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A possibility of enhancing J_c in MgB_2 film grown on metallic hastelloy tape with the use of SiC buffer layer

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Abstract

We have grown MgB_2 on SiC buffer layer by using metallic Hastelloy tape as the substrate. Hastelloy tape was chosen for its potential practical applications, mainly in the power cable industry. SiC buffer layers were deposited on Hastelloy tapes at 400, 500, and 600 ^oC by using a pulsed laser deposition method, and then by using a hybrid physical-chemical vapor deposition technique, MgB_2 films were grown on the three different SiC buffer layers. An enhancement of critical current density values were noticed in the MgB_2 films on SiC/Hastelloy deposited at 500 and 600 ^oC. From the surface analysis, smaller and denser grains of MgB_2 tapes are likely to cause this enhancement. This result infers that the addition of SiC buffer layers may contribute to the improvement of superconducting properties of MgB_2 tapes.

Keywords: MgB_2 films, critical current density, SiC buffer layers, Hastelloy

1. INTRODUCTION

More than a decade ago, a simple binary boride, MgB_2, had been discovered to be a superconducting compound with a $T_c \approx 39$ K [1], one of the highest transition temperatures observed for any non-cuprate material. A great number of experimental and theoretical investigations have been subjected to MgB_2 [2-5], not only to understand its superconducting mechanism, but also to explore its future prospect, especially in the power cable industry.

It has been widely known that SiC doping is one of the effective methods to improve the superconducting properties of MgB_2 [6-8]. In our current work, we are applying SiC in a slightly different form; a form of buffer layer. The usage of amorphous SiC impurity layers had also proven to improve the critical current density (J_c) values of MgB_2 films [9]. Furthermore, based on our previous works [10-11], MgB_2 films with crystalline SiC buffer layers deposited on Al_2O_3 substrates have been confirmed to enhance J_c values.

In order to be able to be manufactured in a larger scale, more applicable metallic substrates are required to produce high-quality MgB_2 superconductors. Wide variety of metallic substrates has been applied in the making of MgB_2 superconducting tapes throughout the years [12-14]. All of which were made without inserting any buffer layer. However, the J_c values of these different substrates-MgB_2 films are not fairly high. For this reason, we have been investigating the usage of SiC buffer layer deposited on metal Hastelloy tape as the substrate in MgB_2 film. Hastelloy itself has been noted to have several advantages, such as highly flexible, low corrosive and low AC loss-material [15]. And as for SiC buffer layer, its presence is highly anticipated to overcome several potential issues that might occur if we use Hastelloy tape as the substrate. Preventing metal diffusion that could penetrate the MgB_2 films, supplying the carbon which may be needed to enhance J_c; are some of the SiC buffer layers expected roles in fabricating MgB_2 tapes.

Principally, this preliminary work was conducted based on our belief that SiC buffer layer plays a significant part in improving MgB_2 superconducting properties when SiC buffer layers placed on the Al_2O_3 substrate. And since the effect of SiC/Hastelloy on MgB_2 tapes has not extensively exposed, there are possibilities of getting interesting results on the superconducting properties of MgB_2 films when SiC is applied on the metal Hastelloy.

This study on SiC buffer layers is essential to accommodate basic knowledge on the feasibility of SiC/Hastelloy structure to improve the J_c values of MgB_2 tapes. Hopefully, by introducing metallic Hastelloy tape as the substrate for SiC buffer layer, there are much room for improvement for the production of better-quality of MgB_2 tapes in the near future.

2. EXPERIMENTS

The substrate used for SiC buffer layer fabrication in this work was metallic Hastelloy tape. A typical pulsed laser deposition process involved heating the substrate to 400, 500, and 600 ^oC, and keeping it at these temperatures for 10 min by means of pulsed laser deposition (PLD) which then

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created a thickness of less than 200 nm. The deposition was conducted inside the vacuum chamber of ~10^{-6} Torr. Laser beams were generated from a KrF excimer laser (λ = 248 nm) and the laser energy was set at 230 mJ with a repetition rate of 8 Hz.

MgB_2 thin films were fabricated inside a hybrid physical-chemical vapor deposition (HPCVD) system. The SiC/Hastelloy tapes were then heated up to 550 °C in 100 Torr of H_2 gas flow for 15 minutes. As for the pure MgB_2, bare Hastelloy tape was used as the substrate. B_2H_6 : H_2 gas flow at 10 : 90 sccm was introduced into the quartz reactor to start the growth of MgB_2 films. At last, the fabricated films were cooled down to room temperature in a flowing H_2 carrier gas. As a result, the thickness of MgB_2 films is less than 1 μm in average.

The surface morphology and the structure of the MgB_2 films were investigated using scanning electron microscopy (SEM) and X-ray diffraction (XRD). The values of critical current density J_c were carried out from the magnetization measurements obtained by using a magnetic property measurement system (MPMS).

3. RESULTS AND DISCUSSIONS

In Fig. 1, the XRD patterns (θ-2θ scans) for both pure MgB_2 films grown on bare Hastelloy tape and MgB_2 films deposited on SiC/Hastelloy buffer layers with three SiC deposition temperatures of 400, 500, and 600 °C are shown. The different temperatures are essential for crystalline SiC buffer layers to be properly grown on the Hastelloy substrates. This was also done in our previous works on $MgB_2/SiC/Al_2O_3$ [10-11]. The crystalline SiC was formed as the temperature increased. However, SiC peaks are hard to detect by XRD alone; they inconsistently appear as

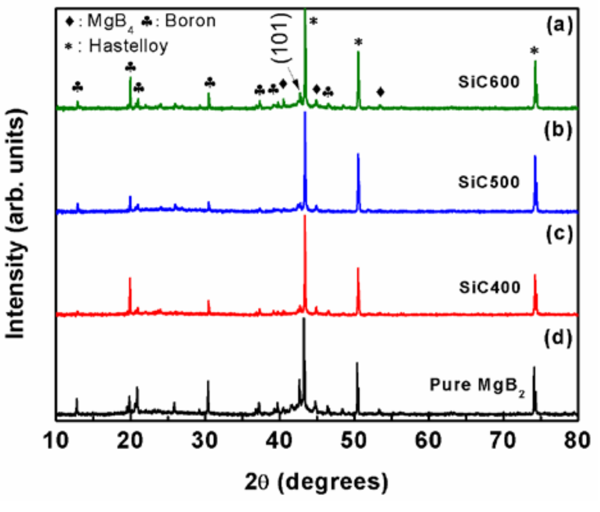

Fig. 1. X-ray diffraction patterns of the MgB_2 films with SiC buffer layers deposited on Hastelloy tape at temperatures of: (a) 400, (b) 500, (c) 600 °C, and (d) Pure MgB_2, respectively. The peaks labeled with an asterisk arise from the Hastelloy tape substrate.

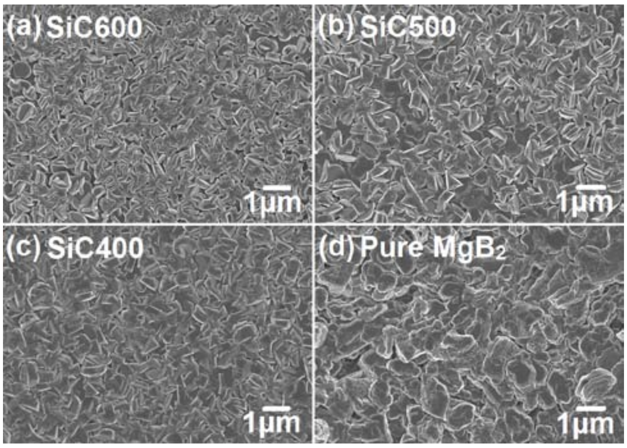

Fig. 2. Plane SEM images for MgB_2 films on Hastelloy tape with SiC buffer layers deposited at different temperatures of: (a) 400, (b) 500, (c) 600 °C, and (d) Pure MgB_2 grown on bare Hastelloy tape.

minor peaks in some of SiC/Hastelloy samples of our other works. This may due to the reaction between SiC and Hastelloy which affected the structure of SiC buffer layers.

As can be seen in the figure, the MgB_2 (101) peaks of MgB_2/SiC/Hastelloy films are becoming less intense, while pure MgB_2 shows a slightly higher intensity of the peak. Other peaks appeared on the patterns are combination between MgB_4 and Boron peaks with various axis orientations. This result is comparable with others' reports on MgB_2/Hastelloy tapes which showed relatively small MgB_2 (101), MgB_4 and Boron peaks [16-18].

In Fig. 2. SEM images of pure MgB_2 film and MgB_2 films deposited at different temperatures on SiC/Hastelloy are presented. The grains of pure MgB_2 in Fig. 2(d) seems to be bulkier than the other MgB_2 films on SiC/Hastelloy. Whereas MgB_2 films deposited on SiC/Hastelloy are showing smaller-leaner grains along with various orientations of the grains which are in conformity with the XRD results that showed all MgB_2 samples have randomly oriented grains. These random-oriented grains are also found in our related works on $MgB_2/SiC/Al_2O_3$ films [11]. At cross section area (not shown here), all MgB_2 samples have approximately less than 1 μm thickness.

In addition, pure MgB_2 film displayed a delaminating problem in which the quality of the film surface deteriorated to a point where the film had become relatively fragile to handle. However, that was not the case with MgB_2/SiC/Hastelloy films where all the samples are firmly attached at the surface. This implies that SiC somehow improve the quality of the surface and prevent the delaminating issue. It also gives us a hint that thicker MgB_2 of more than 1 μm would solve the delaminating issue, and hence significantly upgrade the surface condition. In another on-going work, we have deposited a thicker MgB_2 film on Hastelloy tape and the thicker MgB_2 has been proven to stop the surface to be delaminated.

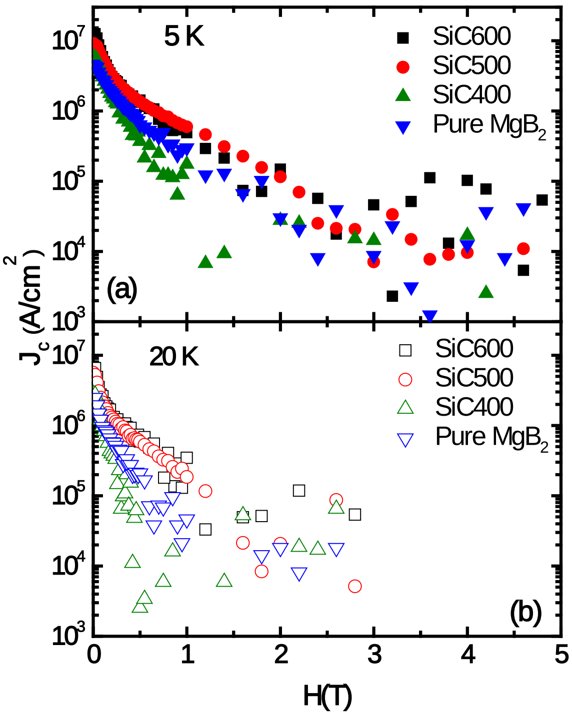

Fig. 3. Effect of SiC buffer layers on the field dependence of critical current density (J_c) curves measured at (a) 5 and (b) 20 K for pure and SiC-buffered-MgB_2 films. MgB_2 samples with SiC buffer layers grown on Hastelloy tape at 500 and 600 ^oC show larger J_c values than those of pure MgB_2 at whole field region.

Another important parameter for practical applications of MgB_2 is the critical current density (J_c). The values of J_c for pure MgB_2 and MgB_2/SiC/Hastelloy films when subjected to an applied magnetic field are showed in Fig. 3. J_c values were obtained from the magnetization hysteresis loops (MHLs) using the Bean critical model [19].

The J_c-H behavior at both temperatures of 5 and 20 K has been improved with the addition of SiC buffer layers deposited at 500 and 600 ^oC, while pure MgB_2 films show relatively lower J_c at the whole magnetic field region. MgB_2 films on the SiC buffer layer deposited at 500 and 600 ^oC showed enhanced J_c values over the whole magnetic field region, despite the fluctuations of the J_c values which are mainly shown in the higher field region. This may be resulted from the slightly smaller grains size of MgB_2 films on the SiC buffer layers when compared with the pure MgB_2 film, as depicted in Fig. 2, which then created a stronger pinning source and hence the enhanced J_c values. On the other hand, the MgB_2 film on SiC buffer layer deposited at 400 ^oC is not showing any enhancement most probably due to the low deposition temperature. This implies that the temperature above 400^oC is most likely providing an optimum condition for SiC to be grown completely on the Hastelloy substrate. Additionally, bigger size of the grains of the pure MgB_2 film might have generated less strong pinning sources which then contributed to the decreased J_c values.

When compared with the J_c values from other MgB_2/Hastelloy tapes [16,18], it is apparent that our J_c has slightly lower values over the whole region. MgB_2 thickness of less than 1 μm may be the cause of this low values. In the M-H curves (not shown here), MgB_2/SiC/Hastelloy films showed weak superconducting signals, thus at high field region, fluctuation increased. In our on-going work on MgB_2/SiC/Hastelloy, thick MgB_2 films of more than 2 μm are proven to produce clear and stronger superconducting signals. Nevertheless, our MgB_2 films have higher J_c values at zero fields than the ones of another report [17].

Even though the enhancement of J_c values of MgB_2/SiC/Hastelloy films are still lower than those of the MgB_2 films grown on SiC/Al_2O_3, as reported in our other related works [10,11]; still, this result indicates a positive signal of the possibility of enhancing J_c values of MgB_2 films by using a SiC/Hastelloy structure.

4. CONCLUSION

SiC buffer layers on metallic Hastelloy tapes are likely to enhance the J_c values of MgB_2 films. Enhancement of J_c is may resulted from the alteration in microstructure, grain sizes, and grain orientations of MgB_2/SiC/Hastelloy films. However, more detailed analysis on the pinning source may provide better understanding on the cause of these J_c enhancements.

Our work emphasizes the importance of fabricating MgB_2 films on SiC buffer layers with potential substrates, such as Hastelloy tape. This preliminary study, practically, provides a good start for more possibilities in fabricating better and more advanced MgB_2/SiC/Hastelloy films. It is our hope that this result would be an auspicious beginning for improving the superconducting properties of MgB_2 tapes which would be a substantial breakthrough in the power cable applications.

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