

Characterization of silicon-carbon thin films for MEMS applications

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Abstract

Silicon carbide (SiC) is a promising material for uncooled infrared (IR) Micro-Electro-Mechanical Systems (MEMS) owing to its high elastic modulus, thermal stability, and infrared absorption properties [1–3]. In this work, we report a comparative characterization of 500 nm thick SiC thin films deposited by Plasma-Enhanced Chemical Vapor Deposition (PECVD) and Pulsed Laser Deposition (PLD), with the objective of evaluating their suitability as structural and absorbing layers in bi-material MEMS microcantilever-based IR sensors [4–5]. Fourier Transform Infrared (FTIR) spectroscopy confirms the formation of Si–C bonds, with absorption peaks centered at $\sim 775.7 \text{ cm}^{-1}$ for PECVD films and $\sim 807.3 \text{ cm}^{-1}$ for PLD films, while revealing the influence of hydrogen and carbon content on bonding configurations in PECVD layers [8–11]. Film thickness and refractive index were measured by ellipsometry, and mechanical properties were evaluated by nanoindentation, showing Young's modulus values ranging from 170 to 190 GPa for PLD films and 114 to 124 GPa for the annealed PECVD films. The results highlight the strong dependence of mechanical performance on deposition technique and bonding density. These findings demonstrate that low-temperature PECVD SiC thin films are suitable candidates for uncooled IR MEMS microcantilever applications.

1. Introduction

Silicon carbide (SiC) has emerged as a promising material for infrared (IR) Micro-Electro-Mechanical Systems (MEMS) due to its favorable mechanical, thermal, and optical properties. Its high elastic modulus, chemical inertness, thermal stability, and ability to absorb infrared radiation make SiC an attractive candidate for uncooled IR sensor applications [1–3]. Uncooled infrared sensors function as temperature detectors, converting incident IR radiation into a measurable thermal or mechanical response. This approach eliminates the need for complex cooling systems, allowing for compact, low-power devices suitable for large-area integration [4, 5].

Among uncooled IR sensors, bi-material MEMS microstructures, such as microcantilevers, are widely used because of their high sensitivity, simple architecture, and compatibility with standard silicon microfabrication processes [6, 7]. These devices typically consist of two thin-film materials with a significant mismatch in their thermal expansion coefficients (TECs). When IR radiation is absorbed, the resulting temperature rise causes differential thermal expansion between the layers, leading to the mechanical deflection of the microstructure. This deflection can be detected using optical, capacitive, or piezoresistive readout methods. MEMS-based IR sensors have applications in medical thermography, night-vision systems, and non-contact temperature measurement.

In this context, selecting and characterizing the absorbing and structural thin films is crucial for determining sensor performance. Common materials used in silicon-based bi-material IR MEMS include silicon carbide (SiC), silicon nitride (SiN_x), and silicon dioxide (SiO₂), due to their well-controlled mechanical properties and compatibility with micromachining processes [6–14]. Hydrogenated amorphous silicon carbide (a-SiC:H) has gained significant attention for microcantilever-based pixels

because of its tunable stress, relatively high Young's modulus, and capability for low-temperature deposition. Typical bilayer configurations include combinations like SiC/Au, SiN_x/Al, and SiO₂/Ti/SiO₂, designed to maximize thermo-mechanical deflection and sensor responsiveness.

This work focuses on the characterization of SiC thin films intended for use as absorbing and structural layers in uncooled IR MEMS microcantilevers. SiC films were deposited using two different techniques: Radio-Frequency Plasma-Enhanced Chemical Vapor Deposition (RF-PECVD, 13.56 MHz) and Pulsed Laser Deposition (PLD) [12]. The samples were elaborated at the Laboratoire des Micro-Nanotechnologies (LMN) at INRS-EMT, Canada. A comprehensive set of characterizations—including Fourier Transform Infrared (FTIR) spectroscopy, ellipsometry, and nanoindentation—was conducted to evaluate the optical and mechanical properties of the deposited films. The objective is to assess how the deposition technique and bonding configuration influence the suitability of SiC thin films for integration into uncooled infrared MEMS devices.

2. Experimental setup

In the first phase, SiC films were deposited using the PLD method at low temperatures. Following deposition, annealing treatments were applied to the films within a temperature range of room temperature to 200°C, 400, 600, 650 and 800°C, utilizing a KrF laser (248 nm, 300 mJ, 20 ns, 20 Hz).

In the second phase, SiC films were synthesized using the PECVD technique at a substrate temperature of 400°C. Samples with varying stoichiometries, Si_xC_{1-x} (where x = 0.3, 0.4, and 0.5, with CH₄ / (SiH₄ + CH₄)) at 180 Pa, 50 mW/cm², and 13.56 MHz, containing less than 2% oxygen), were fabricated.

We conducted a series of characterizations on these samples, which included laser ellipsometry, nanoindentation, and Fourier Transform Infrared (FTIR) spectroscopy. After machining the samples, scanning electron microscopy (SEM).

3. Results and discussion

3.1 FTIR Characterization

To obtain the absorption spectrum of the SiC layer, Fourier Transform Infrared (FTIR) spectroscopy was utilized. The equipment used was a Thermo-Nicolet Nexus 670, provided by CRTSE in Algiers. The results are displayed in Fig. 1.

In Fig. 1a, the measurement results for samples deposited via Pulsed Laser Deposition (PLD) are shown. The SiC peak is narrower for samples deposited at temperatures above 400°C. The temperature dependence of the deposition process is clearly evident; as the temperature increases, the peak larger around 2100 cm⁻¹ decreases.

The results of the PECVD measurements for the samples are presented in Fig. 1.b. Three curves correspond to samples deposited at different carbon concentrations: 50% (with and without annealing), 60%, and 70%. The SiC bond peak reaches its maximum at a carbon concentration of 60%, specifically at a position of 775.7 cm^{-1} . In contrast, the other curves show significant peaks for the C-X, Si-CH₂, Si-H, Si-Hn, CO₂, and C-Hn bonds, which correspond to positions of 613.14 cm^{-1} , 1107.78 cm^{-1} , 2089.4 cm^{-1} , 2369.37 cm^{-1} , and 2906 cm^{-1} , respectively [8–10]. The intensity of these peaks increases with higher carbon content during deposition. It is estimated that when the ratio, denoted as x , is around 0.4, there are the maximum number of bond combinations between silicon (Si) and carbon (C) forming the SiC layer. For other ratios, two situations can arise: (1) an excess of carbon ($x \sim 0.3$), which results in the appearance of various other bonds, and (2) a carbon deficiency ($x \sim 0.5$), which leads to a decrease in the intensity of these peaks. When comparing the effect of temperature in PECVD deposition (Fig. 1.b) to the same temperature used for PLD (Fig. 1.a), we observe different bonds. This discrepancy is primarily due to the fact that PECVD deposition occurs on the surface and is influenced by the radicals present in the plasma. As a result, only the SiC bond peak is evident, while the other bonds are nearly negligible.

3.2 Ellipsometer Characterization

To measure the SiC layer thickness, we used the ellipsometer available in the CDTA cleanroom (Fig. 2a). We characterized only the samples deposited by PLD of the silicon substrates ($2.5 \times 2.5\text{ cm}^2$).

The results obtained are shown in the tables below in Fig. 4.b. The thickness of the SiC thin films deposited by PLD is on average equal to $0.5\mu\text{m}$.

3.3 Nanoindentation Characterization

The mechanical properties of thin films, such as the modulus of elasticity and hardness, are determined using the nanoindentation technique. We utilized the CSM nanoindenter available at the CDTA, which has a force range of 0.1 mN to 500 mN, with a resolution of $0.04\text{ }\mu\text{N}$. Since the sample holder cannot accommodate large samples, we focused on characterizing samples deposited by pulsed laser deposition (PLD). For samples deposited by plasma-enhanced chemical vapor deposition (PECVD) on 4" wafers, we opted to perform characterization after the microfabrication of the structures.

The figure below illustrates how hardness (H) and modulus of elasticity vary with temperature. The Young's modulus (E) increases from 170 GPa to 190 GPa as the temperature rises. Similarly, the hardness (H) also increases, changing from 20.41 GPa to 27 GPa.

The values obtained are comparable to those found in the literature for this test with silicon carbide (SiC). However, we chose a thickness of $0.5\text{ }\mu\text{m}$, while all other tests cited [14] used a thickness of $1\text{ }\mu\text{m}$. This thinner thickness is indeed restrictive for the nanoindenter test; the optimal test depth is 50 nm, which represents 10% of the thin film thickness. However, we obtained results starting at a depth of 150 nm, or 30% of the SiC layer thickness. The Young's modulus values we obtained are close to those of the silicon substrate. To eliminate the substrate effect, this test should have been repeated with SiC membranes, as done in the studies by Hong [15] and Hsu [16]. Another alternative is the fabrication of

the SiC beams through micromachining. The produced mask features cantilever and bridge structures with varying lengths, widths, and spacings, designed for front-facing KOH etching. The specifications for the cantilever structures are as follows:

- - Maximum lengths: 300 μm , 200 μm , 150 μm , 100 μm , and 50 μm
- - Widths: 100 μm , 80 μm , 50 μm , 40 μm , 20 μm , and 10 μm
- - Spacing between structures: 100 μm , 80 μm , 50 μm , 20 μm , and 10 μm .

The SEM image in Fig. 6 shows the MEMS structures after front wet etching. We obtained good selectivity with respect to the Silicon substrate. Furthermore, the SiC cantilevers look very straight after etching the bulk silicon, which confirms that the Young modulus of the SiC thin films is similar to that of the silicon wafer.

4. Conclusion

In this presentation, we characterized silicon carbide (SiC) thin films for applications in microsystem devices, specifically for use in a bilayer structure designed for infrared detection. We examined two types of 500 nm SiC thin films that were deposited using two different methods: Plasma Enhanced Chemical Vapor Deposition (PECVD) and Pulsed Laser Deposition (PLD). Fourier Transform Infrared Spectroscopy (FTIR) characterization confirmed that the deposited films were indeed SiC. We found that the absorption peak for the PLD-deposited samples was centered around a wavelength of 807.27 cm^{-1} , while the absorption peak for the PECVD-deposited samples was at approximately 775.7 cm^{-1} . We succeeded to have SiC thin films with Young modulus near the Si wafer, which results in low stress between the silicon wafer and the SiC thin films.

Declarations

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author Contribution

A writing the final version results interpretation and charaterisation B characterisation and results interpretation C characterisation and results interpretation D characterisation and results interpretation E

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Data Availability

All data generated or analysed during this study are included in this published article.

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Figures

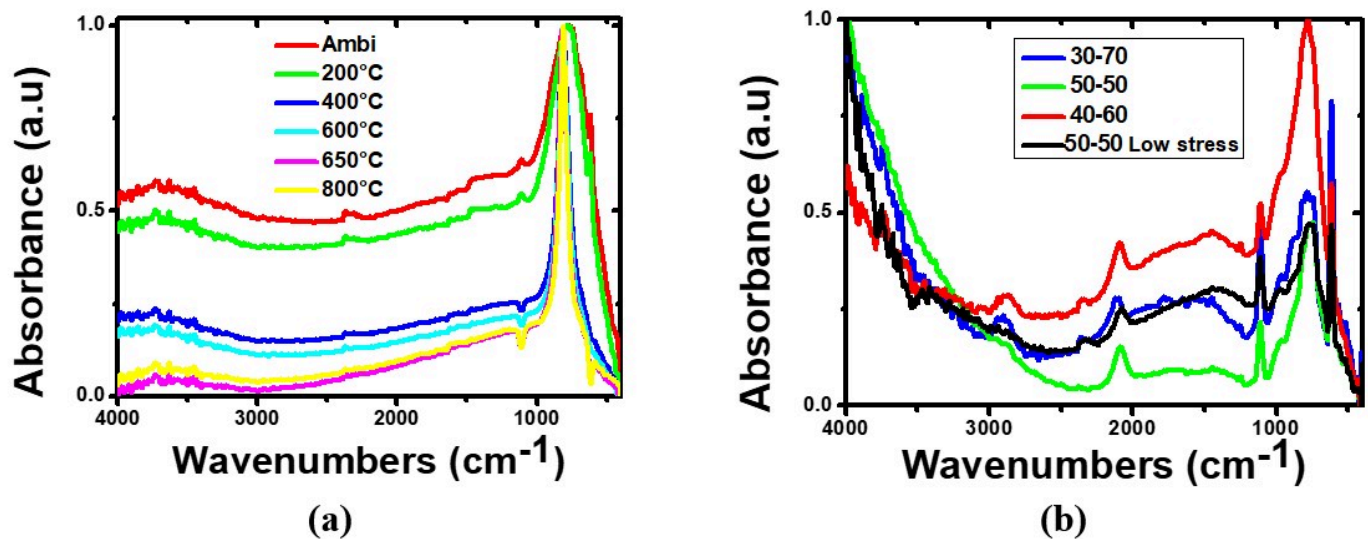


Figure 1

Absorption curves obtained by FTIR of thin films deposited by; a) PLD and b) PECVD.

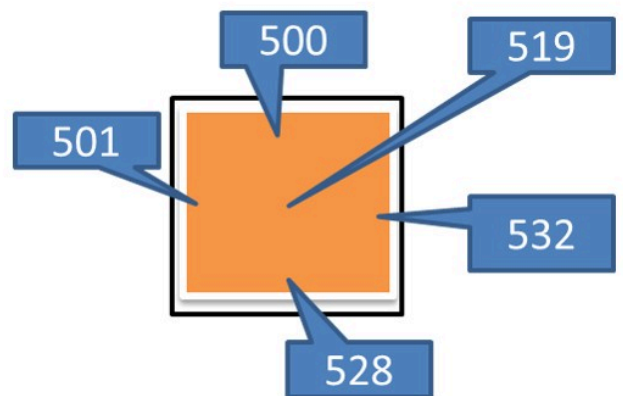


Figure 2

Ellipsometer measuring in a), and b) the measurement points on each sample

Ambiant@ $\Delta Th=38.75$		200°C@ $\Delta Th=0.05$		400°C@ $\Delta Th=0.02$	
nFilm	Thick nm	nFilm	Thick nm	nFilm	Thick nm
3.511	499.11	3.6076	501.98	2.8386	529.04
3.38	520.82	3.6075	502.04	2.8387	529.02
2.54	537.86	3.6074	502.03	2.8386	529.03
600°C@ $\Delta Th=0.2$		650°C@ $\Delta Th=0.23$		800°C@ $\Delta Th=0.12$	
nFilm	Thick nm	nFilm	Thick nm	nFilm	Thick nm
2.7875	548.99	2.6888	534.66	3.2061	469.65
2.7883	548.79	2.6877	534.89	3.2062	469.65
2.7880	548.86	2.6877	534.88	3.2057	469.53

Figure 3

Refractive index and thickness obtained for samples made with PLD with the ellipsometer ($\lambda= 632\text{nm}$, $\Theta= 70^\circ$)

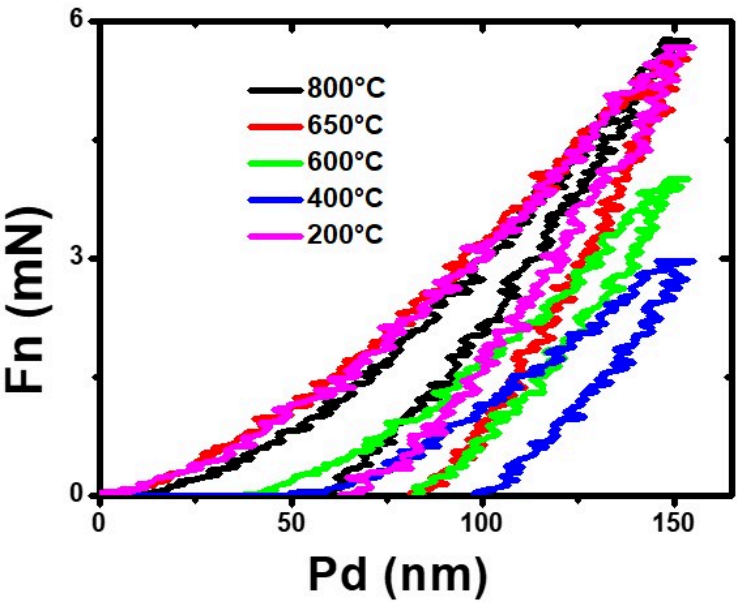


Figure 4

In a) CSM nanoindenter available at CDTA, b) shape of the curves for samples deposited by PLD.

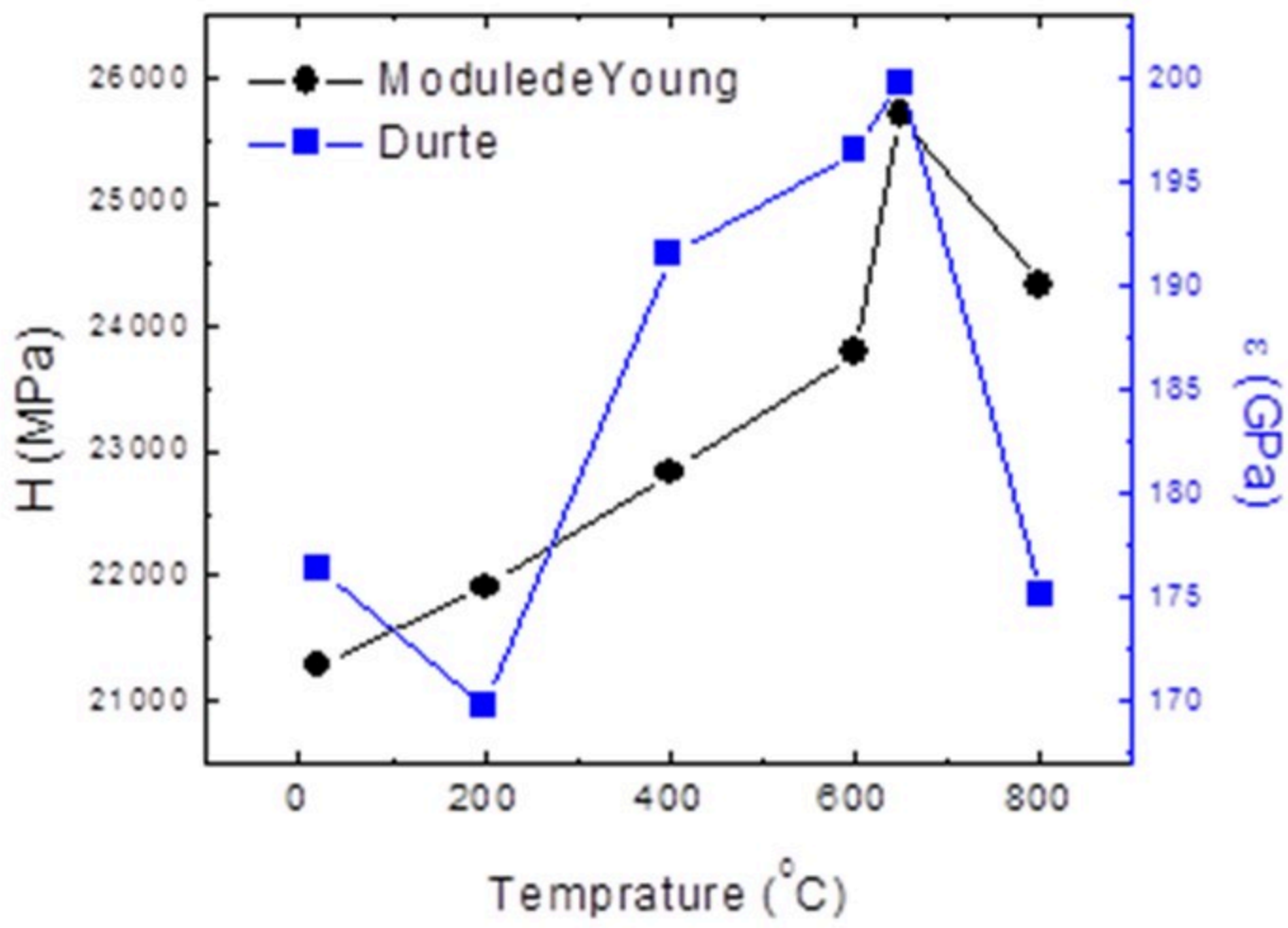


Figure 5

Shape of the elastic modulus and hardness obtained as a function of temperature.

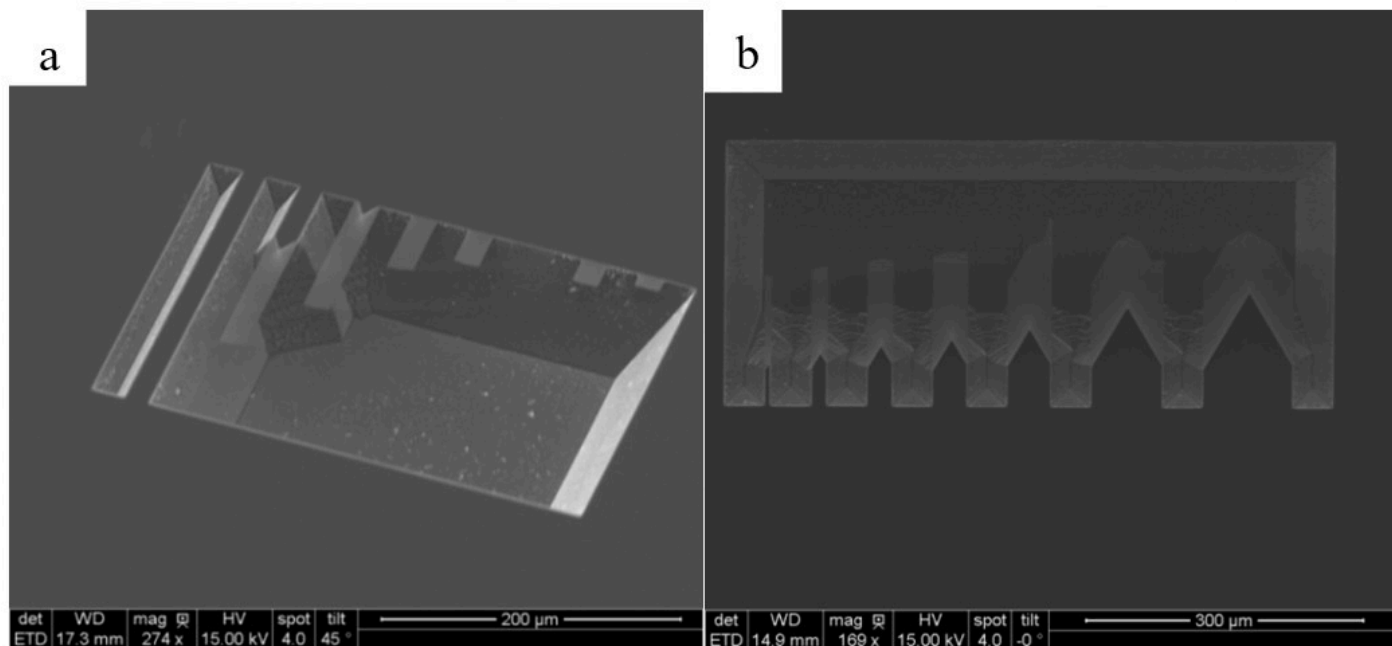


Figure 6

shows the structures obtained after KOH etching on the SiC sample ($x \sim 0.5$). In part a) illustrates bridge and beam structures of varying lengths but with a consistent width. Meanwhile, part b) presents beam structures that differ in width while maintaining a fixed length.