FLUX FLOW IN SUPERCONDUCTING MgB_2 FILMS

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Abstract: In this work the experimental investigation of the resistive transitions broadening for magnesium diboride films and their microstructure is reported. The MgB_2 films were prepared by dc-magnetron sputtering. To explore the microstructure of the films AFM and SAM was performed. The results show a TAFF caused broadening in the resistive transitions at several applied magnetic fields which may result from the microstructure of the films.

INTRODUCTION

Since the discovery of superconductivity (1) MgB_2 attracts extended attention to its physical properties and origin of superconductivity. Magnesium diboride has a T_c which is higher than that of conventional superconductors, a relative simple crystal structure and a higher coherence length in comparison with metal-oxide High-T_c superconductors. The high critical temperature of 39.3 K makes MgB_2 an attractive candidate material for use in digital superconducting microelectronic devices operating at temperatures up to 25 K which are achievable in low cost cryo coolers. Therefore there is a high need to explore the properties and the structure of thin layers of MgB_2.

EXPERIMENTAL AND DISCUSSION

In this work we report about an experimental investigation of the resistive transitions broadening for magnesium diboride films and their microstructure. The MgB_2 films were prepared by dc-magnetron sputtering from Mg-MgB_2 composite targets on single crystalline sapphire substrates and annealing in Mg vapor atmosphere, using the special two-step process described in literature [1]. Fig. 1 shows the resistive transitions R(T_c/T) at several magnetic fields B, which were applied perpendicular to the MgB_2 film plane for one of the investigated samples. In case when the broadening of the resistive transition in a magnetic field is caused by the thermally activated flux motion (TAFF), R(T) can be described by an Arrhenius equation [2]:

$$R = R_0 \exp\left[-U(B,T)/k_B T\right] \qquad (1)$$

Such behavior was found for the investigated films, i.e. the straight line parts of the resistive transitions in Fig. 1 over more than 3 orders of magnitude indicate that the resistive behavior of the

MgB_2 films is caused by the TAFF-process and can be described by Eq. (1), with values for the activation energy U, ranging from U/k_B = 10000 K in low magnetic field down to 300 K in the high field region. Compared to the power law $U(B) \sim B^n$ with the exponent n ~ 1 which usually is observed for layered systems, MgB_2 demonstrates a much stronger field dependence of the activation energy. One of the possible reasons of the strong field dependence of the activation energy of the TAFF-process for MgB_2 that was observed for the investigated films may be a very smooth microstructure and the high purity and stoichiometric composition of the developed MgB_2 films (shown in Fig. 2) resulting a small amount of effective pinning centers.

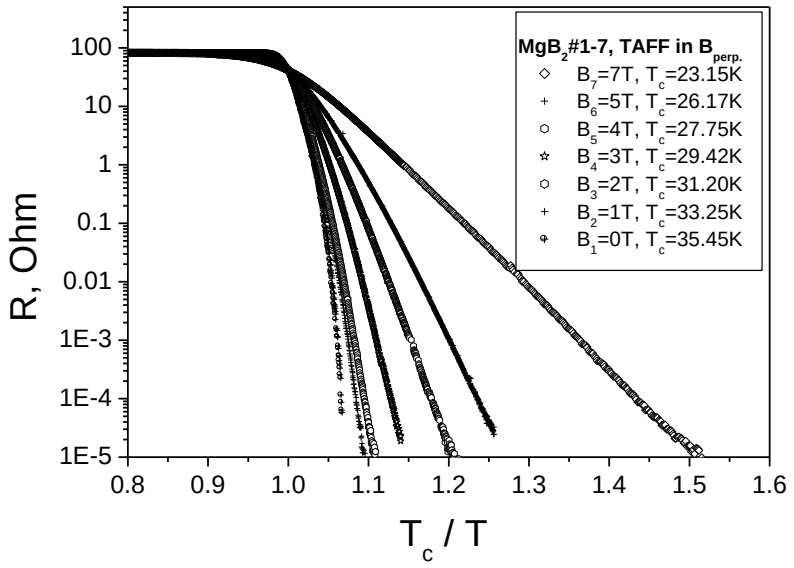

Fig. 1. Arrhenius plot of R(T) | B=const for for a 400 nm thick MgB2 film at different values of the magnetic field perpendicular to the film. From the slope of the linear parts of the curves the value of the activation energy U(B,T) is obtained.

For the investigated samples Atomic Force Microscopy (AFM) was performed. One example shown in Fig.2 was taken in intermittent contact mode on the surface of a 400 nm thick MgB_2 layer and shows a smooth surface structure with small islands and low roughness values. The AFM investigations of the samples were made in contact mode and in intermittent contact mode and showed plain surfaces with uniformly distributed groups of 100 nm - 300 nm (diameter) big islands (typical island distance 12 µm +/- 3 µm). Tapping mode phase imaging and friction microscopy did not show a significant material contrast. The average values for island size (diameter = 49 nm +/- 4 nm), island distance (distance = 50 nm +/- 5 nm) and the value for the surface roughness (RMS = 8,2 nm) are supporting the smooth and homogenous character of this surface.

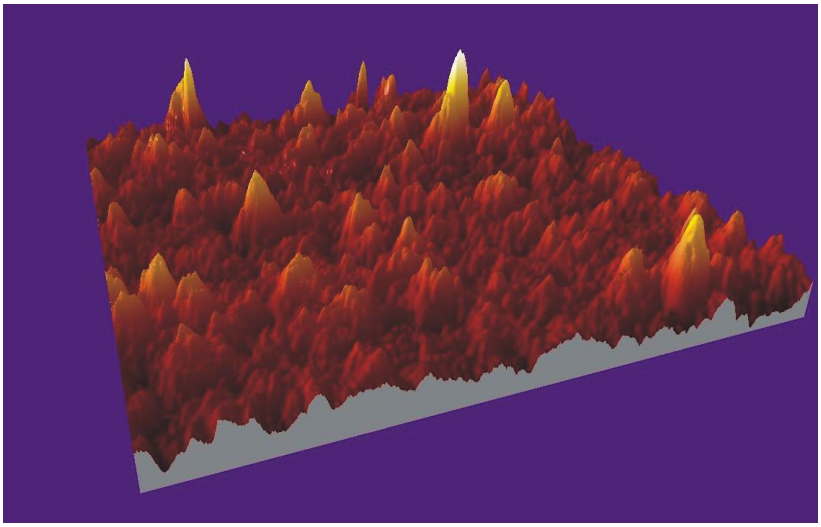

Fig. 2: Scanning Force Microscopy image of the surface of a 400 nm thick layer of MgB_2 on sapphire (T_C=35,45 K) obtained in the intermittent contact mode; scan size: 2.1 µm x 2.1 µm ; z-scale: 20 nm, surface roughness value: RMS = 8.2 nm; av. island diameter: 49 nm; av. island distance: 50 nm.

To explore the inner composition of the examined films Scanning Auger Analysis (SAM) of the MgB_2 films (depth profile shown in Fig.3) was made The results demonstrate the presence of some oxide contamination within two regions, one at the surface of the films and one close to the substrate, as one can see in Fig.3. Both regions show a similar thickness of about 100 nm. The possible reason for the contamination at the surface is normal oxidation process of the material under ambient conditions which always generates oxide containing regions of this thickness in between a short time. Even long time studies with SAM depth profiles show almost the same thickness for oxide contamination that was found here. Freshly prepared MgB_2 layers show almost no oxygen contamination at the surface.

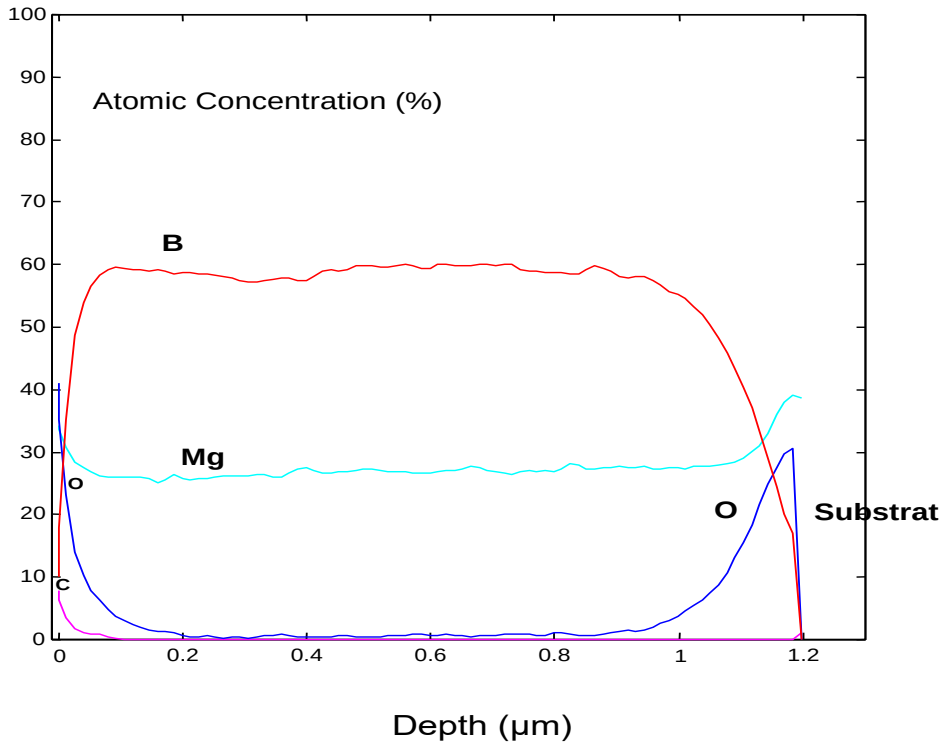

Fig. 3. The data of the Scanning Auger Depth Profile Analysis for the MgB_2 film, presented in Fig. 2. The sample was sputtered with Argon and every 10 nm a Scanning Auger Analysis of the sputtered region was performed. The diagram shows in the region between 0 nm and 100 nm a MgO layer on top of pure MgB_2 in stoichiometric distribution. At the bottom of the MgB_2 film at 1,2 µm thickness the signal from the Substrate starts to rise and the Signal for Mg and B drops down immediately. Between 1,1 µm and 1,2 µm MgO can be identified.

The oxygen contamination near the substrate is either a result of some oxygen diffusion from out the substrate or some interface reaction with the substrate during the heating periods, which both is not very likely the case. It also could possibly be caused by the initial sputter process itself. In the used setup it actually can not be prevented to contaminate the sputter targets during the sample exchange etc., so that the targets which are used to fabricate the precursor films are always

covered by some kind of native oxide layer when the sputtering process starts. There are some reconstructions done at the machine at the moment to check and eventually overcome this process.

CONCLUSION

The microstructure of thin MgB_2 films was investigated with AFM and SAM. A broadening of resistive transitions was reported for several applied magnetic fields. This may result from the smooth microstructure and high purity of the films.

REFERENCES

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