PROOF OF CONCEPT THIN FILMS AND MULTILAYERS TOWARD ENHANCED FIELD GRADIENTS IN SRF CAVITIES*

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Abstract

Due to the very shallow penetration depth of the RF fields, SRF properties are inherently a surface phenomenon involving a material thickness of a few microns thus opening up the possibility of using thin film coatings to achieve a desired performance. The challenge has been to understand the dependence of the SRF properties on the detailed characteristics of real surfaces and then to employ appropriate techniques to tailor these surface properties for greatest benefit. Our goal has been to build a basic understanding of key nano-scale film growth parameters for materials that show promise for SRF cavity coatings. In what follows we will describe our experimental attempts to test the superconducting/insulating/superconducting (SIS) multilayer model proposed by A. Gurevich [1] to shield the bulk of the cavity and hence enable larger accelerating fields than presently possible.

INTRODUCTION

Progress in the development of Nb resonator cavities for particle accelerators in recent years has resulted in a significant increase of RF peak breakdown field up to 170–180 mT at 1.3 GHz. Such field induces a screening current density close to the depairing limit $J_d = B_c / \mu_0 \lambda$ for Nb at T below T_c, where $B_c(0) = 200$ mT is the thermodynamic critical field for Nb, and λ is the London penetration depth. In 2006 A. Gurevich proposed a multilayer coating that could overcome this limit. [1] This model considers the enhancement of parallel B_{c1}, the magnetic field at which it becomes energetically favorable for a vortex to be inside a type II superconductor, in films with thickness d smaller than λ. Thus, with a suitably tailored SIS multilayer, he proposed that it might be possible to take advantage of critical field enhancement and also lower surface impedance. In what follows we show our experimental work to test this model.

EXPERIMENTAL WORK

We have previously reported that it is possible to tailor the microstructure and hence superconducting properties of materials with adequate choice of template and growth conditions. [2, 3] We have also carried out studies on the

thickness dependence of B_{c1} for the particular case of MgB_2. [4] Here we compare three different types of trilayered (SIS) samples, where the bottom layer is bulk-like Nb that mimics the interior surface of a cavity, then an insulating layer and finally another superconductor where we have chosen NbN, NbTiN and MgB_2. The NbN-based and NbTiN-based samples were deposited using reactive DC sputtering, and the MgB_2-based sample using hybrid HPCVD deposition.

Our systematic earlier investigations on MgB_2 films to assess the critical field versus thickness dependence indicated that a suitable thickness for implementing SIS trilayers using this material was around 60 nm. Thus, we prepared such trilayers: 10 nm Au / 60 nm MgB_2 / 15 nm MgO / 600 nm Nb / MgO (100). A comprehensive treatment of HPCVD for the generation of MgB_2 thin films is described elsewhere [5-7].

We note that a gold cap layer was added to avoid degradation and/or contamination of the MgB_2 surface. The penetration field was measured using SQUID (Figure 1). B_{C1} was determined by measuring trapped moments that appear after application and removal of the applied field, following the work of C. Bohmer et al. [8] We note here that similar methodology was applied to determine B_{c1} in the NbN-based trilayer that we reported earlier. Thus, the critical field measured B_{C1} was larger in this multilayer than in a pure Nb reference film (i.e. we found B_{c1} was 1300 Oe for the Nb reference sample vs 1700 Oe for the MgB_2 based multilayer sample). This result is quite encouraging since it indicates magnetic shielding under DC field, but the result is not as impressive as the previously reported result obtained for the NbN based multilayers since in that instance we observed a penetration field of ~ 220 mT, which is much higher than the 170 mT reported for bulk Nb. It is worth mentioning here that SRF impedance characterization of optimal epitaxial MgB_2 films deposited on sapphire also indicated two orders magnitude larger residual SRF impedance than large grain pure Nb thus suggesting a much lossier material than bulk Nb. [9] The observed T_c was 30.2 K for the MgB_2 layer.

A microstructure characterization of the sample was carried out with X-Ray diffraction (XRD) and the theta-2theta scan indicates that the Nb film is (110) oriented in this sample, which has been demonstrated to lead to lower film quality than when it is (001) oriented thus explaining the lower penetration field of the reference Nb sample compared to our previous studies. The MgB_2 layer

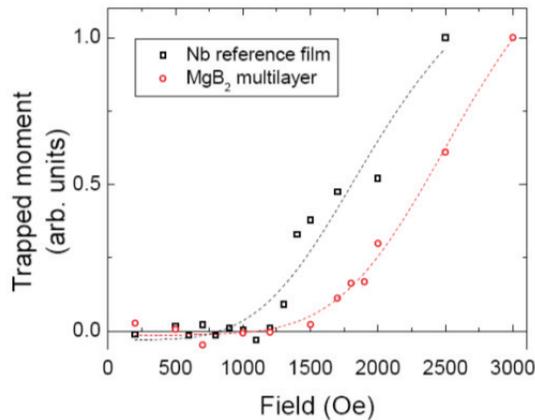appears composed of several highly strained phases (Figure 2).

Figure 1: Penetration field measured with DC SQUID at 5K. A Nb reference films is shown here for comparison, so that the shielding effect of an MgB_2–based multilayer can be assessed. The penetration field is approximately 300 Oe larger than that of the reference pure Nb film sample.
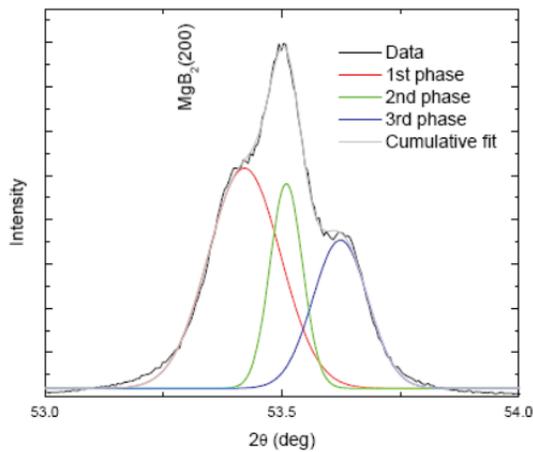

Figure 2: Detail of the XRD scan of a MgB_2-based trilayer. We observed a highly strained MgB2 layer with multiple phases present.

The amount of strain present in the various MgB_2 phases was determined from their shift from the bulk -peak position, $2\theta = 51.863°$ corresponding to a lattice constant of 3.523 Å. Thus, the 1st phase exhibits 2.7108% strain, the 2nd phase exhibits 2.8584% strain and finally the 3rd phase exhibits 3.0514 % strain. Thus, this trilayer had a far from perfect MgB_2 layer compared to similarly grown epitaxial MgB_2 films grown on crystalline sapphire. Despite this fact, we note that there is a shielding effect similar to that observed when using NbN-based multilayers. We also note that MgB_2 film properties degrade with exposure to air/moisture and the resistance

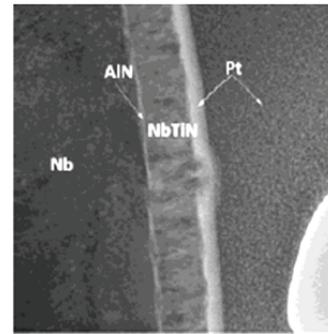goes up, while Tc goes down which may constitute a serious practical issue for SRF cavities applications.

Figure 3: TEM image showing a cross section of a NbTiN-AlN-Nb trilayer.

Although we have achieved promising results with NbN, we have also considered NbTiN since it is another suitable B1 superconductor, similar to NbN but with some advantages. NbN suffers from higher resistivity due to presence of both metallic and gaseous vacancies randomly distributed, while NbTiN presents all the advantages of NbN, a slightly higher T_c (17.8K) and also exhibits enhanced conductivity with higher Ti percentage. NbTiN films deposited by DC reactive sputtering exhibited the best transition temperature when deposited from a composite $Nb_{80}Ti_{20}$ target. NbTiN-based trilayers were deposited on sapphire, and AlN was used as insulating layer (Figure 3).

The surface impedance of NbN-based and NbTiN-based trilayers were measured using the 7.5 GHz Surface Impedance Characterization (SIC) tool developed and commissioned at TJNAF. [10] Figure 4 shows such measurement for a NbTiN-based trilayer while Figure 5 shows it for NbN-based trilayer.
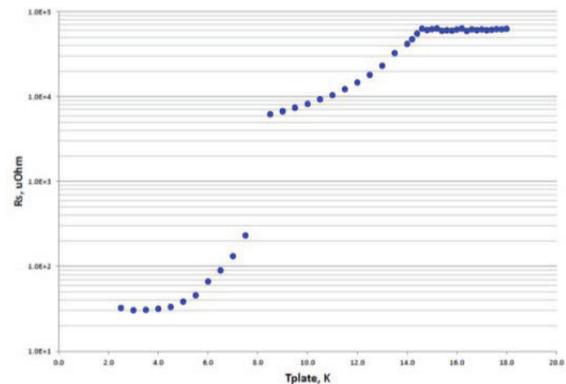

Figure 4: Surface resistance measurements for a NbTiN/AlN/Nb trilayer deposited on sapphire. We note that the residual resistance around 2K is approximately 30 mOhm. We also distinguish two temperature regimes with transitions around 8.5 K and 14.5K, related to Nb and NbTiN respectively.

06 Material studies

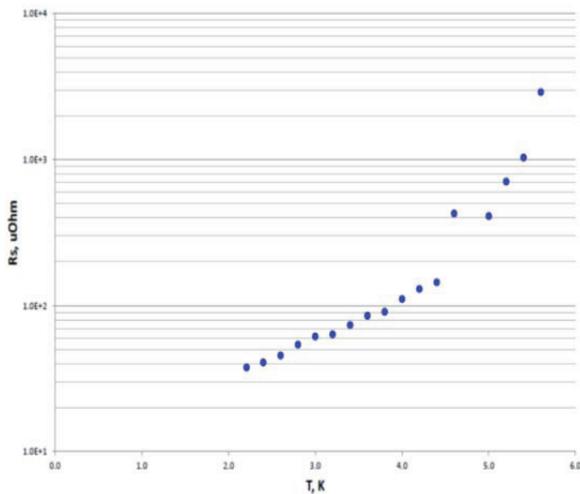**J. Basic R&D Other materials (multilayer, MgB2,. . .)**

Figure 5: Surface resistance measurement for a NbN/MgO/Nb trilayer deposited on a Cu template.

We note that Surface Impedance data reported earlier on a MgB$_2$-based trilayer indicated a residual resistance of 181 μΩ thus almost one order magnitude larger than in the present two NbTiN and NbN-based trilayered samples, which in turn exhibit a residual resistance one order magnitude larger than large grain bulk Nb, suggesting that further studies are necessary to establish the optimal trilayer composition and deposition conditions for this application.

CONCLUSIONS

Multilayers incorporating NbN and following the "Gurevich model" were shown to shield niobium in the pioneer work by Antoine *et al.* using SQUID magnetometry as well as third harmonic analysis [11], [12]. Our own work was able to demonstrate shielding beyond the critical field of Nb also using NbN-based trilayers also using SQUID magnetometry. Here we have shown that other promising superconductors also show promise for this application, but further studies to optimize thin film deposition conditions must be undertaken.

ACKNOWLEDGMENT

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