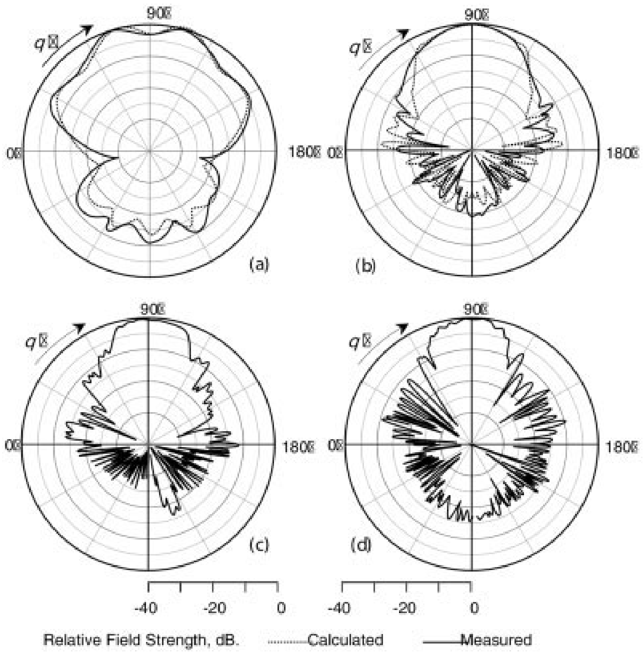

Figure 7 *E*-Plane radiation patterns. (a) 1 GHz, (b) 4 GHz,(c) 8 GHz, and (d) 10 GHz

horn, which was constructed as designed, with no attempt at tuning or improving the impedance performance.

While the band-limited design is for an upper frequency of 5 GHz, it is seen that the horn functions well beyond that frequency. This is because the design is based on the assumption that a true TEM mode exists over the whole of the frequency band. This is, of course, not the case, as the horn radiates a traveling wave as the energy exits the structure; this effect will become all the more pronounced as the frequency increases.

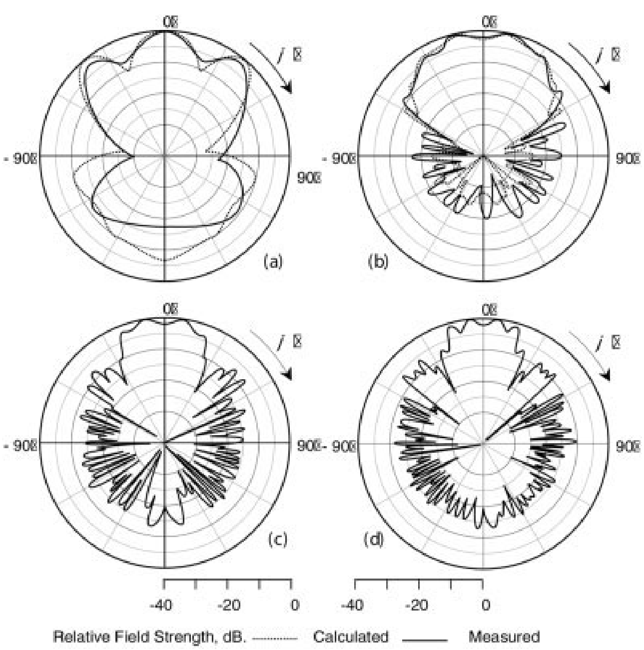

Figure 8 *H*-Plane radiation patterns. (a) 1 GHz, (b) 4 GHz, (c) 8 GHz, and (d) 10 GHz

With minimal effort, a substantial increase in bandwidth can be obtained, if the structure is built with more care. The symmetry of the radiation patterns is an indication of the excellent balance in the feed.

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OPTICAL PROPERTIES OF SIC/SIO$_2$ COMPOSITE THIN FILM

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ABSTRACT: *SiC film was deposited by electron beam-physical vapor deposition on thermal oxidized silicon substrates at 750°C, and SiC/SiO_2 composite thin film was prepared. The obtained composite film was analyzed by Fourier-transform infrared (FTIR) transmission and reflection spectroscopy, and the film reveals an amorphous structure and a high emissivity.* © 2007 Wiley Periodicals, Inc. Microwave Opt Technol Lett 49: 1551–1553, 2007; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.22487

Key words: *optical; SiC; SiO_2; FTIR; EB-PVD*

1. INTRODUCTION

SiC is a promising multifunctional protective coating material for metal thermal protection systems because of their combination of unique physicochemical and mechanical properties in rigid condition, such as ultra high velocity and temperature condition [1, 2].

Although large-area β-SiC films can be grown on Si wafers by chemical vapor deposition CVD [3], these films have a high defect density due to high temperature process above 1300°C. The defects at the SiC/Si interface and in the SiC films will greatly degrade the performance of the optoelectronics devices. On the other hand, the SiC films on Si wafers cannot be fully exploited on high-temperature microelectronic devices due to the leaking SiC/Si heterojunction at elevated temperatures, resulting in a current flow through the substrate [4–6].

To prepare perfect SiC film and improve the oxidation resistance of it, a promising technique appears to be the growth of the SiC films on oxidized Si substrate. Yonekubo et al. have prepared polycrystalline β-SiC films on both substrates of quartz, and thermally oxidized Si at 860°C, by microwave plasma CVD [7]. They conclude that the b-SiC films are useful for sensor elements, such as thermal sensors, when used at high ambient temperatures. Leycuras has also grown SiC films on thermally oxidized Si at 1400°C by CVD with carbonization process [8]. His results show that the 0.4-mm-thick SiO_2 layer on Si has completely disappeared and a perfect SiC/SiO_2 composite thin film is successfully prepared. Because of high emissivity and good oxidation resistance, when SiC/SiO_2 composite thin film used as a protective coating of some section in space vehicle, high emissivity can make it radiate a quantity of thermal energy coming from friction between air flow and vehicle surface to atmosphere, and reduce surface temperature of space vehicle and inward heat transfer. As a result, SiC/SiO_2 composite thin film can bear high ambient temperature and resist oxidation. However, the emissivity of thin film is corresponding to its physical character and belongs to optical property of material. Therefore, it is necessary to research the optical properties of SiC/SiO_2 composite thin film.

2. EXPERIMENTAL

An electron beam physical vapor deposition (EB-PVD), which has a stainless steel chamber with the diameter of 1200 mm and the height of 700 mm, is used in this study. The pumping system consists of a turbomolecular pump in series with a mechanical pump. A SiC ingot (99.9%) of 100 mm in height and 98 mm in diameter is used as sputtering target. A thermally oxidized n-type (111)-Si wafer with a resistivity of 50 Ω cm is used as substrate. The distance between target and substrate is fixed at 150 mm. The oxidized Si substrates are washed using acetone, and ethanol, and then are rinsed in deionized H_2O. The substrate is directly heated using an electron beam, and its temperature is measured by thermocouple. The substrate temperature is maintained at 750°C and the deposition time is 5 s.

Infrared spectra were recorded on a FTIR spectrometer (IFS66, Bruker) between a wave-number range from 400 to 2000 cm^{-1} in transmission and reflection (angles of incidence: 30, with parallel and perpendicular polarization). A gold mirror on glass was used as reference sample. The area of inspection was confined by a circular aperture of 4 mm diameter. This arrangement allowed local measurements with a rough lateral resolution.

3. RESULTS AND DISCUSSIONS

3.1. Transmittance

The FTIR spectra of the as-prepared films are shown in Figure 1. The spectrum shows mode of vibration that characterizes amorphous silicon carbide film [9]. The dominant mode of vibration in Figure 1 is the SiC stretching mode at 800 cm^{-1}. From Figure 1, it can be shown that the transmittance of SiC/SiO_2 composite film is quite low. Moreover, the transmittance is lower and lower with the increase of wave-number from 1000 to 2000 cm^{-1}, which indicates that the transmittance SiC/SiO_2 composite film is even lower at higher frequency of FTIR spectrum. Because of low transmittance, it is difficult of microwave and various space rays to breakdown SiC/SiO_2 composite film, which can greatly reduce film damage resulting from the irradiation of microwave and various space rays, and prevent substrate from thermal destruction.

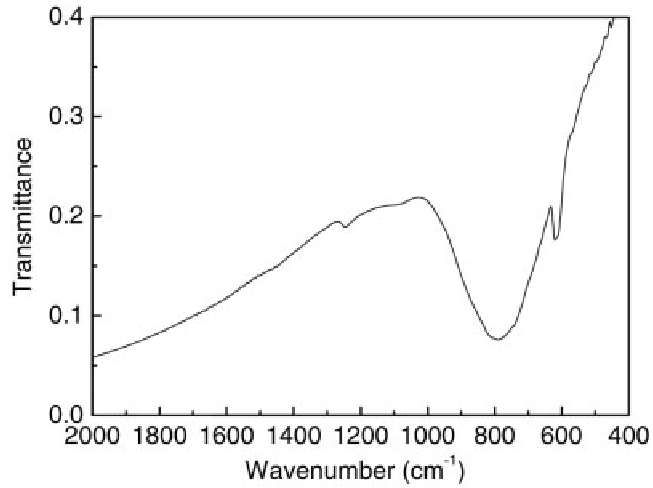

Figure 1 FTIR spectra of EB-PVD amorphous SiC/SiO_2 film

3.2. Reflectivity

The dependence of the reflectivity of SiC/SiO_2 composite film on wave-number is shown in Figure 2. The reflectivity of SiC/SiO_2 composite film is basically located at the range from 0.3 to 0.4. The reflectivity of bulk crystalline SiC exhibits a reststrahlen band of low reflectivity (<10%) between the transverse optical mode at 796 cm^{-1} and the longitudinal optical mode at 979 cm^{-1}. Furthermore, the reflectivity of film decreases with the increase of wave-number, which means that the reflectivity of film will be lower at higher frequency region, as shown in Figure 2.

Amorphous semiconductors exhibit optical absorptivities markedly increased over those of their crystalline counterparts in photon energy regimes below the respective optical band gaps. This is partly due to the presence of gap states in the amorphous phase and, more important, is caused by changes in the *k* selection

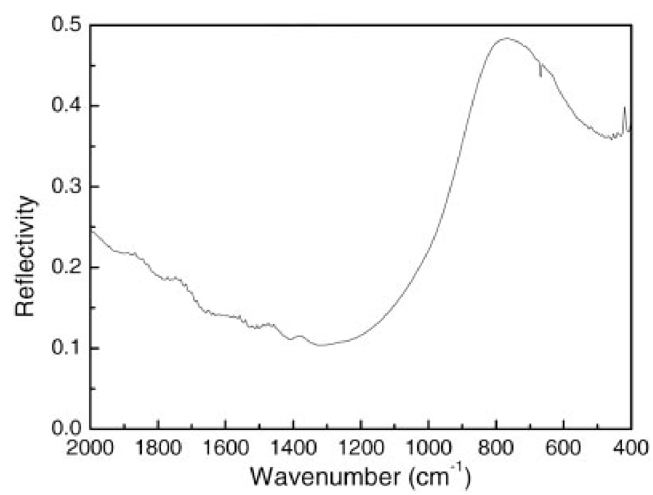

Figure 2 The reflectivity of SiC/SiO_2 film as a function of wavenumber

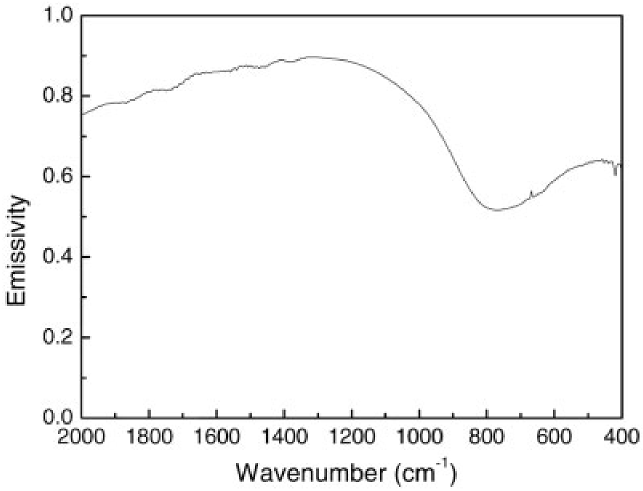

Figure 3 The emissivity of SiC/SiO_2 film as a function of wavenumber

rules turning direct/indirect optical transitions in crystalline materials nondirect after amorphization [10].

3.3. Emissivity

Because $A = 1 - R - T$ (A: absorptivity, R: reflectivity, and T: transmissivity), in the limit of strong absorption ($T = 0$), according to Kirchhoff's law, the emittance is determined by the first surface reflection, such that:

$$\varepsilon(\mathrm{v},T,\theta) = 1 - R(\mathrm{v},T,\theta) \tag{1}$$

where ε is the emissivity, ν is frequency, and the angle θ specifies the observer angle, as shown in Figure 3. Because there is no transmittance, the reflectance equals the single surface power reflection coefficient. According to S.K. Andersson et al., when $n - 1 \gg k > 0.01$ (n and k: the real and imaginary parts of the complex index of refraction), the spectral region occurs in the two-phonon region (shown in Fig. 4), which is the spectral region of highest emissivity for a bulk material. Corresponding with bulk material, the SiC/SiO_2 composite thin film also has a highest emissivity in this spectral region. Moreover, the spectral direction emissivity of SiC/SiO_2 composite thin film has an average spectral direction emissivity value of 0.7 at a wide wave-number range from 400 to 2000 cm^{-1}.

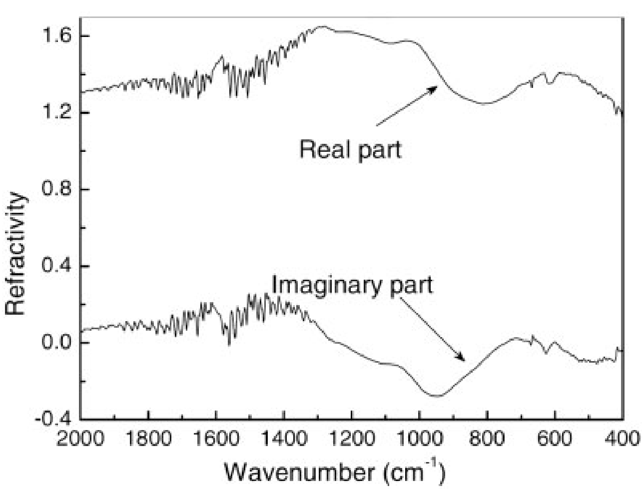

Figure 4 The real and imaginary parts of refractivity of SiC/SiO_2 composite thin film as a function of wavenumber

4. CONCLUSION

The SiC/SiO_2 composite thin film deposited on Si substrate was analyzed with FTIR and transmission spectroscopy. The analysis of the reflectivity and emissivity shows that SiC/SiO_2 composite thin film has a stable spectral direction emissivity at a wave-number range from 400 to 2000 cm^{-1}, which can perfectly bear high temperature and various space ray irradiation.

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