Electromagnetic Interference (EMI) Analysis on Surface Roughness of 3C-Silicon Carbide (3C-SiC) Deposited on Silicon (Si) Substrate

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***Abstract*—Electronic devices may produce undesirable electromagnetic (EM) interference which can degrade the system performance and also affect human health. In this paper, the potential property of 3C-Silicon Carbide (3C-SiC) as the microwave absorbing material is investigated. The reflection coefficient, Γ of 3C-SiC has been measured using an open-ended coaxial sensor. The substrates consisted of films of 3C-SiC of two different thicknesses (0.265µm and 0.285µm) with both polished and unpolished surfaces. The measurements were taken in the frequency range within 1.4 GHz to 18.8 GHz at room temperature. A continuous decrease in the reflection coefficient was measured in 3C-SiC as the frequency increased to 18.8GHz. The results have shown that the rougher surface of unpolished 3C-SiC of 0.285µm thickness could be applied as microwave absorbing material.**

***Index Terms*—3C-SiC; Absorption Coefficient; Electromagnetic Interference; Microwave Absorbing Material; Reflection Coefficient.**

I. INTRODUCTION

The EMI shielding is the key component to protect the workspace and environment from emitted radiation. Therefore, the development of effective microwave absorbing material is required in order to minimize undesired electromagnetic signals. Thus, recent requirements for microwave absorber is now leading towards the development of an efficient microwave absorbing material which is effective in physical performance, easy to fabricate and inexpensive [3]. The microwave absorbing material is used to reduce interference due to electromagnetic energy by dissipating the magnetic or electrical energy. The dissipation occurs when the microwave infiltrating the structure of absorbing material is attenuated by lossy characteristics of the EM wave absorbing the material. Much attention had recently been paid to microwave absorption materials due to their characteristic of microwave absorption in applications e.g. in military technology as well as microwave dark-room and protection [4].

The semiconductor SiC has the high mechanical strength and excellent thermally stable compared to silicon (Si). Approximately 250 polytypes of SiC, the cubic form of 3C-SiC has a small band gap which permits inversion at lower electric field strength [5] and superior electronic properties. The cubic form of 3C-SiC also has an energy band gap at room temperature varying from 2.2eV to 3.4eV. 3C-SiC also have a good oxidation resistance, large electric breakdown and wide frequency range properties. Moreover, 3C-SiC acts as a good potential biomaterial for application in electronic devices and micro-electromechanical systems (MEMS). One of the unique features of 3C-SiC is that it can be epitaxially grown onto Si and this could be an alternative potential to microwave absorbance application [6].

The electromagnetic absorbing properties of various forms of SiC including powder, foam, nanofibers, and matrix composites has been studied [7]. However, the performance of SiC in electromagnetic absorption has proven unsatisfactory. So, to act as microwave absorbing material, another layer has been commonly combined with SiC. These composites offer better cooperative interaction which has resulted in improved microwave absorption properties [8]. For instance, Xiaowei et al. [4] have shown excellent electromagnetic absorbing properties of composites based on SiC at elevated temperatures up to 800°C. In a similar manner, the existence of electrical insulation between the 3C-SiC layer and Si substrate at the SiC/Si heterojunction may offer a new perspective on the thin film ability to work as microwave absorbing material apart from its traditional applications in semiconductor field [9]. Hence, the current study focuses on 3C-SiC thin films ability to absorb microwave within the scope of layer thickness and surface roughness.

II. METHODOLOGY

Substrates of 3C-SiC thin films with thicknesses of 0.265 µm and 0.285 µm were used in these experiments with both polished and unpolished surfaces. The fabrication process of these samples has been reported in [6], [10]. These 3C-SiC thin films are grown on the Si wafers with the thickness of 650 µm by using Low-Pressure Chemical Vapour Deposition (LPCVD). The 3C-SiC thin films thicknesses were measured by NANOMETRICS Nano Spec/AFT 210 by assuming their refractive index is at 2.65 [10]. Another method which is simple but yet excellent to determine the 3C-SiC thin films thicknesses is by observing their surface color. A 0.265µm 3C-SiC film should exhibit medium purple color (RGB code:

147-112-219) surface while the color of a 0.285µm 3C-SiC film should be medium sea green (RGB code: 60-179-113) [11].

The crystal qualities of the epitaxial layers were determined using X-ray diffractometry (XRD). The θ-2θ locked XRD scans were performed with CuKα radiation using a Bruker D8 advance X-ray diffraction system. The acquisitions were taken from 301° to 951° with an increment of 0.0051°/step and the duration of each step of 0.5 s. The morphology of the surfaces of the 3C-SiC was further analyzed by Atomic Force Microscopy (AFM). The 3D and phase images of 3C-SiC/Si using AFM were taken using Atomic force microscope, Shimadzu, SPM-9500 J2 and the area scanned were approximately 5×5µm^2. Γ was measured using the Agilent E8362B PNA Network Analyzer in conjunction with the open-ended coaxial sensor in the frequency range from 1.4 GHz to 18.8 GHz. All samples were initially cleaned with acetone and distilled water prior to measurement. The sample was placed in contact with the open-ended coaxial probe and Γ was measured through PNA as shown in Figure 1. The constant standard loads method consisted of open, short and load are used within PNA in the calibration. This method utilized several fixed properties connection standard as illustrated in Figure 2. Prior to measurement, the calibration of the dielectric probe was required in PNA to remove any systematic error.

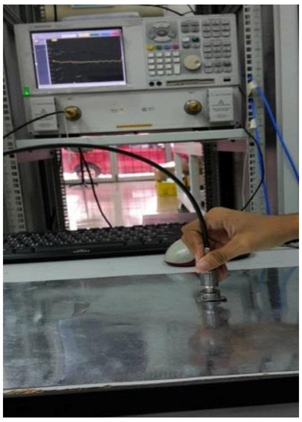


Figure 1: Reflection Coefficient, Γ Measurement of 3C-SiC/Si.

Figure 2: Fixed Properties Calibration Standard.

III. RESULTS AND DISCUSSIONS

A. XRD Analysis

In Figure 3, the XRD patterns confirm the quality of the epitaxially grown 3C-SiC films on Si substrate. The 3C-SiC (200) and 3C-SiC (400) peaks are evident while the Si peak is represented by Si (100). All the peaks have a high degree of crystal orientation where no other crystal planes are present. The rocking curve data shows the full-width at half-maximum (FWHM) value of 1.05 degrees for the 3C-SiC (200) peak which indicates good crystal quality [12]

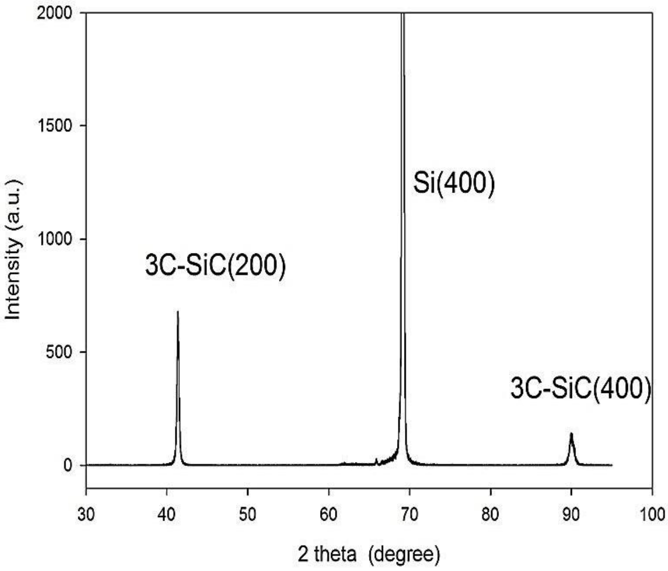


Figure 3: XRD Patterns of the 3C-SiC/Si Sample.

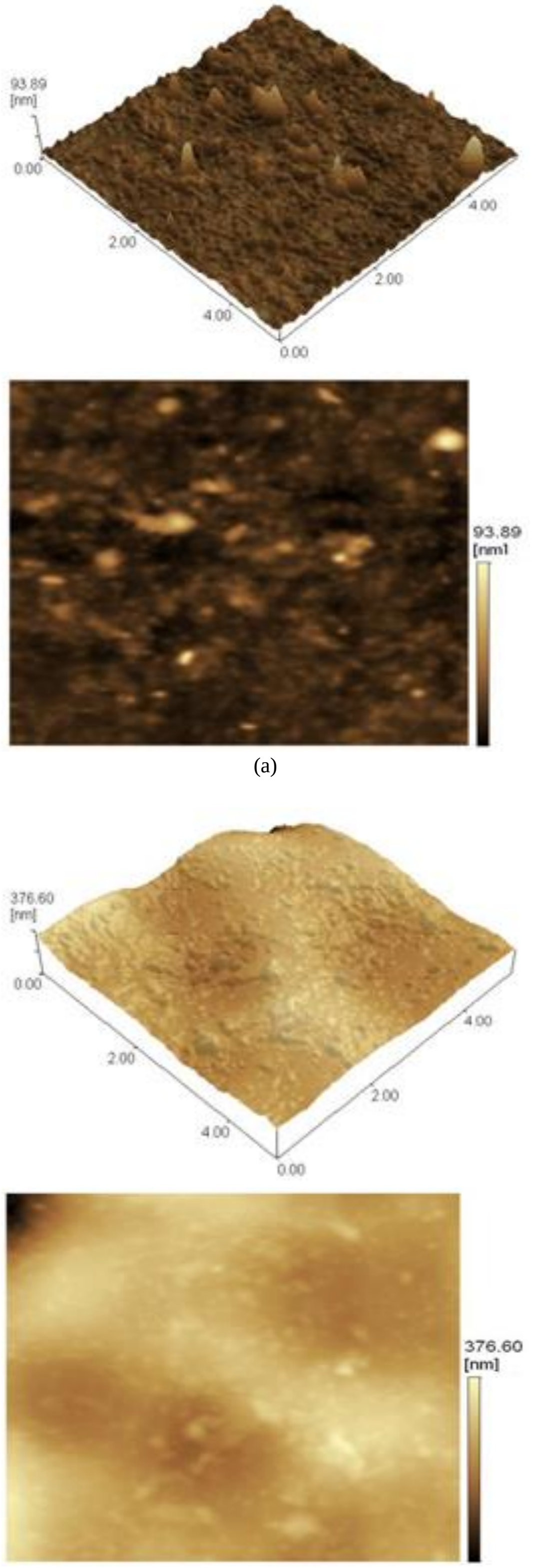
B. Atomic Force Microscopy (AFM)

Atomic Force Microscopy (AFM) is used to study surface roughness. According to the previous study, AFM was used to observe the surface morphology of materials e.g. conductive polymer thin films and 6H-SiC. In AFM, there are several parameters involve to analyze the surface morphology viz. roughness parameters, amplitude or height parameters, functional or statistical and spatial parameters. AFM plays an important role as roughness will affects the electrical, optical and magnetic properties of thin films. The average roughness (R_{ave}) and the root-mean-square roughness (R_{rms}) are widely used to provide a description of height variations. The R_{rms} is commonly used to characterize coating surface of the material.

Figure 4 and Figure 5 show the 3D and 2D AFM images of 0.265 µm and 0.285 µm in both surfaces respectively. Figure 4(a) and Figure 5(a) illustrates that the unpolished surfaces for both thicknesses contain more peaks than the valley. But, the polished surfaces for 0.265 µm and 0.285 µm of 3C-SiC/Si showing that valleys are dominant in the surface morphology and therefore has made it becomes more planer. Hence, a large number of peaks and valleys present in AFM images influence the R_{rms} and R_{ave} values. From Table 1, it can be observed that as the thickness of 3C-SiC thin film increases, the R_{rms} and R_a values are increases. It can be said that the unpolished surface of 0.285 µm 3C-SiC/Si is rougher than the unpolished surface of 0.265 µm 3C-SiC/Si due to the highest values of R_{rms} and R_{ave}.

Table 1
Comparison of Surface Roughness for Different Thicknesses of 3C-SiC

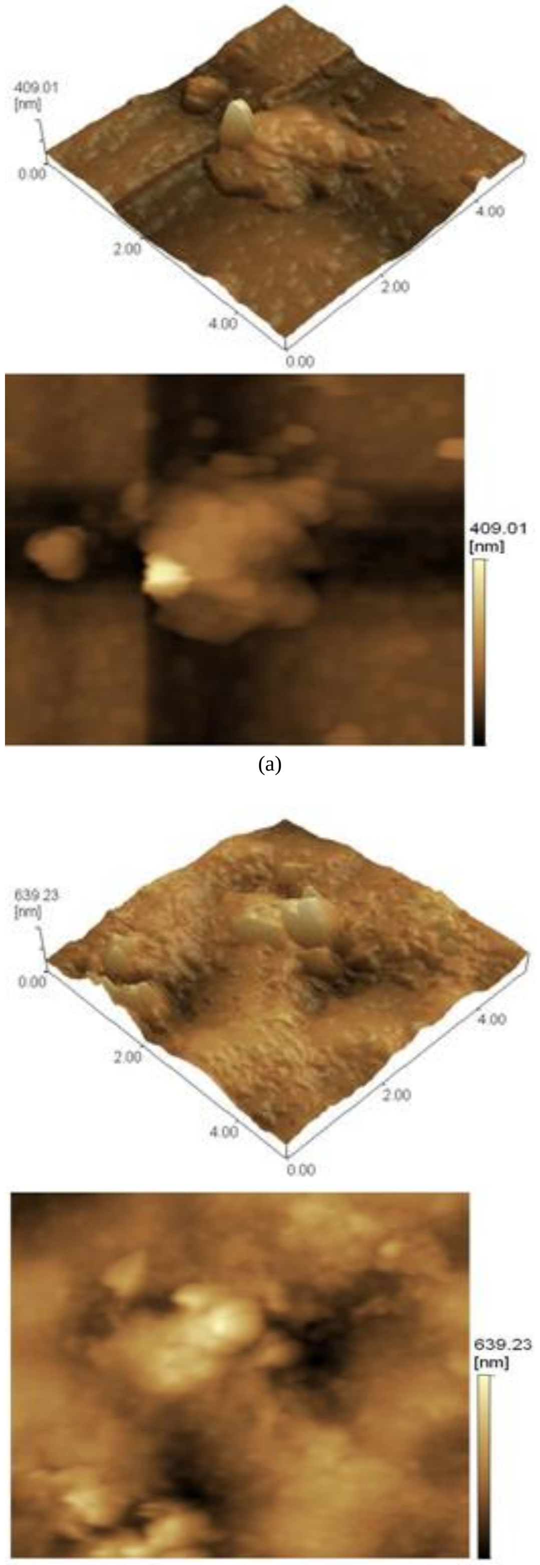
Thickness of 3C-SiC	Polished Surface		Unpolished Surface	
	R_{rms}	R_{ave}	R_{rms}	R_{ave}
0.265 µm	7.56	4.85	45.63	36.83
0.285 µm	44.28	33.56	84.6	65.13



(a)

(b)

Figure 4: 3D and 2D AFM images of 0.265 µm 3C-SiC/Si Sample. (a) Polished surface. (b) Unpolished surface.



(a)

(b)

Figure 5: 3D and 2D AFM images of 0.285 µm 3C-SiC/Si Sample. (a) Polished surface. (b) Unpolished surface.

C. Reflection Measurement

Figure 6 shows the measured reflection coefficient, Γ for polished and unpolished Si. At a frequency of 1.4 GHz, both surfaces of silicon achieve a maximum |Γ|. An increase in frequency results in a decrease in the |Γ| of both polished and unpolished Si. At a frequency of 18.8 GHz, the polished Si has |Γ| of 0.5, higher than |Γ| of unpolished Si which is 0.35. This shows that unpolished Si has higher microwave absorbability than polished Si at a frequency of 18.8 GHz. Figures. 7 and 8 show a similar trend where at low frequency, both polished and unpolished surfaces with thickness of 0.265 µm 3C-SiC exhibit maximum |Γ| (Figure7). It is attributed to 0.265 µm 3C-SiC is grown on the 650 µm Si wafer where the Si is much thicker than the 3C-SiC. However, |Γ| decreases for both surfaces when the frequency increases. At 18.8 GHz, the polished and unpolished 0.265 µm 3C-SiC show reflection coefficients of 0.91 and 0.81, respectively. Hence, it can be inferred that polished surface of 0.265 µm 3C-SiC has lower microwave absorbability than unpolished surface because more energy is reflected.

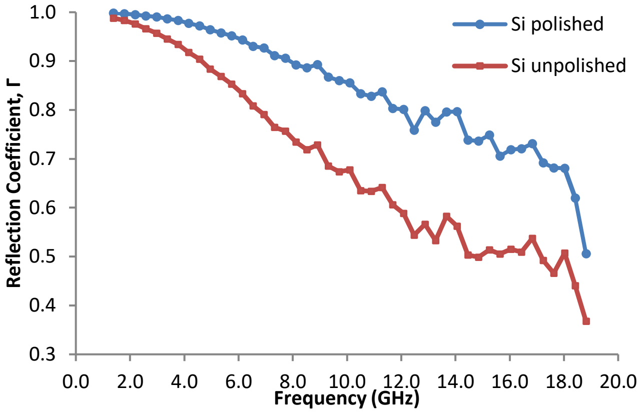


Figure 6: Variation of the reflection coefficient, |Γ| for 650µm Si.

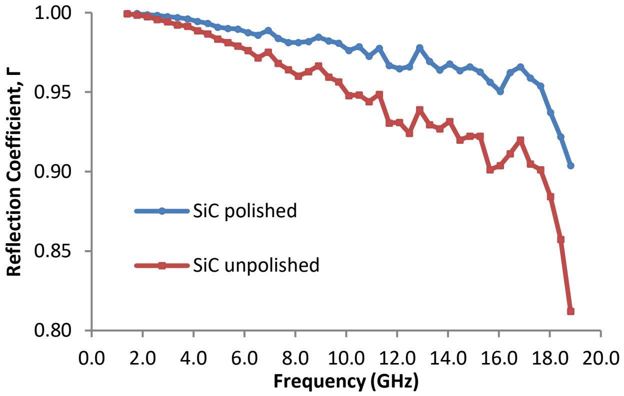


Figure 7: Variation of the reflection coefficient, |Γ| for 0.265 µm 3C-SiC deposited on 650µm Si Substrate.

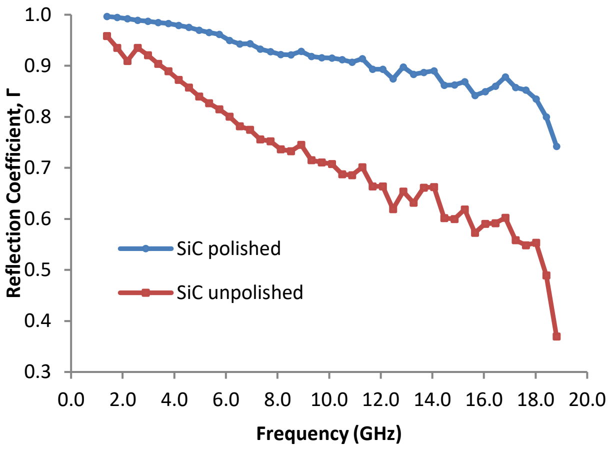


Figure 8: Variation of the reflection coefficient, |Γ| for 0.285 µm 3C-SiC deposited on 650µm Si Substrate.

The variation of |Γ| for 0.285 µm 3C-SiC is as displayed in Figure 8. Since the sample is grown on a silicon wafer, both surfaces achieve maximum |Γ| at 1.4 GHz. Beyond 1.4 GHz, the |Γ|. The unpolished of 0.285 µm 3C-SiC shows good absorbing properties within 18 GHz to 18.8 GHz due to its low |Γ| which is less than 0.5. The |Γ| for polished 0.285 µm 3C-SiC slowly decreases from 0.85 to 0.75 within 18 GHz to 18.8 GHz. It can be said that the polished 0.285 µm 3C-SiC reflects more energy than the unpolished surfaces.

The difference in variation of |Γ| for all samples can be proven by the AFM results where it shows that 0.265 µm 3C-SiC does not show good absorbability due to specular reflections while 0.285 µm 3C-SiC has the preparation of abundant cavity. Moreover, the rough surface tends to trap the energy and absorb by the Si through multiple reflections within cavities. SiC itself is considered as good reflector while Si has been known for its good microwave absorbability [13]-[14].

On the other hand, the microwave absorption coefficient [15] can be calculated by using equation. This equation is to determine the how much energy can be absorbed by the samples for different surfaces and thicknesses.

$$A = 1 - |\Gamma|^2 \qquad (1)$$

Thus, the lower the |Γ|, the higher will be the absorption rate. It can be said that for the microwave absorbers to achieve optimum performance, more attention should be paid to the thickness and the EM parameters since the EMI shielding effectiveness data which vary with the thickness of the sample and frequency [16] at which the measurement is carried out. Based on Figure 7 and Figure 8, the polished surface of both thicknesses of 3C-SiC has similarities i.e. the low capability to captivate the microwave energy within space between 3C-SiC and Si at 1.4 GHz to 18.8 GHz compared to the unpolished surface. It can be said that polished surface tends to act as a reflector because polished 3C-SiC shields the Si from the exposure of microwave energy. Meanwhile, the unpolished surface tends to trap more microwave energy and maintain the exposure due to its surface roughness which has an abundant cavity. Even though the polished surfaces act as a good reflector but the unpolished surfaces are still the best and preferable option. Hence, it can be concluded that the unpolished surface of 0.285 µm of 3C-SiC shows better absorbing properties at frequencies 18 GHz to 18.8 GHz where it exhibits |Γ| less than 0.5.

IV. CONCLUSION

Experimental work for a study on EMI analysis of 3C-SiC/Si surface roughness and thickness has been done. Based on the XRD result, it shown that the 3C-SiC/Si used is a high-quality 3C-SiC which proven by the high peaks of 3C-SiC and Si. Meanwhile, the AFM results show that both polished and unpolished surface of the 0.285 µm thick 3C-SiC is rougher than the polished and unpolished 0.265 µm 3C-SiC. The rougher surface of the thicker version of the 3C-SiC could provide potential cavities which might trap and enable Si to absorb the energy. From the |Γ| results, it can be concluded that when the frequencies increases, the |Γ| of all samples are decreases. It can be inferred that the polished surface of 3C-SiC is smooth and tends to reflect more microwave energy and acts as a reflector. While, the unpolished surface of 3C-SiC captivates more microwave energy and has good microwave absorbability. In comparison to these two thicknesses and surfaces of 3C-SiC, it can be concluded that 0.285 μm of unpolished 3C-SiC achieves lower |Γ| than other samples at frequencies 1.4 GHz to 18.8 GHz. Hence, the rough surface of the thicker 3C-SiC film deposited on a Si substrate could have the potential to be used as a microwave absorbing material.

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