTIR*
PACS: 81.15.Jj, 78.66.Sq, 78.20.Bh

INTRODUCTION

Silicon carbide is the most effective material for the production of semiconductors. Silicon carbide powder is also used as a nuclear fuel for fusion reactors [1-2]. SiC mainly exhibits strong chemical bonding, strength, and at the same time, better electrical, optical, and thermal properties than other materials, which is the basis for its effective use in many electronic devices [3-5]. Since silicon carbide thin films have a wide optical energy gap, it can be used in the production of UV detectors. The study of the properties of nanoscale materials is one of the important problems facing modern solid-state physics. The properties of such materials can differ significantly from the properties of both bulk materials and individual nanoparticles that make up the composition [16]. Thus, nanocomposite materials are the basis for the creation of new materials with specific structural, electronic, and optical properties, which are determined by the size, shape, and arrangement of the nanoparticles in their composition.

Recent research results show that silicon carbide is one of the materials that can replace traditional materials in the preparation of semiconductor materials. Due to the electronic properties of silicon carbide thin films, it is one of the main materials in the preparation of new-age optoelectronic and photoelectronic devices. Silicon carbide thin films are used for energy storage in LEDs, nanoelectronics, optoelectronics and photoelectronics, and various other sensors.

Silicon carbide thin films can be deposited by various methods, such as plasma-enhanced chemical vapor deposition (PE-CVD), molecular beam epitaxy (MBE), laser-assisted deposition (PLD), and radio-frequency magnetron sputtering (RF-PVD). Of the various options, reactive magnetron sputtering is the most widely used due to its relative simplicity, high deposition rate, good adhesion, and low production cost [6]. In this work, the optical and X-ray structural properties of SiC films grown by radio frequency RF magnetron sputtering were studied.

EXPERIMENTAL TECHNIQUE

In this study, SiC thin films were deposited on the surface of a silicon monocrystalline substrate using a radio frequency magnetron sputtering device. The deposition process was performed at a temperature of 400 °C using an automatically controlled vacuum furnace. The sputtering rate during the deposition of silicon carbide thin films in an argon atmosphere at a vacuum of 10^{-4} Torr was 50 Å/s, and a power of 240 W at a frequency of 100 kHz and D=70% were used for 6-8 minutes in the reactive radio frequency mode. The maximum sputtering rate of the magnetron was 50 Å/s. A circular silicon carbide (SiC) target with a diameter of 76.2 mm and a compound composition of (99.9%) was used [7,8].

Powder X-ray diffraction is a method for studying the structural properties of a material using X-ray diffraction (X-ray diffraction) from a powder or polycrystalline sample of the material under study [9,10]. The results of the study

Cite as: M.A. Davlatov, K.T. Dovranov, X.T. Davranov, S.N. Xusanov, A.R. Kodirov, S. Xolikulova, East Eur. J. Phys. 2, 330 (2025), https://doi.org/10.26565/2312-4334-2025-2-41

are manifested in the dependence of the radiation intensity on the angle of incidence. The advantage of this method is that it is very convenient for determining the structural composition of each substance, even if its structure is unknown. A thin film of silicon carbide was studied by X-ray diffraction and elemental analysis. The identification of the samples was carried out based on the diffraction patterns recorded on a computer-controlled XRD-6100 (Shimadzu, Japan) apparatus.

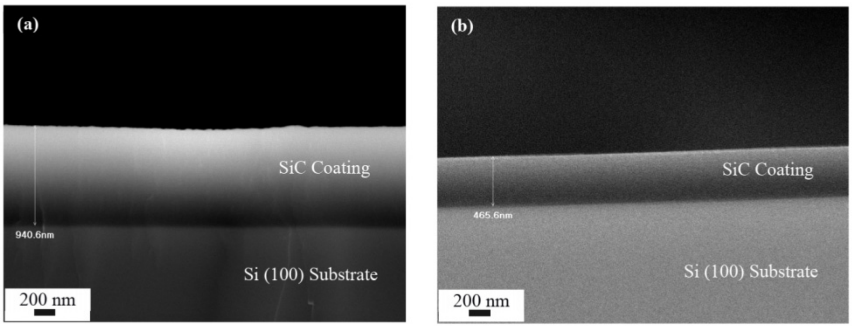

Figure 1. Cross-sectional SEM micrographs of SiC films deposited at a methane flow rate of 35% (a) without external heating at – 50 °C (b) with external heating at – 250 °C [13]

The deposition parameters of thin silicon carbide films deposited by reactive DC magnetron sputtering were studied. According to SEM results, the coating thickness decreased significantly with increasing gas (methane) flow rate and temperature. It is also clear from microstructural examinations that denser coatings were formed with increasing deposition temperature. Figure 1 shows the observed changes in coating thickness and morphology [13].

RESULTS AND THEIR DISCUSSION
X-ray diffraction analysis

Figure 2 shows the X-ray diffraction (XRD) patterns for a silicon carbide thin film grown by radio frequency (RF) magnetron sputtering. The X-ray diffraction patterns of a silicon carbide thin film with a thickness of 300 nm show five peaks at diffraction angles. These peaks correspond to angles of 35, 41, 59, 71, and 75. The Miller indices correspond to the (111), (020), (202), (311), and (222) planes, respectively [14].

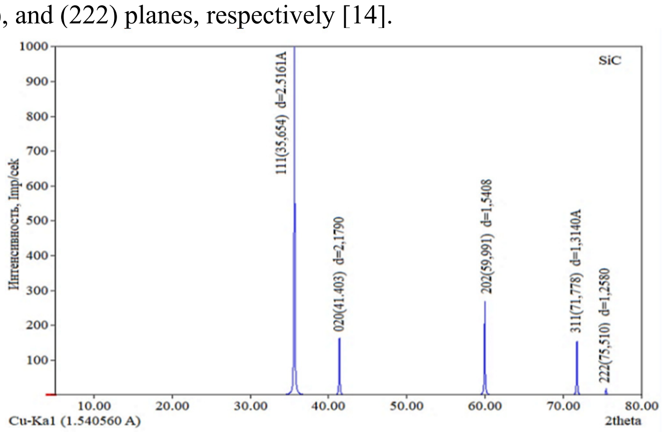

Figure 2. XRD analysis and Miller indices of a silicon carbide thin film grown on a silicon monocrystalline substrate are presented.

Figure 3 shows the crystal structure of SiC. It was found that the silicon carbide crystal lattice is cubic (pr. gr. Pbnm) and consists of two chemical elements: Si, C. This result was obtained by using the Profix software to obtain the “cif” results of the X-ray spectrum data obtained using the XRD-6100 measuring device, and our results were compared with the results of SiC films grown by other methods [15].

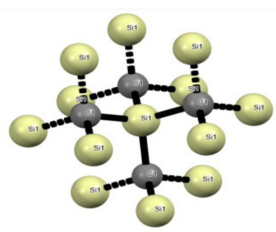

Figure 3. Crystal structure (cubic structure pr. gr. Pbnm)

Figure 4 shows the transmission spectra of SiC thin films of different thicknesses measured using the Qatr-10 (diamond crystal) attachment of the FTIR device. Magnetron sputtering has a strong and direct effect on the optical properties of the films obtained in different modes. In general, according to the results obtained in the infrared transmission spectrum in the range of 400-3000 cm^{-1}, a significant transmission spectrum was obtained for films with a thickness of 300 nm and 400 nm. With increasing thickness, the transmission spectrum in the range of 400-480 cm^{-1} in the far-IR region showed a relative decrease from 13.1% to 8.9%. The low value of the transmission in the IR region is part of the optical properties of SiC, where its values are associated with the value of the optical band gap in the UV region.

Infrared spectroscopy analysis

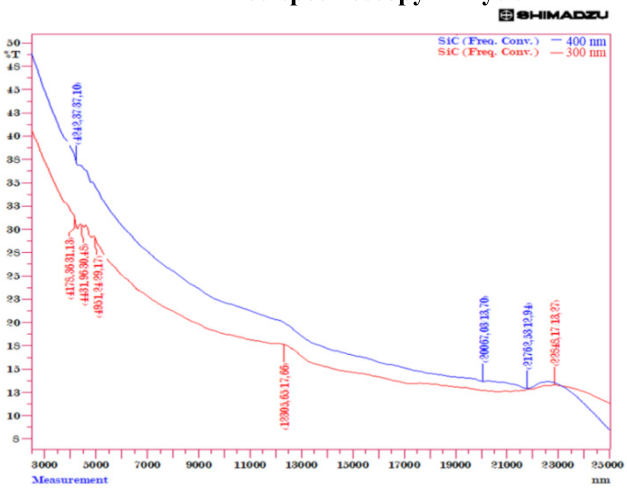

Figure 4. Transmission spectrum of 300-400 nm thick SiC thin films

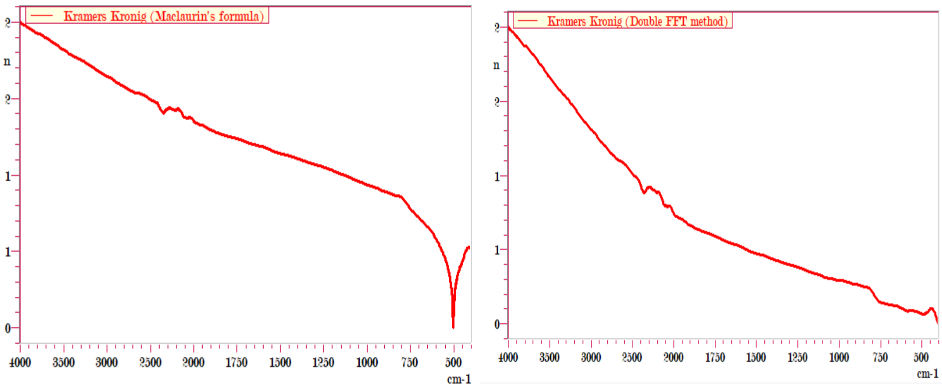

Figure 5. Double FFT method and Maclaurin's spectra based on the processing of the FTIR spectrum of SiC thin films.

The refractive index of the film was calculated based on the processing of the infrared transmission spectrum of SiC thin films, and the refractive index was found to be 2.62 by the Double FFT method according to the Kremers-Kroing function [17]. Based on the Maclaurin formula [18], the infrared absorption corresponding to the wave number of 490 cm^{-1} is confirmed to be n=2.6. The absorption spectra of SiC films with a thickness of 300 nm and 400 nm at infrared wavelengths are presented in Figure 6. The absorption (A) values were estimated based on the transmission values. It was observed that the optical absorption values decreased. This makes such a film suitable for use in the production of optoelectronic devices. According to the results of the ultraviolet absorption spectrum of silicon carbide, the refractive index at 632.8 nm is 2.63.

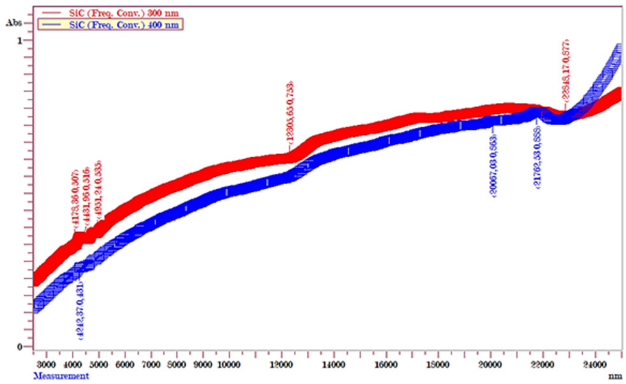

Figure 6. Infrared absorption spectra of SiC thin films with a thickness of 300 nm and 400 nm.

The results of the analysis of SiC thin films were carried out using a Fourier transform infrared spectrophotometer to determine the molecular vibrations. This analysis allows us to assess the quality of the material. As can be seen from the FTIR spectrum, since there are no excessive vibrations, we conclude that there are no impurities or defects in the film. Also, characteristic peaks associated with Si-C and C≡C vibrations were detected. At a wave number of 780 cm^{-1}, where the IR absorption was 88.7%, a characteristic Si-C stretching absorption was observed. At a wave number of 2180 cm^{-1}, it corresponds to a triple covalent bond of C≡C. The covalent characters of Si-C-Si and C-Si-C bonds are characterized by three base potentials [11]. By analyzing the FTIR spectra, the dependence of the photon energy on the Kubelka-Munk [7] function $(ahv)^2$ for SiC was obtained. Based on the obtained results, the band gap for the SiC film was calculated. According to the calculation results, the band gap for SiC is 3.2 eV, which is an extrapolated straight line of the curve between (hv) and $(ahv)^2$. SiC thin films can be widely used in electronic and optical engineering, optoelectronics, solar selective coatings, blue light-emitting diodes, and phototransistors due to their unique properties as a result of the formation of a radio frequency magnetron sputtering device.

CONCLUSIONS

In a radio frequency (100 kHz, D=70%) magnetron sputtering device, 320 nm thick and well-adhered SiC thin films were successfully grown on Si (111) and glass substrates. According to the results of XRD analysis, it was found that the silicon carbide crystal lattice is cubic (pr. gr. Pbnm) and is a compound of two chemical elements: Si, C. FTIR spectroscopic analysis showed a relative decrease in the transmission spectrum in the far-IR region from 13.1% to 8.9% with an increase in the thickness of the SiC film. Also, characteristic peaks associated with Si-C and C≡C vibrations were detected. A characteristic Si-C stretching absorption was observed at a wave number of 780 cm^{-1}, where the IR absorption was 88.7%. At a wavenumber of 2180 cm^{-1}, it corresponds to a triple covalent bond of C≡C. The study is promising for the future study of the formation mechanism of SiC films and the improvement of their optical properties.

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СТРУКТУРНІ ХАРАКТЕРИСТИКИ ТА ОПТИЧНІ ВЛАСТИВОСТІ ТОНКИХ ПЛІВОК SiC, ОТРИМАНИХ МЕТОДОМ RF-PVD

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Проведено дослідження напівпровідникової сполуки карбіду кремнію, яка широко використовується як найбільш характерний матеріал для виготовлення напівпровідників. У радіочастотному (RF) режимі пристрою магнетронного розпилення тонкі плівки SiC товщиною 300-400 нм були сформовані в середовищі Ar у вигляді реакційноздатного газу у вакуумі 10^{-4} Торр. У радіочастотному режимі використовувалася потужність 240 Вт з частотою 100 кГц і D=70%. Максимальна швидкість розпилення магнетрона становила 50 Å/с. Використовували круглу мішень з карбіду кремнію (SiC) діаметром 76,2 мм і вмістом сполуки (99,9%). Рентгенографічний аналіз отриманих плівок проводили на приладі XRD-6100 і визначали індекси Міллера. Крім того, були визначені оптичні параметри тонких плівок. Спектроскопічний аналіз FTIR показав відносне зниження спектра пропускання в дальній ІЧ-області з 13,1% до 8,9% зі збільшенням товщини плівки SiC в діапазоні 480-400 $см^{-1}$. Також були виявлені характерні піки, пов'язані з коливаннями Si-C і C≡C. Характерне поглинання при розтягуванні Si-C спостерігалося при хвильовому числі 780 $см^{-1}$, де ІЧ-поглинання становило 88,7%. При хвильовому числі 2180 $см^{-1}$ це відповідає потрійному ковалентному зв'язку C≡C. Результати показали, що оптичні та електричні властивості плівок SiC можна легко налаштувати, змінюючи концентрації Si та C у покритті для однакової товщини плівки.

Ключові слова: *магнетронне розпилення; карбід кремнію; рентгенофазовий аналіз; спектр пропускання; показник заломлення; FTIR*