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MgB_2 Thin Films on SiC Buffer Layers with Enhanced Critical Current Density at High Magnetic Fields

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Abstract

We have grown MgB_2 superconducting thin films on the SiC buffer layers by means of hybrid physical-chemical vapor deposition (HPCVD) technique. Prior to that, SiC was first deposited on Al_2O_3 substrates at various temperatures from room temperature to 600°C by using the pulsed laser deposition (PLD) method in a vacuum atmosphere of ~10^{-6} Torr pressure. All samples showed a high transition temperature of ~40 K. The grain boundaries of MgB_2 samples with SiC layer are greater in amount, compare to that of the pure MgB_2 samples. MgB_2 with SiC buffer layer samples show interesting change in the critical current density (J_c) values. Generally, at both 5 K and 20 K measurements, at lower magnetic field, all MgB_2 films deposited on SiC buffer layers have low J_c values, but when they reach higher magnetic fields of nearly 3.5 Tesla, J_c values are enhanced. MgB_2 film with SiC grown at 600°C has the highest J_c enhancement at higher magnetic fields, while all SiC buffer layer samples exhibit higher J_c values than that of the pure MgB_2 films. A change in the grain boundary morphologies of MgB_2 films due to SiC buffer layer seems to be responsible for J_c enhancements at high magnetic fields.

Keywords : MgB_2 thin film, SiC buffer layer, critical current density.

I. Introduction

The 39 K superconductor MgB_2 has attracted tremendous interest for its potential in high magnetic-field applications [1- 3]. MgB_2 possesses a number of attractive properties, including strongly coupled grain boundaries [4]. Within the past decade, there have been many attempts to enhance the high-field performance of MgB_2, including using irradiation [5] and adding dopants such as carbon [6], SiC [7] and ZrB_2 [8]. Among these methods, carbon doping has proven to be an effective way to enhance H_{c2} and high-field J_c [9, 10]. An even more dramatic enhancement of H_{c2} has been seen in the case of carbon-doped MgB_2 films produced by hybrid physical–chemical vapor deposition (HPCVD) [11, 12]

Improving the J_c in MgB_2 films is important because attaining a high critical current is one of the prime requirements for practical applications of superconducting films [13]. Chromic *et al.* [14] fabricated MgB_2 thin films on SiC buffered Si substrates and Yao *et al.* [15] produced very thick MgB_2 films (60–140 μm) doped with SiC nanoparticles. These methods have successfully enhanced the J_c except for the MgB_2 thin films on SiC buffered Si substrates, although the samples showed lower superconducting transition

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temperatures comparing with the pure MgB_2.

In this paper, we studied the effect of SiC buffered Al_2O_3 substrate on MgB_2 thin films. This preliminary work was done for future project of growing SiC buffered MgB_2 thin films on metal hastelloy substrate. In this case, SiC buffer layers are needed for few reasons, one is to hinder the diffusion of the metal elements into the MgB_2 films, and also to provide the carbon doping needed to enhance J_c values, and another one is to minimize the lattice mismatch between the metal hastelloy and the MgB_2 films. By studying the conditions and effects of the SiC buffer layers toward MgB_2 films, we can draw a clear line of what to expect in the next study of SiC buffered hastelloy substrate.

II. Experimental details

SiC buffer layers were first deposited on 5 × 10 mm size Al_2O_3 substrates by pulsed laser deposition (PLD) technique with various temperature of room temperature, 500° and 600°C. The deposition was conducted inside the vacuum chamber of ~10^{-6} Torr for 20 minutes with a SiC target (99.95 % purity). Laser beams were generated from a KrF excimer laser (λ=248 nm). The pulse energy was set at 250 mJ with a repetition rate of 8 Hz.

MgB_2 thin films of ~180 nm thickness were grown on SiC buffer-layer-deposited-sapphire substrates by using HPCVD technique. The films were heated up to 550°C in 200 Torr of ambient H_2 gas. Next, B_2H_6 (5% B_2H_6 + 95% H_2) at 20 sccm was introduced into the quartz reactor to start the growth of MgB_2 films.

The growth time for all samples was around 15 minutes. Finally, the fabricated films were cooled down to room temperature in a flowing H_2 carrier gas.

The MgB_2 thin films were investigated by using X-ray diffraction (XRD), scanning electron microscopy (SEM), and a magnetic property measurement system (MPMS). Resistance measurements were carried out by using the standard four-probe method.

III. Results and discussions

Fig. 1 shows XRD patterns of θ–2θ scans of the SiC buffer layers deposited on the top of the Al_2O_3 substrates. The SiC buffer layers fabricated on sapphire substrates with deposition temperatures of room temperature, 500°C and 600°C are labeled SiC RoomT, SiC 500, and SiC 600, respectively. The only substantial SiC peak is the (103) reflection, which shows that SiC is oriented with its *c*-axis normal to the substrate. Significant SiC intensities which began to develop with the increase of the deposition temperatures confirm that the films contain hexagonal textures in the film plane.

The temperature dependences of the resistance for MgB_2 thin films grown on SiC buffer layers at temperatures of room temperature, 500 °C, and 600 °C are shown in Fig. 2, respectively. The inset of Fig. 2 shows a magnified view near the superconducting transition temperature and the resistance values are normalized at 50 K. All samples showed a high transition temperature of ~40 K and narrow superconducting transition width ($\Delta T = T_{c,on} - T_{c0}$) of about 0.4 K, indicating good homogeneity of the samples. Little changes in T_c and ΔT_c also suggest that SiC buffer layers have minimal effects on the superconducting properties of MgB_2.

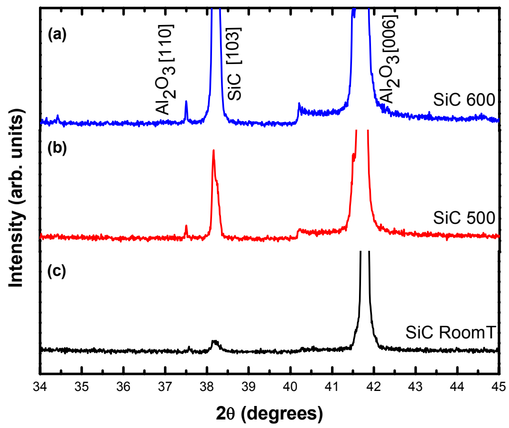

Fig. 1. X-ray diffraction patterns of SiC buffer layers grown inside PLD at temperatures: (a) 600 °C, (b) 500 °C, and (c) Room temperature

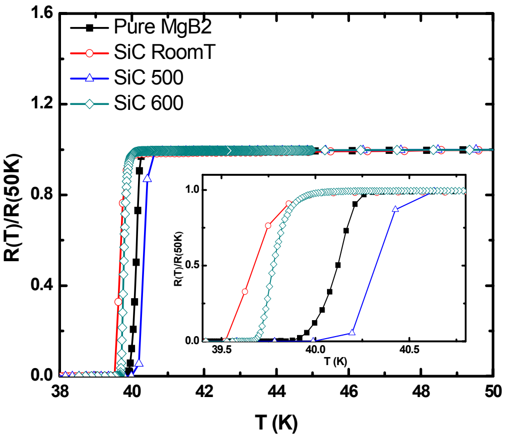

Fig. 2. Resistance as a function of temperature for MgB_2 thin films grown on SiC buffer layers deposited on Al_2O_3 substrates. The inset shows an enlarged view near the T_c and the resistance values are normalized by the resistance at 50 K. T_c is determined when the transition from normal-superconducting state starts indicated by T_{conset}.

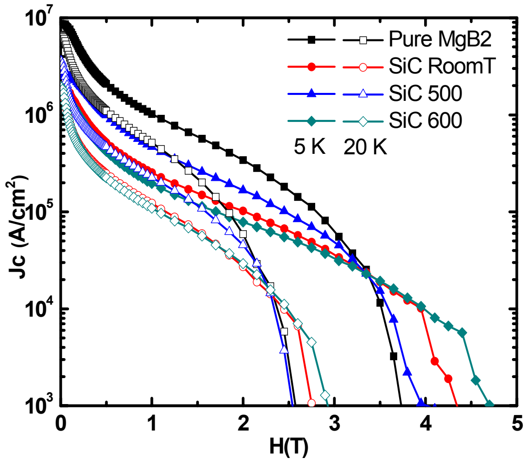

Fig. 3. The critical current density (J_c) versus applied magnetic field at 5 and 20 K for pure and SiC buffer layered MgB_2 thin films. The SiC 600 °C has the highest J_c enhancement and all SiC buffered samples show higher J_c values than the pure MgB_2 thin film at high field region.

The critical current densities (J_c) of each film at 5 and 20 K were calculated from the M–H hysteresis loops by using Bean's critical state model and plotted in the $J_c - H$ relations, as shown in Fig. 3. The magnetization hysteresis measurements were performed by using an MPMS with applied fields varying from -5 T to 5 T, which are not shown here. Magnetic fields were applied perpendicular ($H \perp ab$) to the film plane. At both 5 K and 20 K measurements, at lower magnetic field, all MgB_2 films with SiC buffer layers had low J_c values, but when they reached high magnetic field of nearly 3.5 Tesla, J_c values were enhanced. MgB_2 film with SiC grown at 600°C had the highest J_c enhancements at high magnetic fields, while all SiC-buffered samples exhibit higher J_cs than those of the pure MgB_2 film. These results indicate that the SiC buffer layer deposited at 600°C provide the optimum condition for the J_c enhancement of MgB_2 at high fields.

The surface morphologies of the SiC-buffered MgB_2 thin films on Al_2O_3 substrates were obtained using scanning electron microscopy (SEM). Fig. 4 shows that all SiC-buffered MgB_2 thin films have hexagonal-like grain shapes. Compared to the pure MgB_2 film, grains were large and bulky, which lead to less flat surface and poor connectivity between grains.

Jung *et al.* [16] has reported a simple method for the enhancement of J_c in MgB_2 thick films on top of amorphous SiC impurity layers. J_c enhancements were observed through the whole magnetic field region. Their results suggest that the SiC particles along with the columnar grain boundaries in the MgB_2 thick films serve as strong pinning centers.

On the other hand, we used crystalline SiC in our work, thus produced rougher MgB_2 surface which result in huge J_c enhancements specifically at high fields. As it can be seen in the SEM images, the MgB_2 on SiC buffer layers are showing smaller density of grain boundaries and larger pores on the MgB_2 surface which are contrary to the pure MgB_2 surface. These surface defects may also contribute to the existence of the pinning centers in MgB_2.

However, the effect of carbon doping in the form of SiC buffer layer has not thoroughly investigated yet in our current work. A further research on how carbon doping in the form of SiC buffer layer affecting the J_c values of the MgB_2 films is needed in order to have more comprehensive understanding.

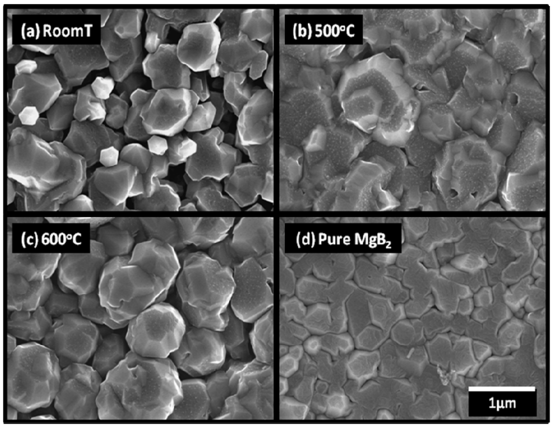

Fig. 4. SEM images of the MgB_2 thin films grown on SiC buffer layers: (a) SiC Room temperature, (b) SiC 500 ^oC, (c) SiC 600 ^oC, (d) Pure MgB_2 on Al_2O_3.

IV. Conclusions

In conclusion, the J_c enhancement of the MgB_2 thin films with SiC buffer layers was shown to have an interesting behavior. At high field region, the J_c values of MgB_2 films with SiC buffer layer were uniquely enhanced, while an opposite behavior was observed at low field region. The SiC buffer layer which was deposited inside the PLD chamber at 600 ^oC turned out to have the highest J_c enhancement at high fields. From the surface morphology analysis, changes in the shape and density of grain boundaries of MgB_2 due to crystalline SiC buffer layer may be considered as a dominant pinning mechanism in MgB_2 thin films and could play an important role in enhancing J_c at high magnetic fields. A future study on how carbon doping in the form of SiC buffer layer affecting the J_c values of the MgB_2 films will be needed to obtain more sufficient understanding on the pinning mechanism of MgB_2 films.

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