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Ceramics International 40 (2014) 47–55

CERAMICS INTERNATIONAL

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# High-temperature microwave bilayer absorber based on lithium aluminum silicate/lithium aluminum silicate-SiC composite

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Received 26 April 2013; accepted 27 May 2013
Available online 6 June 2013

**Abstract**

The microwave absorbing properties of lithium aluminum silicate (LAS) and LAS–SiC double layer composite absorbers were investigated within the frequency range of 8.2–12.4 GHz at 300–500 °C. The composite absorbers for use as high-temperature radar wave-absorbing materials were developed by hot-pressing LAS glass–ceramic and LAS–SiC composite, which were used as the impedance transformer layer and the low-impedance resonator layer, respectively. Nanometer-size β-SiC powders were fabricated at the relatively low sintering temperature of 1450 °C in argon atmosphere. The structure and morphology of the SiC powders were characterized using thermogravimetry-differential scanning calorimetry (TG-DSC), X-ray diffractometry (XRD) and scanning electron microscopy (SEM). The electromagnetic absorbing properties of the double layer at different temperatures and SiC contents were measured at normal temperature (27 °C) and high temperature by a vector network analyzer. The results indicate that the contents of nanometer-size β-SiC can increase the relative permittivity and dielectric loss of the double layer microwave absorbers. At high temperatures, the microwave absorber consisting of a 2-mm-thick layer of LAS ceramic and a 2-mm-thick layer of LAS–SiC composite with 10 wt% SiC content exhibited excellent performance with a minimum absorption at −42.8 dB at 10.5 GHz and the absorption bandwidth (reflection loss less than −10 dB) of 3.5 GHz in the X-band. The minimum reflection loss measured at 300–500 °C was less than −24 dB.


*Keywords:* Ceramic-matrix composites; Layered structures; High-temperature microwave absorption; Lithium aluminum silicate; D. SiC

## 1. Introduction

Recently, radar absorbing materials (RAMs) used as military stealth materials which have attracted significant attention for radar cross section (RCS) reduction applications [1–3]. Stealth materials in weapons can be categorized into normal-temperature and high-temperature applications according to their optimal uses. Most magnetic materials are constrained by their respective Curie temperatures and easily lose their low reflectivity characteristics at high temperatures because of the associated loss of their magnetic properties. Thus, magnetic absorbing materials are generally used only in the normal-temperature stealth region of weapons applications but are not suitable for hyper-velocity missiles, rockets or aircrafts in which the engines output significant heat. In comparison to magnetic materials, however, ceramic dielectric composites perform with suitable lossy capabilities and relatively stable complex permittivities in the range of room temperature to high temperature [4]. Silicon carbide (SiC) was studied as a dielectric structural ceramic due to its high strength and hardness, low density, good resistance to oxidation, high thermal stability and high thermal conductivity at elevated temperatures [5–7]. Additionally, SiC is considered to be one of the most important microwave absorbing materials due to its sufficient dielectric loss in microwave radiation [8–10].

The β-SiC phase is widely used in industrial applications and is the subject of a variety of research efforts due to its superior properties. Further, it is inorganic and acts as a high-temperature wave absorbing material; consequently, it can be used as an absorber matrix. Typically, silicon carbide is produced by the carbothermal reduction of silica using the

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http://dx.doi.org/10.1016/j.ceramint.2013.05.101

Acheson process, which involves heating silica sand and carbon to high temperatures (2500 °C) in an Acheson graphite resistance furnace [11]. The commercial product has a large grain size and is invariably contaminated with oxygen. Several other fabrication processes can be used to obtain SiC, including polymer pyrolysis [12], chemical vapor deposition (CVD) [13] and hot pressing. Most of the above-mentioned approaches require temperatures higher than 1500 °C and consume significant quantities of energy. In contrast, sol–gel processing is one of the most advanced methods for the fabrication of β-SiC powders and can be performed at room temperature by homogenizing a sol system derived from the initial liquid components [14–24]. In comparison to ferrites, SiC is used in high temperature conditions, and its loss factor increases with temperature [10,25]. Unfortunately, few systematic studies on the microwave absorption properties of SiC-based absorbers have been performed in high-temperature environments, and most documented characters refer to normal temperatures.

In this work, nanometer-size β-SiC powders were fabricated at a relatively low temperature by the sol–gel process and were expected to exhibit better microwave absorption properties than the commercially produced powders. The powder phase components and morphology were studied with X-ray diffraction (XRD) and scanning electron microscope (SEM), respectively. To achieve a broadened absorption bandwidth of the dielectric absorber, a double layer absorber was developed in which the β-SiC powders were mixed with lithium aluminum silicate (LAS) glass–ceramics to form the SiC–LAS composite layer as a low impedance resonator, and the other layer from the LAS glass–ceramics acts as the impedance transformer layer [4,20]. In this study, an enhanced microwave absorption characteristic was observed for the LAS/LAS–SiC composite absorbers. The microwave absorbing properties of this material are further discussed below.

## 2. Experimental

### 2.1. Preparation of the β-SiC powders

A fixed quantity of phenolic resin (a condensation polymer of methanol and phenol with a softening temperature of 80–90 °C) was mixed with ethanol and stirred until it dissolved. Then, the reagent TEOS (tetraethyl orthosilicate, $Si(CH_3CH_2O)_4$ ) was mixed with several drops of HCl in a solution of deionized water and ethanol. The HCl solution was slowly poured into the phenolic resin/ethanol solution, followed by 48 h of stirring at room temperature to hydrolyze the TEOS and form the sol. Finally, a small amount of hexamethylenetetramine ($C_6H_{12}N_4$) in ethanol solution (35 wt%) was added to the sol dropwise to accelerate the polymerization and form the gel. The gel was then baked in an oven at 100 °C for 24 h, aged and dried to form the xerogel precursor. The xerogel was then placed in a quartz boat, which was inserted into the central position of a high-temperature tube furnace. The tube was covered at both ends, and the gas flow into the tube was controlled by a valve in the cover. The tube was first purged with argon; then, the argon flow was fixed at 40 $cm^3$/min. The xerogel was heat-treated at 1450 °C for 2 h with a heat ramping speed of 2 °C/min in argon. Under these conditions, a carbothermal reduction occurred in the xerogel, forming the SiC powders. The phenolic component in the xerogel served as a carbon source in the carbothermal reduction. Another component, $NH_4NO_3$, released gases upon heating, which prevented condensation and formed the internal pores. The relatively low temperature employed in this method (other methods require 1550 °C or higher) suppresses crystal grain growth. The formation of pores by gas release suggests that porous nanometer-size SiC powders can be achieved with this method. The products are also expected to possess relatively high dielectric dissipation. The synthesized raw SiC powders were calcined in air to remove carbon residues and washed with HF to remove $SiO_2$. Additionally, the LAS glass was prepared from analytical grade reagents of $SiO_2$, $Al_2O_3$ and $Li_2O_3$ in a molar ratio of 4:1:1, fabricated by the hot-pressing method.

### 2.2. Preparation of the LAS/LAS–SiC double-layer composite absorber

The high-temperature microwave composite absorbers composed of a LAS layer and a LAS–SiC layer were fabricated by the hot-pressing method. Hot-press sintering of the LAS glass–ceramic formed the outer layer, which is an impedance transformer layer. The inner layer was formed by hot-press sintering of SiC powders evenly distributed within the LAS glass–ceramic. The inner layer worked as a low impedance resonator. The width and length of both layers were 15 cm with thicknesses of 1 mm, 2 mm or 3 mm, depending on the specific experimental design. The layers were laid on the substrate as follows: the inner layer (i.e., the LAS–SiC layer or low impedance resonator) was applied to the substrate first; then, the outer layer (i.e., the LAS layer or impedance transformer layer) was deposited on top. The resulting composite is a so-called "double-layer microwave absorbing material." The reflection loss or reflectivity was then measured at normal and high temperatures. The structure of the double-layer microwave absorber is shown in Fig. 1.

### 2.3. Characterization

X-ray diffractometry (XRD) was used to analyze the crystallographic composition and poly types of the carbothermal reduction products. Thermogravimetry-differential scanning calorimetry (TG-DSC) measures weight changes in materials for determining the composition, thermal stability and related phenomena. The morphologies of the powders were observed by scanning electron microscopy (JEOL,

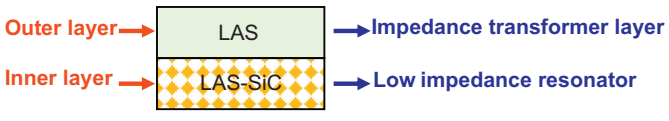


Fig. 1. The structure of the double layer microwave absorber.

JSM-2000). The measurements of the electromagnetic wave absorption properties for use as microwave absorbers were obtained using a PNA vector network analyzer (E8362B, Agilent Technologies, CA). The reflection loss measurement was obtained from the sample backed with an aluminum plate.

### 2.4. Microwave absorption properties

#### 2.4.1. Fundamental theory

When an electromagnetic wave strikes a metal, it cannot penetrate the metal and instead generates total reflection. When the microwave or electromagnetic wave irradiates an absorbing material, however, part of the wave may be reflected by the material, while the remaining fraction of the wave penetrates into the material. Materials can deplete the electromagnetic wave to reduce its energy in one of two ways.

Generally, we use the value of reflection loss as a standard to analyze the absorbing performance of single layer materials. The optimum absorption thickness and reflection loss can be obtained by Eqs. (1)–(3) [26].

$$Z_{\text{in}} = Z_0\sqrt{\frac{\mu_r}{\varepsilon_r}}\tanh\left[\left(j\frac{2\pi}{\lambda}\right)d\sqrt{\mu_r\varepsilon_r}\right] \tag{1}$$

$$\Gamma = \frac{Z_{\text{in}} - Z_0}{Z_{\text{in}} + Z_0} \tag{2}$$

$$RL(\text{dB}) = 20 \times \log|\Gamma| \tag{3}$$

where $Z_{\text{in}}$: the input impedance; $Z_0$: the characteristic impedance of air

$\mu_r = \mu' - j\mu''$ : thecomplex permeability

$\varepsilon_r = \varepsilon' - j\varepsilon''$ : thecomplex permittivity

$d$: the thickness of the absorber
$\lambda$: the wavelength of the electromagnetic wave
$\Gamma$: the reflection coefficient
$R$: the reflection loss

When the construction is a double layer absorber, the reflection loss is illustrated by Eq. (4) [4,27]

$$RL(\text{dB}) = 20 \times \log\left|\Gamma\right| = \frac{\left[\left(\sqrt{\mu_1/\varepsilon_1}\tanh(\gamma_1 d_1) + \sqrt{\mu_2/\varepsilon_2}\tanh(\gamma_2 d_2)/\sqrt{\mu_1\varepsilon_2/\mu_2\varepsilon_1}\tanh(\gamma_1 d_1)\tanh(\gamma_2 d_2) + 1\right)\right] - 1}{\left[\left(\sqrt{\mu_1/\varepsilon_1}\tanh(\gamma_1 d_1) + \sqrt{\mu_2/\varepsilon_2}\tanh(\gamma_2 d_2)/\sqrt{\mu_1\varepsilon_2/\mu_2\varepsilon_1}\tanh(\gamma_1 d_1)\tanh(\gamma_2 d_2) + 1\right)\right] + 1} \tag{4}$$

where $\gamma = j(2\pi f/c)\sqrt{\mu\varepsilon}$, and $d$ is the thickness of absorbing impedance layer.

#### 2.4.2. Measurement methods for microwave absorption

The electromagnetic attenuation test for the microwave absorbers investigated in this study were measured at different temperatures with the microwave free-space measurement method using a PNA vector network analyzer (E8362B, Agilent Technologies, CA) system. The electromagnetic wave return-loss measurement system was utilized for detection, and the electromagnetic scanning frequency range was 8.2–12.4 GHz. Prior to obtaining this measurement, a metal plate of the same size as the specimen (15 × 15 $cm^2$) was placed in the test position to calibrate the horizontal level and to measure its reflectivity. Then, the microwave absorber was placed on top of the metal plate, and the intensity of its reflection attenuation was measured. The angle of the antenna was adjusted to measure the original reflection. Then, the glass ceramic absorber was placed on the metal plate, and the decayed reflection was measured. The relationship between the reflection loss and energy is shown in Eqs. (3) and (4). The reflection loss can be calculated as follows (Eq. (5).

$$RL(\text{dB}) = 10 \times \log\left(\frac{P_r}{P_0}\right) \tag{5}$$

$P_r$: the power of the reflected wave; $P_0$: the power of the incident wave

## 3. Results and discussion

### 3.1. Microstructure and morphology

Fig. 2 shows the TG-DSC analysis of the SiC precursor. The thermal decomposition has three stages: in the first stage, heat is absorbed from 0 °C to 400 °C, and water and ethanol evaporate; in the second stage from 400 °C to 700 °C, exothermic reactions occur, and the material undergoes approximately 40% weight loss, which may be caused by the continuous cross-linking of Si polymer molecules in the gel and decomposition of the resin; in the third stage from 700 °C to 1000 °C, the reactions have become stable, and $SiO_2$ has formed in addition to free C atoms. Fig. 2(b) shows the XRD patterns of SiC powders synthesized at 1450 °C for 2 h. The characteristic 2$\theta$ peaks at 35.5°, 41.2°, 60°, 72° and 75.5° are compared with JCPDS (series #: 29–1129) and confirmed to be consistent with β-SiC. The strong peaks are intense and sharp, indicating that the crystalline granular β-SiC powders were synthesized at the relatively low temperature of 1450 °C. According to the literature report in [28], β-SiC is stable at room temperature but tends to transform into α-SiC after calcination at temperatures higher than 1600 °C. Fig. 2(c) shows the SEM morphology of the β-SiC powder samples calcined at 1450 °C. The powders are shaped into irregular cubes with a dimensional range of approximately 30–50 nm. According to the literature [29], the irregular powders have a relatively large surface area, which makes the nanopowders possess large conduction losses and enhances their microwave absorbing properties.

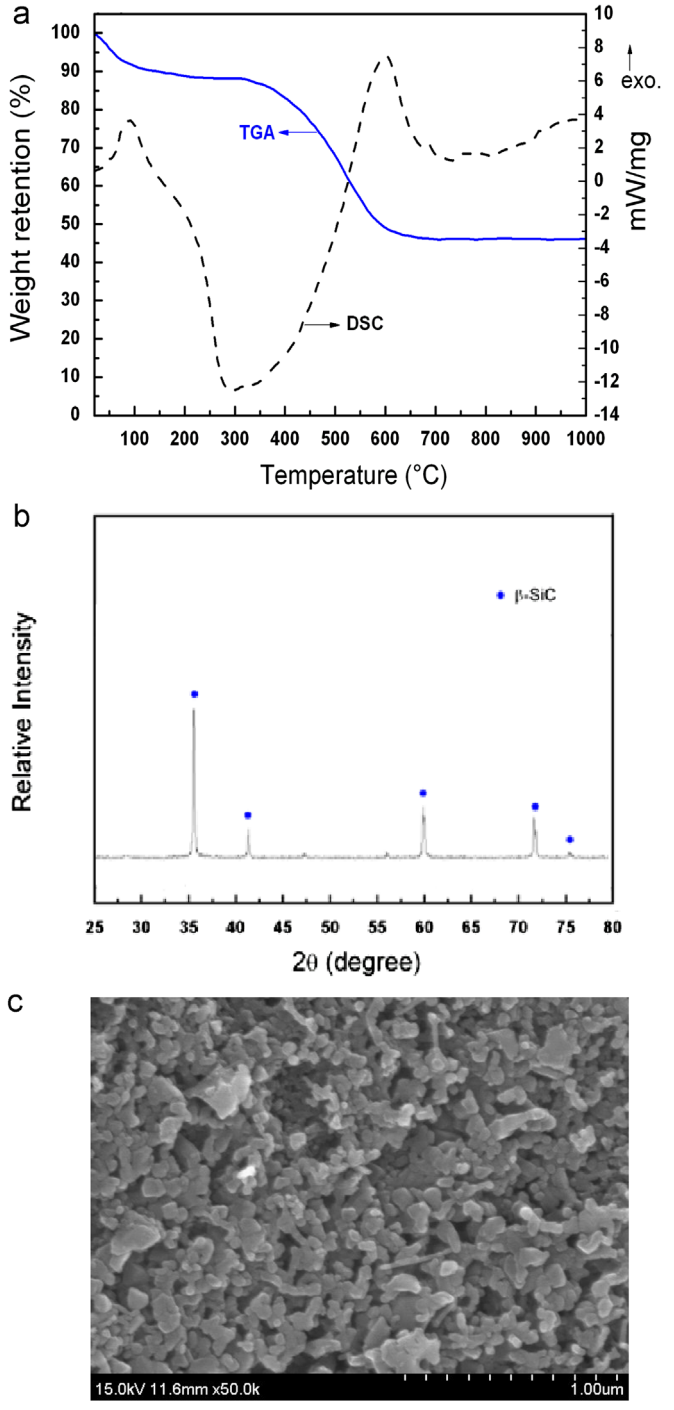


Fig. 2. (a) Thermal analysis of the precursors; (b) XRD patterns of the SiC powders sintered at a temperature of 1450 °C; and (c) SEM morphology of the β-SiC powders synthesized at a temperature of 1450 °C.

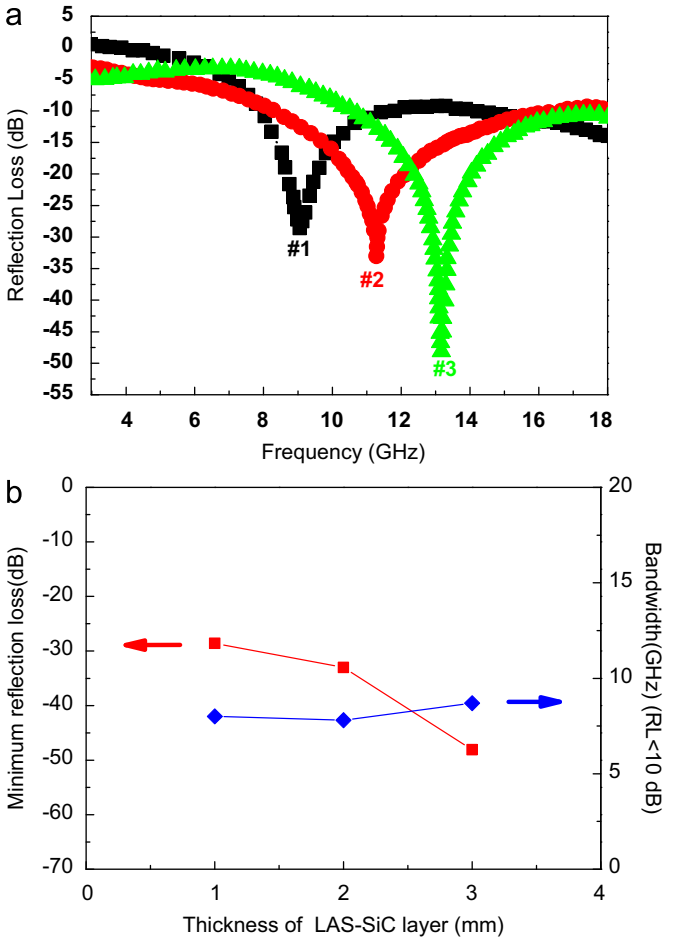


Fig. 3. (a) Reflection loss of the LAS/LAS–SiC double layer microwave absorber with different thicknesses of the LAS–SiC layer at normal temperature. (b) Variation of the minimum reflection loss and the bandwidth (RL less than −10 dB) as a function of LAS–SiC thickness.

Table 1
Sample code of LAS/LAS–SiC double layer microwave absorbers.

| Sample code | LAS glass ceramic layer (mm) | LAS–SiC composite layer (mm) | Nanometer SiC content (wt%) |
|---|---|---|---|
| # 1 | 2 | 1 | 10 |
| # 2 | 2 | 2 | 10 |
| # 3 | 2 | 3 | 10 |
| # 4 | 2 | 2 | 5 |
| # 5 | 2 | 2 | 15 |

### 3.2. Microwave absorption performance at normal temperature

#### 3.2.1. Effect of the SiC–LAS layer thickness on the absorption properties

Fig. 3(a) shows the microwave absorption properties of the LAS/LAS–SiC double-layer microwave absorbers with serial sample numbers #1, #2 and #3 (shown in Table 1) at fixed LAS thickness; the absorption properties were measured with a vector network analyzer in the range of 3–18 GHz at normal temperature. The reflection loss peak shifts to high frequency with an increase in the LAS–SiC thickness. Sample #1 shows a minimum absorption value of −28.6 dB at 9.0 GHz and an absorption bandwidth less than −10 dB in the frequency range of 8.1–11.8 GHz and 14.2–18.0 GHz. Sample #2 shows a minimum absorption value of −33.0 dB at 11.3 GHz and an absorption bandwidth less than −10 dB in the frequency range of 8.5–16.3 GHz. Sample #3 shows a minimum absorption

value of −48.1 dB at 13.2 GHz and an absorption bandwidth less than −10 dB in the frequency range of 10.7–18 GHz. Sample #1, which is the thinnest microwave absorber sample, exhibits less than 10 dB of reflection loss in two regions, making it the most suitable sample for applications in the X-band (8.2–12.4 GHz) and the Ku-band (12–18 GHz). However, sample #3 is thicker, which causes the reflection loss of less than −10 dB within the 8.7 GHz bandwidth. Although sample #3 is relatively thick, its minimum absorption value of −48.1 dB renders it the most suitable sample for applications in the Ku-band. Sample #2 exhibits the reflection loss at less than −10 dB within the 7.8 GHz bandwidth and also is suitable for use in the X-band and the Ku-band. Fig. 3 (b) shows the change in the minimum reflection loss and the bandwidth (RL less than −10 dB) with respect to changes in thickness of the different LAS–SiC layers. It can be observed that the minimum reflection loss decreases with increasing LAS–SiC layer thickness. However, the microwave absorption bandwidth (RL less than −10 dB) shows a slight decrease followed by an increase with increasing LAS–SiC layer thickness. This result indicates that sample #3 has the best microwave absorption properties (i.e., the minimum reflection loss and maximum absorption bandwidth) in comparison with the other two samples (samples #1 and #2) in the range of 3–18 GHz at normal temperature. However, if the microwave frequency of interest is constrained to the X-band (8.2–12.4 GHz), sample #2 exhibits better absorption properties than the other two samples.

### 3.2.2. *Effect of the SiC content on the absorption properties*

Fig. 4(a) shows the reflection loss of the microwave absorbers with different SiC contents (#2, #4 and #5) in which the reflection loss peak initially increases and then decreases. With an increase in the SiC content, the peak shifts to a lower frequency. The absorption bandwidth (RL less than −10 dB) of sample #4 is 3.3 dB at 12.4–15.7 GHz, and the minimum reflection loss is −26.0 dB at 13.6 GHz. However, the absorption bandwidth (RL less than −10 dB) of sample #5 is 4.7 dB from 6.9 GHz to11.6 GHz. The minimum reflection loss value is −30.1 dB at 9.5 GHz. Fig. 4(b) shows the variation in the minimum reflection loss and the bandwidth (RL less than −10 dB) with respect to different SiC contents. It can be observed that sample #2 with a SiC content of 10 wt% has the lowest reflection loss and the broadest microwave absorption bandwidth in comparison to the others of the same thickness in the range of 3–18 GHz at normal temperature.

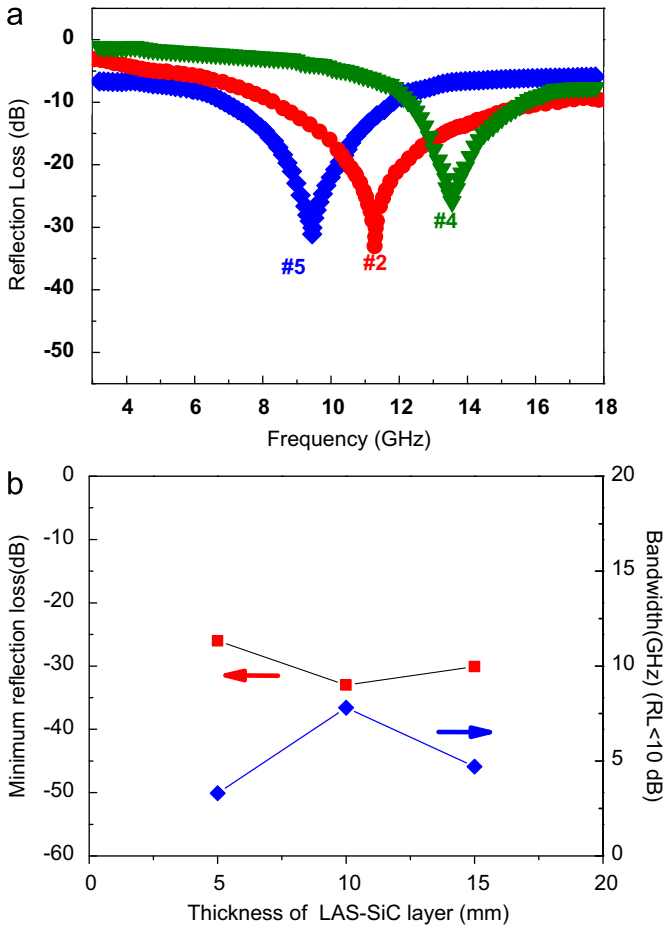


Fig. 4. (a) Reflection loss of the double-layer microwave absorber with different contents of SiC powders at normal temperature. (b) Variation of the minimum reflection loss and the bandwidth (RL less than −10 dB) by SiC content.

### 3.3. *Enhanced electromagnetic absorbing characteristics at high temperature*

### 3.3.1. *Effect of the SiC–LAS composite thickness on the absorption properties*

To study the reflection loss behaviors of the double layer microwave absorbers at high temperature, samples were prepared by hot-pressing and then measured at 300 °C, 400 °C and 500 °C. As shown in Fig. 5(a)–(c), the reflection loss is greatly dependent on the LAS–SiC thickness and the measurement temperature. From the reflectivity curves in Fig. 3(a) and Fig. 5(a)–(c), it can be seen that the reflection loss peak of sample #1 at normal temperature shifts to a higher frequency with increasing temperature. In contrast, both samples #2 and #3 shift to lower frequencies with increasing temperature. For double layer samples #1–3 with the same SiC contents, when the temperature is increased, the bonding reaction of the LAS material gradually increases as well, producing an inflation of LAS layer and LAS–SiC layer, causing the reflection peaks shift to lower frequencies. In Fig. 5(a), sample #1 has a minimum absorption value of −27.5 dB at 9.7 GHz and an absorption bandwidth (RL less than −10 dB) of 4.2 GHz in the frequency range of 8.2–12.4 GHz. Sample #2 shows a minimum absorption value of −42.8 dB at 10.5 GHz and an absorption bandwidth (RL less than −10 dB) of 3.9 GHz in the frequency range of 8.5–12.4 GHz. Sample #3 shows a minimum absorption value of −31.3 dB at 8.3 GHz and an absorption bandwidth (RL less than −10 dB) of 1.7 GHz in the frequency range of 8.2–9.9 GHz. At 400 °C, Fig. 5(b) demonstrates that sample #1 has a minimum absorption value of −18.1 dB at 9.9 GHz and an absorption bandwidth (RL less than −10 dB) of 4.2 GHz in the frequency range of 8.2–12.4 GHz. Sample #2 shows a minimum absorption value of −26.4 dB at 10.2 GHz and an

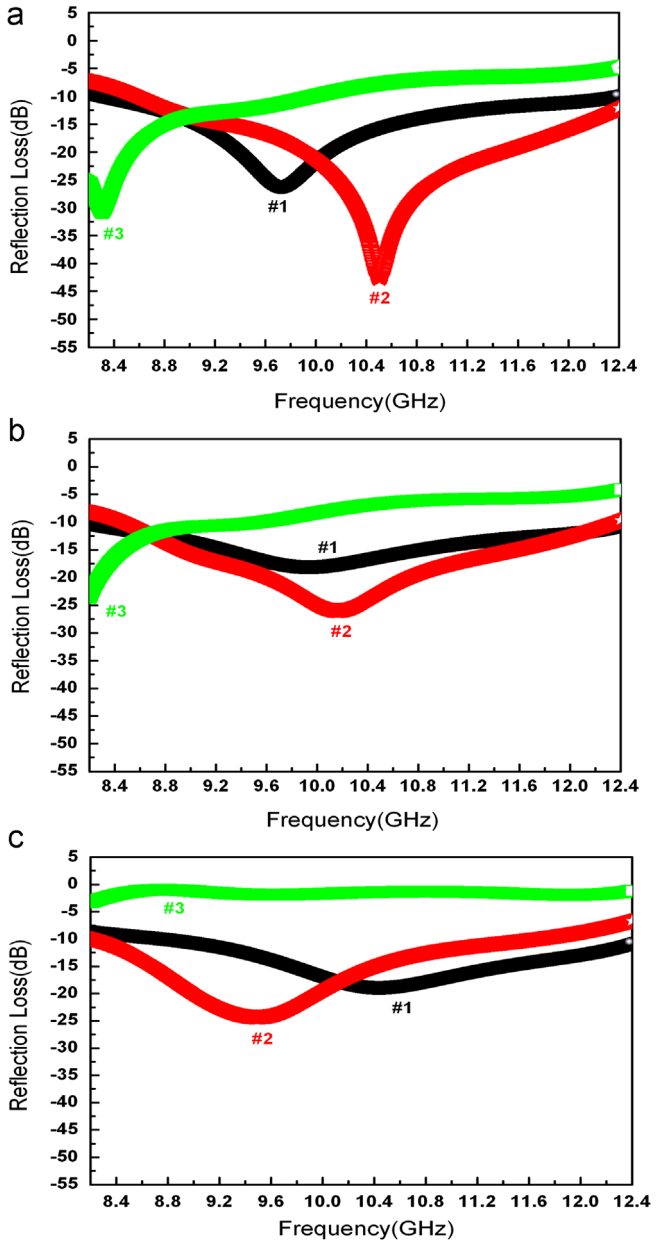


Fig. 5. Reflection losses of the double-layer microwave absorber with different thicknesses of SiC/LAS composite layers at high temperatures of (a) 300 °C, (b) 400 °C and (c) 500 °C.

absorption bandwidth (RL less than −10 dB) of 3.9 GHz in the frequency range of 8.5–12.4 GHz. Sample #3 shows a minimum absorption value of −24.6 dB at 8.2 GHz and an absorption bandwidth (RL less than −10 dB) of 1.1 GHz in the frequency range of 8.2–9.3 GHz. At the relatively high temperature of 500 °C, Fig. 5(c) demonstrates that sample #1 has a minimum absorption value of −17.3 dB at 10.4 GHz and an absorption bandwidth (RL less than −10 dB) of 4.1 GHz in the frequency range of 8.2–12.4 GHz. Sample #2 shows a minimum absorption value of −24.1 dB at 9.5 GHz and an absorption bandwidth (RL less than −10 dB) of 3.9 GHz in the frequency range of 8.2–11.7 GHz. Sample #3 shows a minimum absorption value of −4.2 dB at 8.2 GHz and an absorption bandwidth (RL less than −10 dB) of 0 GHz. The reflection loss of the microwave absorbers exhibits a passivation phenomenon with an increase in temperature; in particular, the reflection loss of samples #1 and #3 decreases steeply at temperatures above 400 °C. The curves of samples #1–3 show the variations in reflection loss as a function of the LAS–SiC composite layer thickness and the measurement temperature; here, the thickness of the impedance transfer layer is fixed. This result indicates that the wave impedance of sample #2 in the X-band is the best among the three samples at high temperature; hence, a good wave impedance match is achieved between the impedance transfer layer and the low-impedance resonator layer. According to the "matched-wave-impedance" concept, the wave impedance at the surface of the metal-backed material layer is equal to the intrinsic impedance of free space. Based on this concept, the LAS/LAS–SiC double layer microwave absorber is a resonant-type absorber, according to the dielectric loss mechanism of microwave attenuation. A suitable match is required to more effectively attenuate the electromagnetic wave, but the thickness mismatch of the microwave absorber leads to electromagnetic wave impedance mismatch at the air–material interface.

Fig. 6(a) shows the reflection loss properties in terms of the LAS–SiC thickness (1 mm, 2 mm and 3 mm) at different temperatures (300 °C, 400 °C and 500 °C) in the range of 8.2–12.4 GHz. The intensity of the reflection peaks is quite sensitive to the LAS–SiC thickness and the temperature. The peak intensities of the reflection loss curves initially decrease and then increase with increasing thickness of the LAS–SiC layer. Sample #2 with a 2-mm-thick layer of LAS–SiC exhibits a significantly favorable reflection loss in comparison to samples #1 and #3. However, the intensities of the reflection peaks increase with increasing temperature. Fig. 6(b) also shows that the bandwidth (RL less than −10 dB) is greatly dependent on the LAS–SiC thickness and the temperature. In the X-band, the bandwidths of the double layer absorbers decrease with increasing LAS–SiC thickness; a similar result can be observed for increasing temperature. Consequently, a large decay occurs in sample #3 (a 3-mm-thick layer of LAS–SiC) at 500 °C. A comparison of Fig. 6(a) and (b) shows that the absorption properties of sample #2 are significantly better than those of samples #1 and #3 in the X-band. This outcome can be explained by the fact that the LAS layer, which possesses a low relative permittivity ($\varepsilon_r$) and an impedance close to that of free space, can prevent the entering electromagnetic wave from reflecting before arriving at the surface of high relative permittivity (i.e., the LAS–SiC layer); furthermore, at this boundary, the thickness of the LAS–SiC layer at the same SiC content causes a mismatch with the LAS thickness. Therefore, the thickness mismatch of the LAS–SiC layer leads to the electromagnetic wave impedance mismatch of the double layer microwave absorbers at the air–material interface.

### *3.3.2. Effect of the different SiC contents on the absorption properties*

Fig. 7 shows the reflection losses of the double layer microwave absorber with different SiC contents in the SiC–LAS composite at high temperatures in the range of 300–500 °C. From the reflectivity

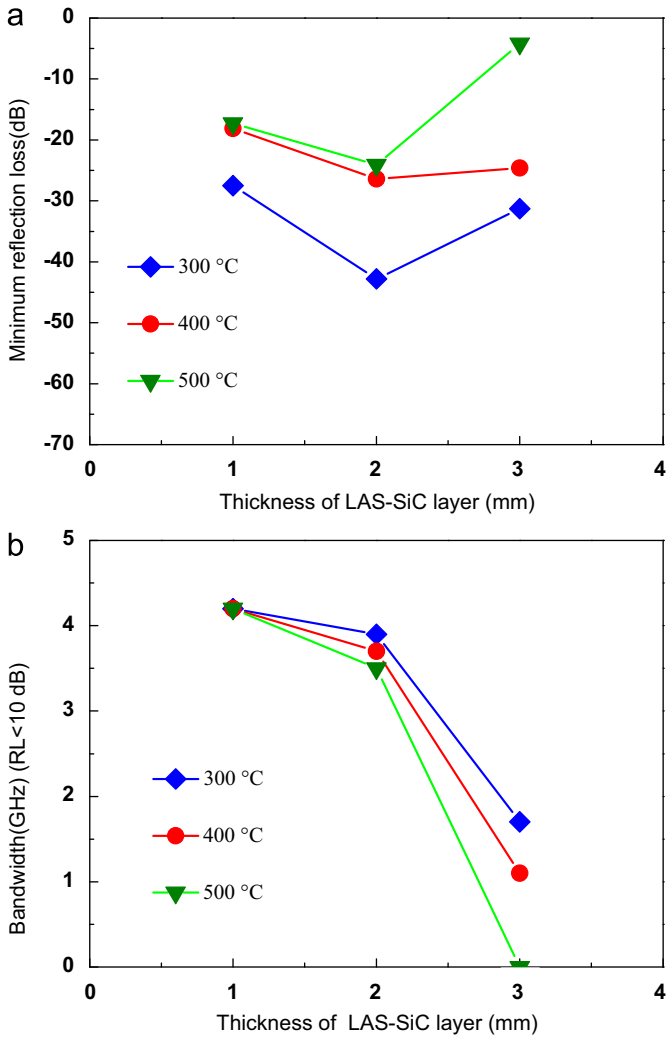


Fig. 6. (a) Minimum reflection loss dependence of the LAS–SiC thickness of samples #1, #2 and #3 at the same SiC content. (b) The bandwidth (RL less than −10 dB) dependence of the LAS–SiC thickness of samples #1, #2 and #3 at the same SiC content.

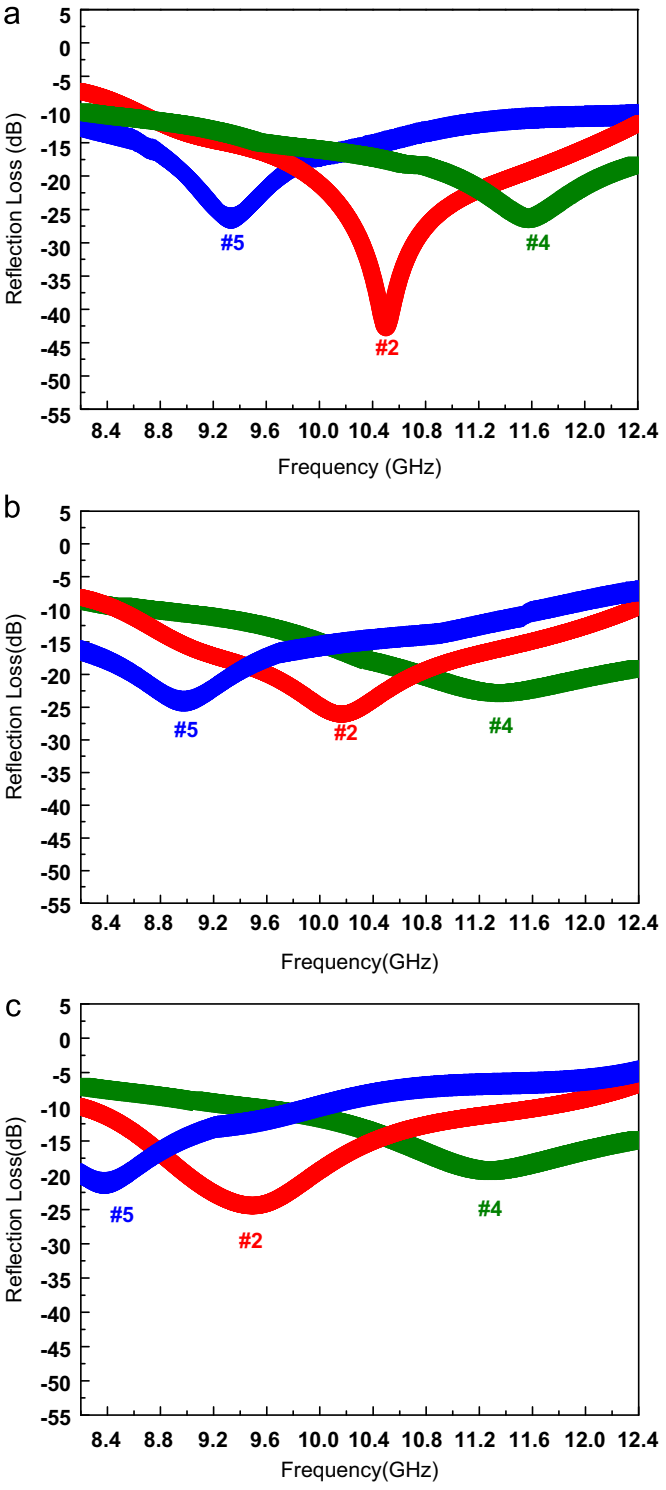


Fig. 7. Reflection losses of the double-layer microwave absorber with different thicknesses of SiC/LAS composite layers at high temperatures of (a) 300 °C, (b) 400 °C and (c) 500 °C.

loss curves in Fig. 7(a)–(c), it can be seen that the position of the reflection loss peak shifts to lower frequency with increasing SiC content. From Eq. (4), it is known that the reflection loss is determined by the relative permittivity, the relative permeability, the thickness and the frequency. The role of the relative permittivity becomes increasingly significant when the other factors are fixed; this phenomenon occurs because SiC is a non-magnetic material, and the dissipation of its powders at high frequencies is determined only by the dielectric loss [5]. Consequently, as more SiC content is added to the samples, the relative permittivity of the absorbers gradually increases. The influence of SiC powders on the electromagnetic properties of the double layer microwave absorbers is readily apparent. The dielectric loss of SiC can either be due to ion migration loss (including DC conductivity loss), ion jump and dipole relaxation losses, ion vibration and deformation losses, or electron polarization loss. Therefore, the higher dielectric losses suggest enhanced capabilities of the produced double layer microwave absorbers in the microwave range. Therefore, when the SiC powders are used in the high temperature conditions, their dielectric loss factors increase with temperature [10,25], which is beneficial for microwave absorbing properties.

Fig. 8(a) shows the minimum reflection losses with different SiC contents (5 wt%, 10 wt% and 15 wt%) at different temperatures (300 °C, 400 °C and 500 °C) in the range of 8.2–12.4 GHz. It can be seen that the reflection losses of the samples display negligible changes with the SiC content at 400 and 500 °C. However, at 300 °C, the variation is significant, and sample #2 (with 10 wt% SiC) exhibits the largest reflection loss value. The lowest reflection loss of sample #2 is −42.8 dB at 10.5 GHz at the temperature of 300 °C. The bandwidth (RL less than−10 dB) variation of the samples in terms of the SiC content at different temperatures is further illustrated in Fig. 8 (b), which demonstrates the bandwidth decreases with increasing temperature. At the lower temperatures of 300–400 °C, the effect of the SiC content on the bandwidth is insignificant. However, at 500 °C, the bandwidth variation with the SiC content is significant, especially for samples #4 and #5. However, it should be noted that sample #2 (with 10 wt% SiC) displays little variation and has more than 3.5 GHz of bandwidth (RL less than −10 dB) in the X-band within the temperature range of 300–500 °C. Furthermore, sample #2 exhibits excellent performance in comparison to the other samples; in particular, the bandwidth (RL below −10 dB) absorption of sample #2 reaches 3.5 GHz and has a minimum reflection loss of −42.8 dB at 10.5 GHz at 300 °C.

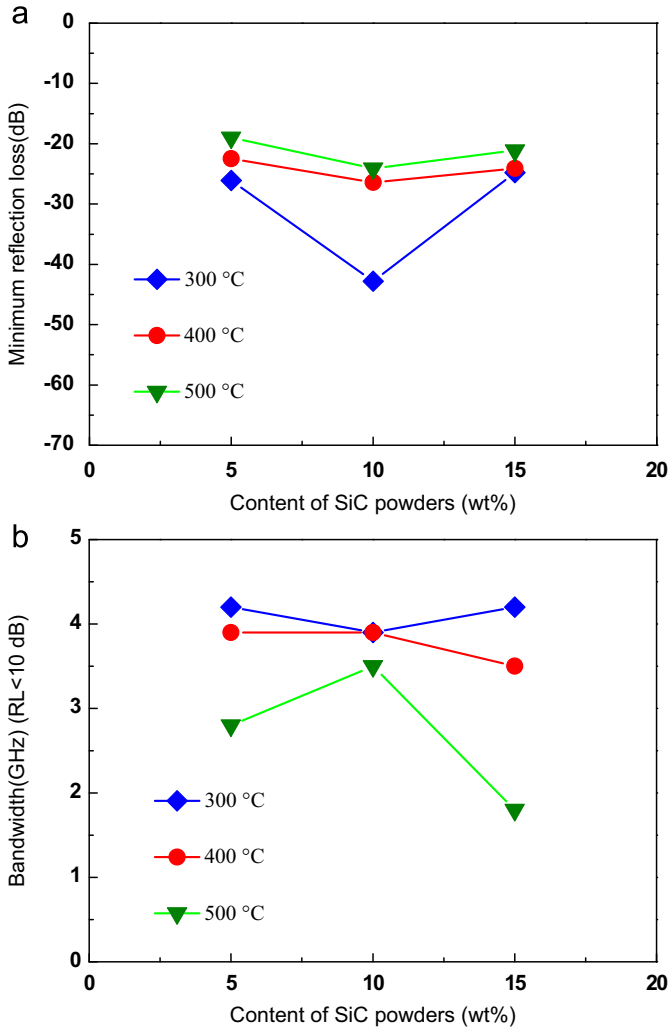


Fig. 8. (a) Minimum reflection loss dependence of the SiC contents of samples #2, #4 and #5 at the same LAS–SiC thickness. (b) The bandwidth (RL less than −10 dB) dependence of the SiC content of samples #2, #4 and #5 at the same LAS–SiC thickness.

## 4. Conclusions

Nanometer-size β-SiC powders with diameters in the range of approximately 30–50 nm were synthesized successfully at relatively low sintering temperatures. The electromagnetic absorbing properties of the LAS/LAS–SiC double layer microwave absorbers in the X-band were investigated at high temperatures, and the β-SiC powders were found to contribute to critical dielectric losses at high temperature, which can be considered to be the dominating factor in the enhanced reflection loss. Furthermore, the microwave absorption properties were remarkably influenced by the impedance matching conditions of the LAS–SiC thickness and the SiC content, especially at high temperature. The double layer microwave absorbers consisting of 2-mm-thick LAS ceramic as the impedance transformer layer and 2-mm-thick LAS–SiC ceramic as the low impedance resonator exhibits excellent X-band microwave absorption in the temperature range of 300–500 °C. The prepared LAS/LAS–SiC double layer microwave absorbers demonstrated their potential for use as high-temperature absorbers in the X-band.

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