TESTS ON MGB2 FOR APPLICATION TO SRF CAVITIES*

T. Tajima#, A. Canabal, LANL, Los Alamos, NM 87545, USA, Y. Zhao, Univ. Wollongong, NSW 2522, Australia, A. Romanenko, Cornell Univ., Ithaca, NY 14850, USA, C. Nantista, S. Tantawi, SLAC, Menlo Park, CA 94025, USA, L. Phillips, JLab, Newport News, VA 23606, USA, Y. Iwashita, Kyoto ICR, Uji, Kyoto 611, Japan, I. Campisi, ORNL, Oak Ridge, TN 37831, USA, B. Moeckly, STI, Santa Barbara, CA 93111, USA

Abstract

Magnesium diboride (MgB_2) has a transition temperature (T_c) of ~40 K, i.e., about 4 times higher than niobium (Nb). Studies in the last 3 years have shown that it could have about one order of magnitude less RF surface resistance (R_s) than Nb at 4 K and seems to have much less power dependence than high-T_c materials such as YBCO. However, it was also found that it will depend on the way you deposit the film. The result from on-axis pulsed laser deposition (PLD) showed rapid increase in R_s with higher surface magnetic fields compared to the film deposited with reactive evaporation method.

INTRODUCTION

A number of studies on MgB_2 have been carried out due to its near metallic nature, simplicity and lower fabrication cost compared to high T_c materials such as BSCCO and YBCO.

One of the good features of MgB_2 for radio-frequency (RF) applications is the absence of "weak links" between grains. The losses at grain boundaries of present high-T_c materials rapidly increase with higher surface magnetic fields, which has prevented us from using them for superconducting RF (SRF) cavity applications [1-3].

Although the T_c (~40 K) of MgB_2 is not as high as YBCO, it is about 4 times that of Nb (9.2 K). This is still beneficial in terms of the reduction in cryogenic costs. If the cavity can operate at 10 K, the cryogenic costs will probably be less than half of the costs for 4 K operation, assuming that the cavity Q_0 will be the same at 10 K (MgB_2) and at 4 K (Nb).

MGB2 COATING TECHNIQUES

To the best of our knowledge, the coating techniques that have been studied are physical vapor deposition (PVD), chemical vapor deposition (CVD), molecular beam epitaxy (MBE), electrochemical plating, pulsed laser deposition (PLD), hybrid physical CVD (HPCVD), reactive evaporation, coaxial energetic arc deposition, and sputtering. Among these, HPCVD and reactive evaporation methods seem to give highest quality films. Very encouraging results with the films prepared by reactive evaporation have been reported [4-6].

In Ref. [6], we proposed to use PLD to coat a cavity. To check the feasibility of this technique, we coated some substrates made of Nb and Al_2O_3.

*Work supported by the Department of Energy

#tajima@lanl.gov

Pulsed Laser Deposition (PLD)

The coating has been done at University of Wollongong [7]. Figure 1 shows a schematic of the equipment. We tried the deposition in two modes, on-axis, i.e., the substrate surface is facing the MgB_2 target, and off-axis, i.e., the substrate surface is normal to the MgB_2 target with a screen as shown in Fig. 1.

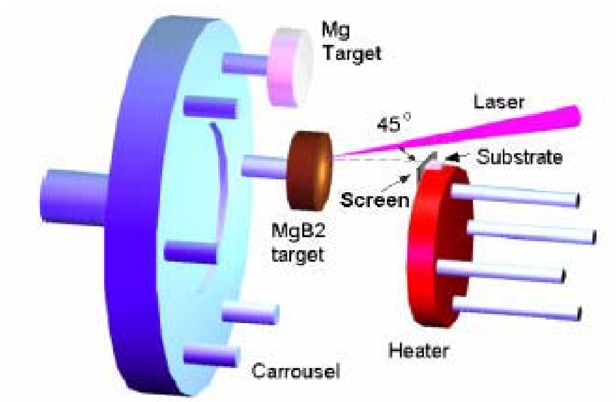

Figure 1: An illustration of off-axis PLD [1].

A KrF laser (λ=248 nm, 25 ns) was used in 120 mTorr Ar atmosphere, then an *in-situ* annealing was carried out at 680 °C for 2 min in a 760 Torr Ar atmosphere [7].

Figures 2 and 3 show cross sections of on-axis and off-axis depositions on Al_2O_3 substrates, respectively.

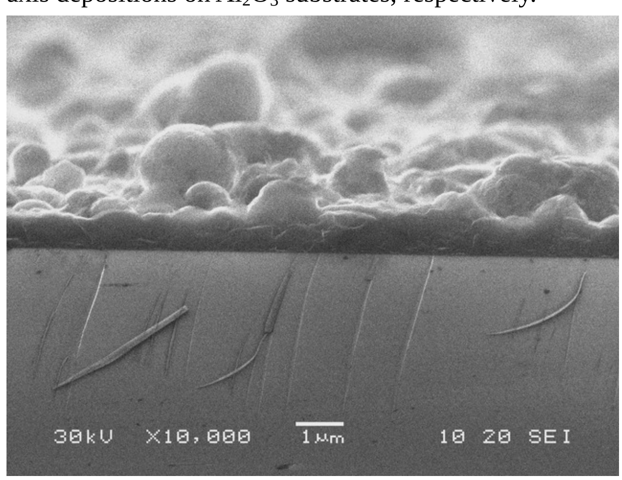

Figure 2: A SEM image of the cross section of on-axis deposited MgB_2 film (ID: 250705) on Al_2O_3. The film has a thickness of 400-500 nm and many droplets are present on top of the film.

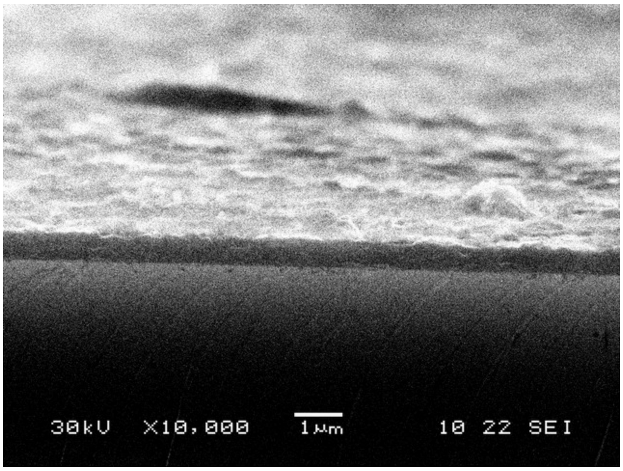

Figure 3: A SEM image of the cross section of off-axis PLD MgB_2 film (ID: 300705v) on Al_2O_3-C substrate. The film thickness is 500-700nm.

Apparently, the off-axis PLD gives better surface than on-axis, but still has defects spread over the surface as seen in Fig. 4.

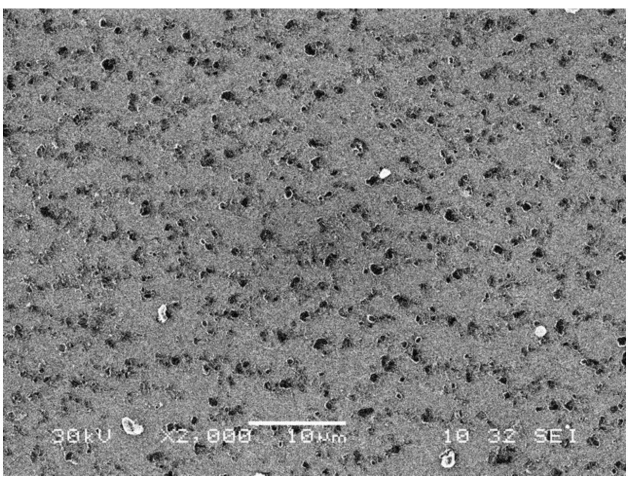

Figure 4: Surface of off-axis PLD MgB_2 film (ID:300705v) on Al_2O_3-C substrate.

Figure 5 shows a result of magnetic moment measurements for on-axis PLD samples. T_c was measured to be ~27 K. In our experience, transport measurements usually show much narrower ΔT_c than magnetic moment measurements. The first two substrates (Al_2O_3 and Nb) were placed side by side, but the third one (Al_2O_3) was measured separately. From the fact that the two curves for the Al_2O_3 and Nb substrates are very close, we can conclude that the MgB_2 film deposited on Nb with a 680 °C *in-situ* annealing for 2 min does not react with Nb substrate, and thus it is possible to develop MgB_2 coating on Nb with PLD.

No off-axis coating was tried on the Nb substrate since the substrate (14.6 mm-diameter disk) was too large for the equipment. Also, no SEM image of the film coated on the Nb substrate was taken since it was difficult to cut the sample to show a clear cross section. Its surface was as rough as the sample shown in Fig. 2. In addition, the substrate itself was quite rough (R_a~400 nm) as well.

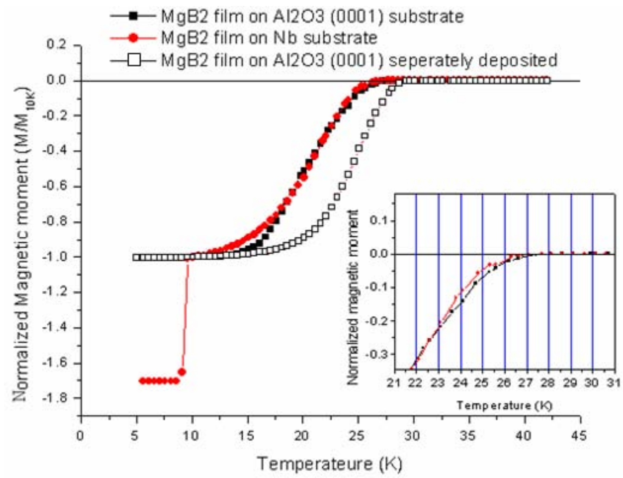

Figure 5: Normalized magnetic moment as a function of temperature for on-axis PLD MgB_2 films deposited on Nb and Al_2O_3.

Power Dependence of RF Surface Resistance

Figure 6 shows the RF surface resistance (R_s) dependence on surface magnetic fields for the MgB_2 films deposited on Nb substrates with on-axis PLD and with reactive evaporation methods. The measurement was carried out at Cornell University using a 6 GHz TE_{011} mode cavity. The detail of the equipment is described in Ref. [8].

It was found that, although the surface resistance at low field is similar to each other, the power dependence is very different. While the film deposited with reactive evaporation method showed little increase with magnetic fields, the on-axis PLD film showed a rapid increase.

This clearly shows that, while MgB_2 film is intrinsically absent from weak links, depending on how you deposit or grow the film, the weak link behavior can occur.

Another thing that we might be able to deduce from the fact that the low-field R_s for both films with PLD and reactive evaporation techniques are almost the same, despite the fact that the MgB_2 film with on-axis PLD shows much poorer surface quality compared to the one with reactive evaporation, is that the low-field R_s might be significantly affected by the substrate roughness.

An independent measurement of low-field R_s of the film coated with reactive evaporation method on r-plane sapphire having a surface roughness R_a<0.2 nm showed an R_s lower than Nb at 4 K [4], whereas the films deposited on a rough surface of R_a~400 nm have shown about one order of magnitude higher R_s than Nb as shown in Fig. 6.

Figure 7 shows a surface morphology of a 550-nm thick MgB_2 film deposited on an r-plane sapphire with reactive evaporation technique. A very smooth and densely packed surface with roughness of 4.4 nm was achieved.

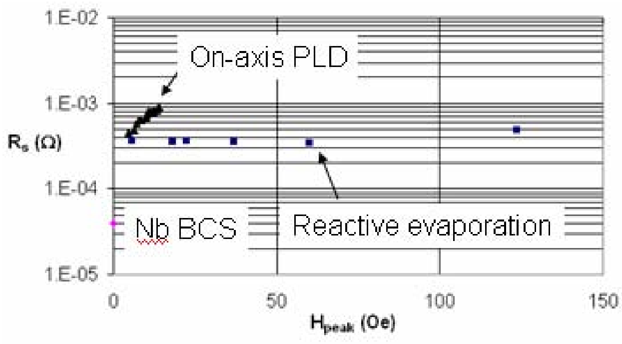

Figure 6: Surface resistance at 10 GHz as a function of surface magnetic field. The data was scaled from 6 GHz data using f^2 law.

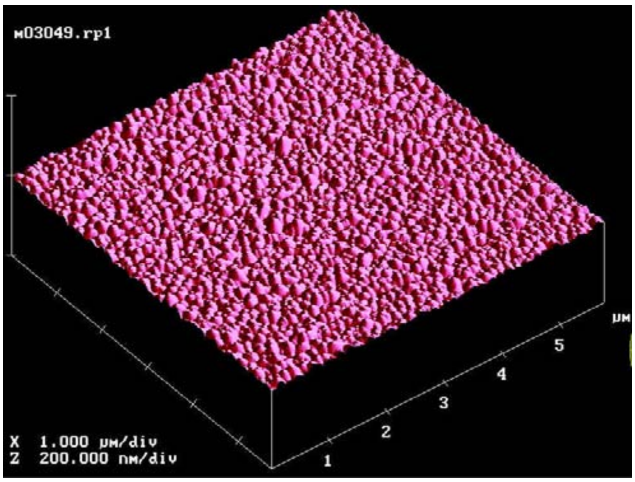

Figure 7: Surface morphology of the MgB_2 grown on r-plane sapphire with reactive evaporation method [5, 9]. The film thickness and the rms surface roughness are 550 nm and 4.4 nm, respectively [9].

FUTURE PLANS

In addition to investigate the effect of substrate surface roughness on the R_s, and the improvement of the quality with PLD films, the following tests are being prepared.

- Measurement of RF critical magnetic field of a MgB_2 bulk sample using a specially made TE mode cavity shown in Fig. 8 at SLAC [10].

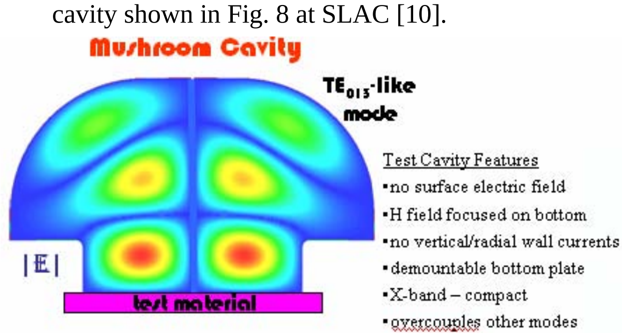

Figure 8: A SLAC cavity for testing superconducting materials [10].

- Measurement of R_s dependence on surface magnetic fields at higher power using a cavity shown in Fig. 9 with a calorimetric method at JLab [11].

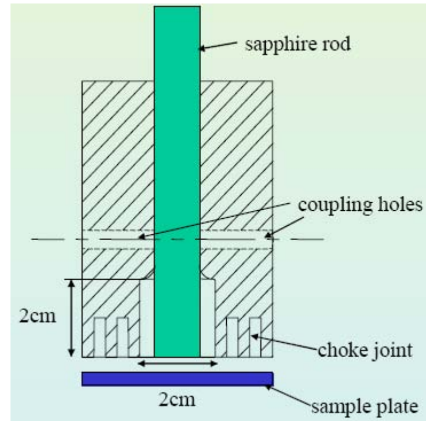

Figure 9: JLab cavity for testing the power dependence using calorimetry [11].

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