STUDIES ON SUPERCONDUCTING THIN FILMS FOR SRF APPLICATIONS*

T. Tajima#, N. Haberkorn, L. Civale, G. Eremeev**, M. Hawley, R. Schulze, A. Zocco, LANL, Los Alamos, NM 87545, U.S.A.
J. Guo, V. Dolgashev, D. Martin, S. Tantawi, C. Yoneda, SLAC, Menlo Park, CA 94025, U.S.A.
B. Moeckly, STI, Santa Barbara, CA 93111, U.S.A.
T. Doi, Kagoshima Univ., Kagoshima 890-0065, Japan
A. Matsumoto, NIMS, Tsukuba, Ibaraki 305-0047, Japan

Abstract

In order to overcome the fundamental limit of Nb's critical magnetic field (~ 200 mT) that corresponds to E_{acc} ~50 MV/m, an idea of coating several thin layers of a superconductor has been proposed. MgB_2, a superconductor that has a T_c of ~39 K, has been studied to explore the effect of coating in terms of DC and RF critical magnetic fields, and RF surface losses.

MgB_2 has shown an excellent behavior, although there is some discrepancy between DC and RF measurements.

INTRODUCTION

In 2005, Gurevich suggested a way of enhancing sustainable magnetic field on the SRF cavity by adding one or more thin superconductors [1]. His idea is based on the fact that the critical magnetic field, B_{c1}, in parallel with the superconductor surface increases with reducing thickness of the layer once it becomes thinner than the magnetic penetration depth, λ. The increased field can be predicted using the following formula.

$$B_{c1} = \frac{2\phi_0}{\pi d^2}\left(\ln\frac{d}{\tilde{\xi}} - 0.07\right), \ d < \lambda, \qquad (1)$$

where ϕ_0 is the flux quantum (2.07 x 10^{-15} weber), d the film thickness and $\tilde{\xi} = 1.07\xi$ (coherence length). Figure 1 shows predicted B_{c1} as a function of film thickness.

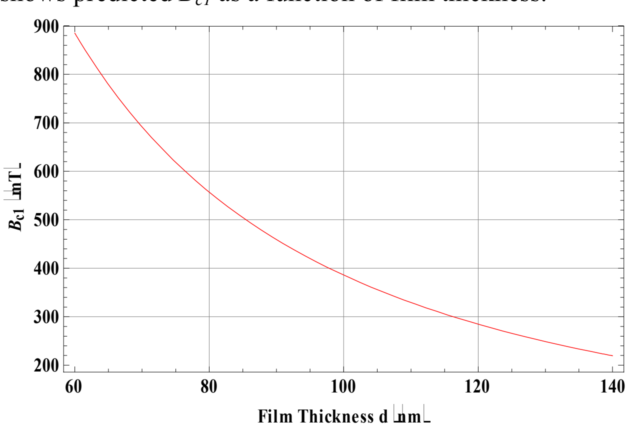

Figure 1: Calculated critical magnetic field of MgB_2 film in parallel with the surface as a function of the film thickness from Eq. (1). A coherence length of 5 nm and magnetic penetration depth of 140 nm were assumed.

*Work supported by the DTRA.
#tajima@lanl.gov
**Presently at TJNAF.

Figure 2 illustrates an example of 105 nm thick MgB_2 layer coated on top of Nb with a dielectric layer such as Alumina. If the assumptions are correct and 170 mT can be sustained on the Nb surface, this coating could increase the surface field to ~ 355 mT, which corresponds to ~100 MV/m with B_{peak}/E_{acc} ~ 3.55 mT/(MV/m).

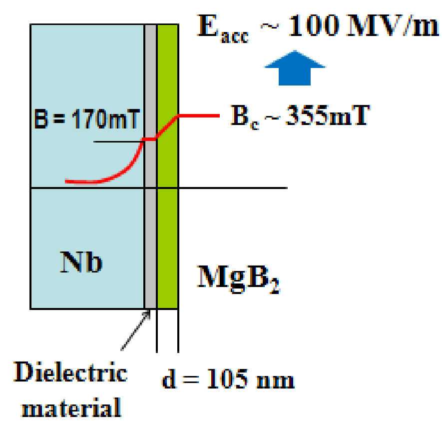

Figure 2: A simple example of field enhancement. It assumes that the cavity is designed with B_{peak}/E_{acc} ~ 3.55 mT/(MV/m).

Our first goal is to determine the thick film B_{c1} of candidate superconductors and demonstrate its increase with thinner films, and achieve B_c > 200 mT with flat samples. In this paper, we will focus on MgB_2 since it is the only material that we have measured RF critical fields so far.

MEASUREMENT AND ANALYSIS TECHNIQUES

A Quantum Design Magnetic Property Measurement System (MPMS) SQUID has been used for DC measurements such as T_c and B_{c1} (= $\mu_0 H_{c1}$).

The RF surface resistance and critical magnetic field of samples have been measured at SLAC using an 11.4 GHz pulsed Klystron that can produce up to ~50 MW peak power, and a hemi-spherical TE_{013}-mode cavity made of copper with demountable flat plate that can hold a sample of 2-3 inches in diameter.

Atomic force microscopy (AFM) has been used for surface morphology analyses. X-ray photoelectron spectroscopy (XPS) and Auger electron spectroscopy (AES) have been used to analyze the chemical compositions and depth profile of the chemical elements.

SAMPLES

Substrates

For RF measurements at SLAC, 2 inch diameter wafers have been used. After some series of initial measurements, we decided to use ~1.1 mm thick single-grain Nb wafers as substrates in order to avoid cracking of the coated surface due to mechanical stress. Presently, these wafers are polished to an rms roughness of <1 nm with chemical-mechanical polishing (CMP) [3]. We have also used 2-inch Sapphire or Si wafers as substrates in order to study the effect of Nb substrate on the coating by comparing the results with those coated on Nb substrates.

Coating

For MgB_2 coating, the samples prepared with 2 techniques were measured. One technique is a reactive co-evaporation developed at STI, California, U.S.A. [4], and the other is an electron beam co-evaporation developed at Kagoshima Univ., Kagoshima, Japan [5]. The latter technique has an advantage of lower substrate temperature (250 °C) compared to the former technique (550 °C), but the T_c is lower as shown in the following section.

DC MEASUREMENTS RESULTS

Figures 3 and 4 are 2 examples of magnetization measurement to determine H_{c1}. The unit "mT" for the magnetic field is related to the "Oe" for the field strength as 1 [mT] = 10 [Oe]. The H_{c1} is defined as the point where the magnetization curve starts to deviate from the linear dependence of the Meissner state, i.e., the point where vortices start to penetrate into the material. Although this determination may slightly overestimate H_{c1} due to the presence of surface barriers, it still provides a consistent comparison among the various MgB_2 films.

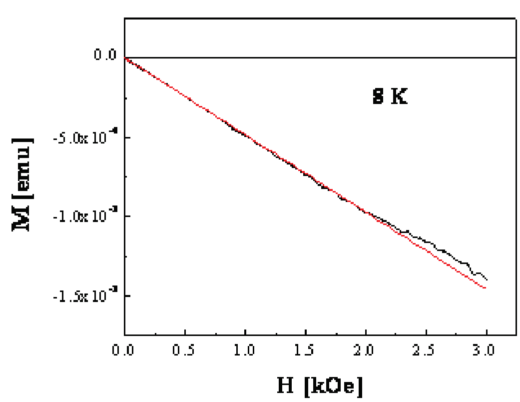

Figure 3: Magnetization curve as a function of applied magnetic field for ~300 nm thick MgB_2 film (T_c ~ 39 K) deposited on a c-cut sapphire substrate at STI.

Figures 5 through 8 show measured H_{c1} as a function of temperature for a Nb rod prepared from a single-grain Nb as a reference, ~300 nm MgB_2 film prepared by STI, ~330 nm and ~290 nm films prepared by Kagoshima Univ., respectively.

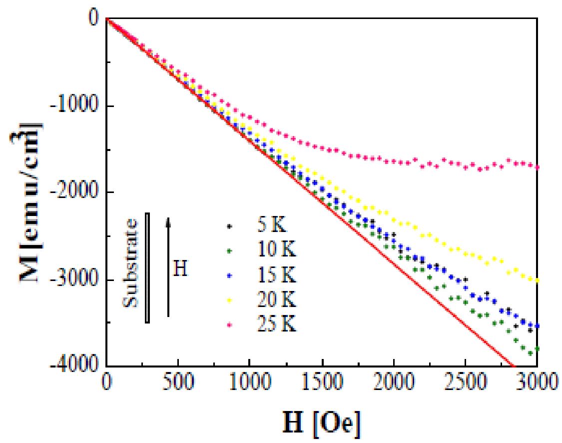

Figure 4: Magnetization curves as a function of applied magnetic field at various temperatures for ~290 nm thick MgB_2 film (T_c ~ 31.8 K) deposited on a Si substrate at Kagoshima Univ.

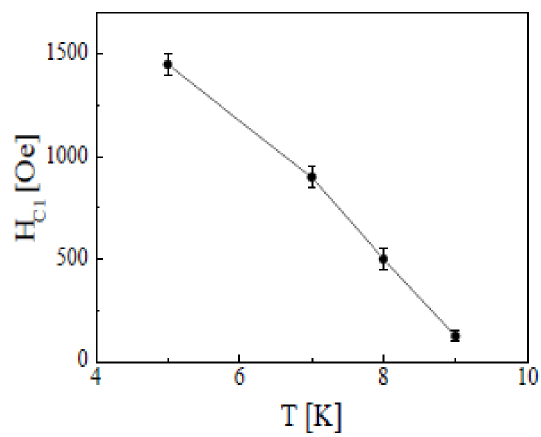

Figure 5: H_{c1} vs. temperature for a Nb sample as a reference.

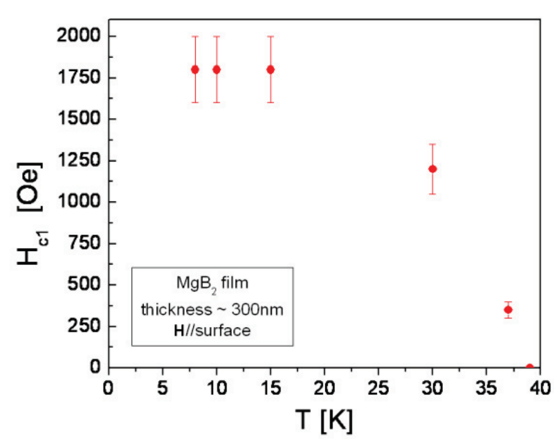

Figure 6: H_{c1} vs. temperature for ~300 nm MgB_2 sample coated on c-cut sapphire at STI.

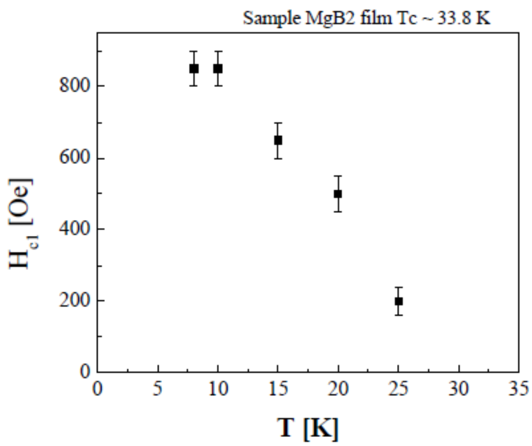

Figure 7: H_{c1} vs. sample temperature from magnetization measurements of ~330 nm thick MgB_2 sample prepared by Kagoshima Univ.

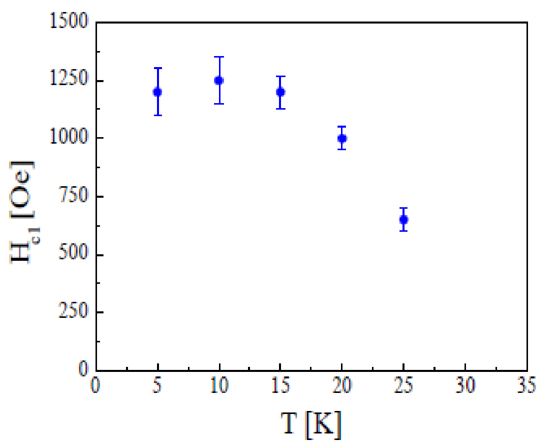

Figure 8: H_{c1} vs. sample temperature from magnetization measurements of ~290 nm thick MgB_2 sample (T_c ~ 31.8 K) prepared by Kagoshima Univ.

11.4 GHz RF MEASUREMENTS RESULTS

Figure 9 summarizes Q_0 - T measurements results at low power.

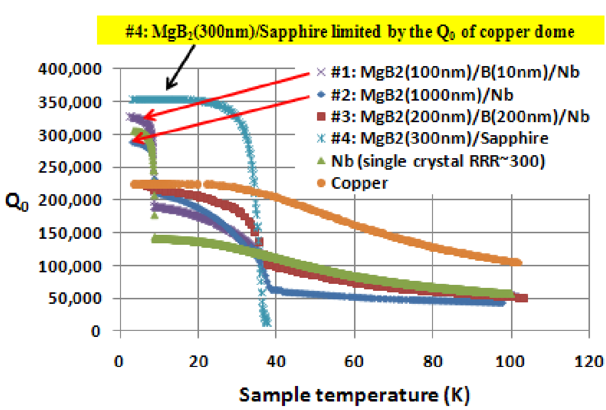

Figure 9: Q_0 vs. temperature at low field at 11.4 GHz for various MgB_2 coatings together with Nb and copper as references.

The MgB_2 film coated on sapphire showed very low losses compared with other samples. Following surface analyses showed some cracks on the surface of 1000 nm MgB_2 film, indicating that the field has penetrated into the Nb substrate through cracks. Also, an increased amount of oxygen and Mg at the interface of Nb and B or MgB_2 has been detected, suggesting some degradation due to a formation of a layer with high RF losses.

Figure 10 shows Q_0 as a function of peak magnetic field at 3 K for a 300 nm MgB_2 film coated on sapphire. There was a clear quench at 25 mT, i.e., $H_{c,\,RF}$ = 250 Oe. This value is significantly lower than the H_{c1} of ~1800 Oe as shown in Fig. 6.

We plan to test thin layers (~50 nm each) of films to demonstrate an increase of H_{c1} and $H_{c,\,RF}$.

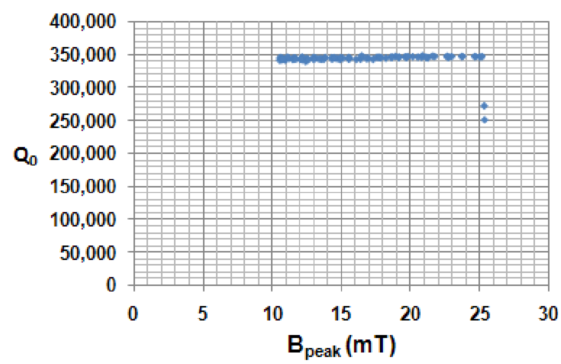

Figure 10: Q_0 as a function of peak magnetic field at 3 K for a 300 nm MgB_2 film coated on a c-cut sapphire substrate at STI.

CONCLUSIONS AND FUTURE PLANS

MgB_2 has been studied as a candidate for SRF applications. It seems to have excellent DC and RF properties, although there is a discrepancy between measured H_{c1} (up to ~1800 Oe) and measured RF critical field (~250 Oe). We plan to find out the reason for this discrepancy as well as to demonstrate the effect of thinner films.

REFERENCES

[1] A. Gurevich, “Enhancement of rf breakdown field of superconductors by multilayer coating,” Appl. Phys. Lett. 88, (2006) 012511.

[2] J. Guo et al., “A Cryogenic RF Material Testing Facility at SLAC,” IPAC’10, Kyoto, May 2010, WEPEC073, p. 3049 (2010); http://www.jacow.org.

[3] Polishing has been done at Cabot Microelectronics Polishing Company, Illinois, U.S.A.

[4] B.H. Moeckly and W.S. Ruby, “Growth of high quality large area MgB_2 thin films by reactive evaporation,” arxiv/cond-mat/0601669v1, January 2006.

[5] K. Nagatomo et al., “Fabrication of MgB_2 thin films by electron beam evaporation technique,” Physica C 426-431 (2005) 1459.