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FABRICATION OF LARGE-AREA MgB_2 FILMS ON COPPER SUBSTRATES*

Xin Guo, Zhimao Ni, Kexin Liu†, School of Physics and State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China
Can Yang, Qingrong Feng, School of Physics and State Key Laboratory for Artificial Microstructure and Mesoscopic Physics, Applied Superconductivity Research Center, Peking University, Beijing, China

Abstract

Magnesium diboride (MgB_2) is a promising candidate material for SRF cavities because of its higher transition temperature and critical field compared with niobium. To meet the demand of RF test devices, the fabrication of large-area MgB_2 films on metal substrates is needed. In this work, MgB_2 films with 50-mm diameter were fabricated on Cu substrates by using an improved HPCVD setup at Peking University. The transition temperatures of MgB_2 film on Cu substrate and with Mo buffer layer on Cu substrate are 36.2 K and 36.5 K, respectively. The fabrication processes, surface morphology, superconducting properties of these large-area MgB_2 films are presented.

INTRODUCTION

Bulk niobium superconducting radio frequency (SRF) cavities for particle accelerators have been in operation for more than 50 years, and the RF performance is approaching the theoretical limit. To further improve the RF performance, it is important to investigate alternative materials with higher superheating critical fields to satisfy the demands for higher accelerating gradients and lower operating cost. MgB_2 has shown potential as an alternative material for the application of SRF cavities [1, 2]. With a higher transition temperature (39 K), a larger energy gap, a higher critical field, it is expected to have a high quality factor (Q_0) and high accelerating gradient (E_{acc}) for MgB_2 coated cavities.

Considering mechanical and thermal stability of cavities, it is necessary to fabricate MgB_2 films on metal substrates. Characterization of the RF properties of these MgB_2 films is an important step to evaluate the feasibility of MgB_2 coated SRF cavity. Hence, large-area MgB_2 films are needed to meet the demand of RF test devices, in which the MgB_2 coating is a part of the test cavity. In our previous work, we reported the results of large-area MgB_2 films on niobium substrates. T_c values measured at different positions on the film range from 38.4 to 40.6 K, showing good uniformity. In RF tests, the film exhibits a low R_s of about 120 μΩ at 4 K and 11.4 GHz, close to that of bulk Nb [3].

Cu is an ideal thin film cavity body material because of its good thermal conductivity and machinability. However, the reaction between Cu and Mg make it challenging to fabricate MgB_2 film on Cu substrate. It has been reported previously that lower reaction temperature can help to fabricate MgB_2 thin films on Cu substrates [4-6]. Sputtering Mo on Cu substrate may further suppress the Mg-Cu reaction. In this work, we fabricated 50-mm diameter MgB_2 films on copper substrates using a modified hybrid physical-chemical vapor deposition (HPCVD) setup. The fabrication process, superconducting properties of the large-area MgB_2 films on Cu substrate as well as Cu substrate with Mo buffer layer are investigated.

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† email address: kxliu@pku.edu.cn

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Film Preparation

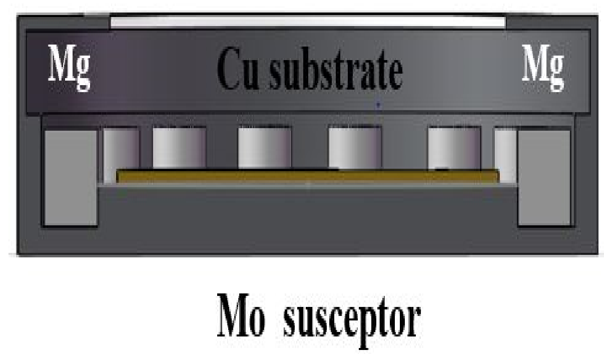

Figure 1: The profile of the improved susceptor for MgB_2 film fabrication on Cu substrate.

The modified HPCVD setup for 50-mm diameter MgB_2 films fabrication on Nb substrates has been described in detail in our previous work [3]. In particular, adding a wall about 9 mm in height surrounding the molybdenum susceptor to achieve uniform Mg vapor distribution over the substrate. To improve the quality of MgB_2 film on copper substrate, the reaction temperature is lower. Then the structure of the susceptor need to be modified further to help Mg vapour move towards the centre of the substrate. On the basis of the susceptor for deposition MgB_2 on niobium substrate, one more wall was added on the top of Mg ignots. Other changes, the height of Mg ignots and Cu substrate, contribute to forming a lower temperature at the centre of the substrate. These changes help Mg distribution on the top of the Cu substrate more uniform. The profile of the improved susceptor for MgB_2 film fabrication on Cu substrate is shown in Figure 1.

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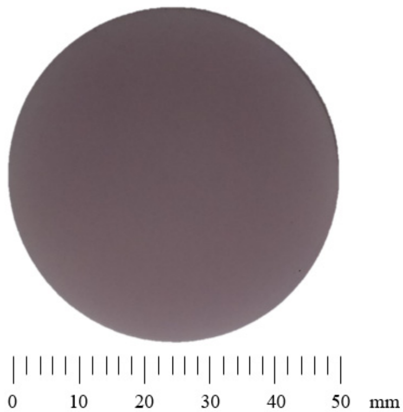

Figure 2: The picture of a 50-mm diameter MgB_2 film on Cu substrate.

The Mg ignots placed around the substrate as the Mg source. A mixed gas of 5% diborane (B_2H_6) and 95% hydrogen was supplied as the boron source. During the film fabrication, hydrogen was used as the background gas at a flow rate of 300 sccm and the pressure was kept about 4 KPa. When Cu substrate getting white (Mg react with Cu, around 480 °C) B_2H_6 mixture at a flow rate of 10 sccm was introduced into the chamber, then the film deposition occurred. The reaction time was last for 30 minutes. Figure 2 shows a picture of the 50-mm diameter MgB_2 film on Cu substrate.

Structure Properties

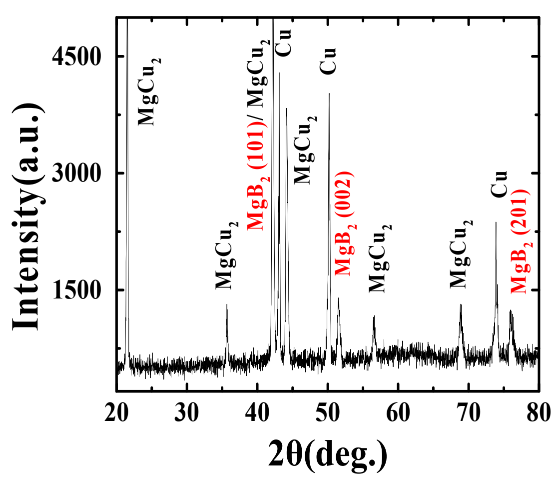

Figure 3: The x-ray diffraction pattern of the MgB_2 film on Cu substrate.

Figure 3 shows an x-ray diffraction (XRD) pattern for the MgB_2 film on Cu substrate. The reaction temperature is lowered to suppress Mg-Cu reaction, but there still exist the $MgCu_2$ peaks. The (101), (002) and (201) MgB_2 peaks indicate a polycrystalline film structure. The surface morphology of the MgB_2 film measured by scanning electron microscopy (SEM) is shown in Figure 4. Clear hexagonal MgB_2 crystalline structure could be identified, and the film is well connected.

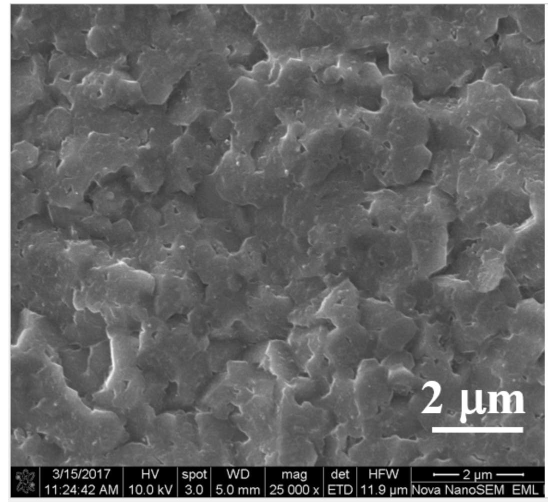

Figure 4: The morphology of MgB_2 film on Cu substrate.

DC Superconducting Property

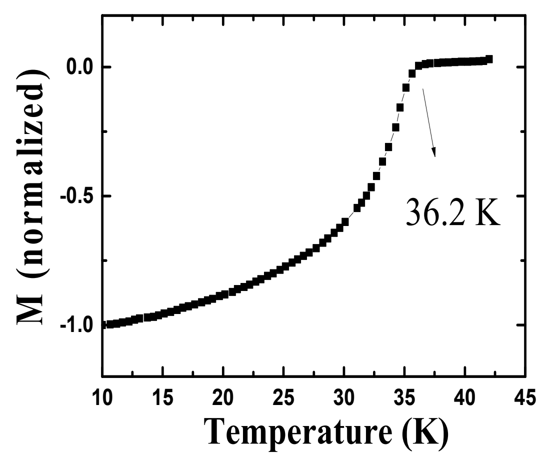

Figure 5: M-T curve of the MgB_2 film fabricated on Cu substrate.

The temperature-dependent magnetization (M –T) was measured on a Quantum Design magnetic property measurement system (MPMS-7). As shown in Figure 5, the superconducting transition temperature of MgB_2 film on Cu substrate is about 36.2 K. This value is a little lower than the MgB_2 film fabricated on Nb substrate. More likely the Mg-Cu alloy affect the superconducting property of MgB_2 film.

LARGE-AREA MgB_2 FILMS ON COPPER SUBSTRATES WITH Mo BUFFER LAYER

It has been shown previously that high quality MgB_2 film can be fabricated on Mo substrate [7]. We tried to suppress the reaction between Mg and Cu by introducing Mo buffer layer on top of Cu substrate. Prior to MgB_2 film growth, the Cu substrates were mechanical polished, and then deposited 100 nm Mo using magnetron sputtering method. The MgB_2 film on Mo-Cu substrate fabrication process followed the same process for MgB_2 film on Cu substrate.

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Structure Properties

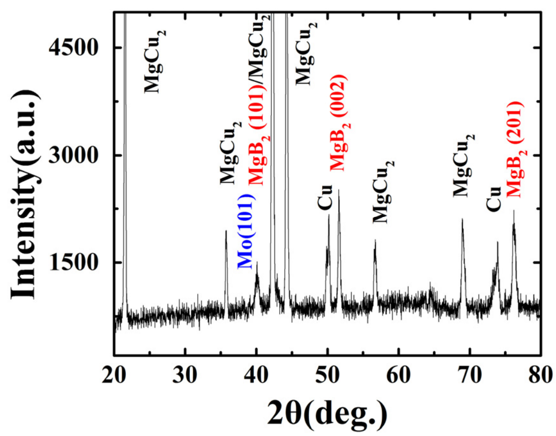

Figure 6: The x-ray diffraction pattern of the MgB_2 film on Mo-Cu substrate.

Figure 6 shows an XRD pattern for the MgB_2 film on Mo-Cu substrate. Besides the obvious (101), (002) and (201) MgB_2 peaks, the $MgCu_2$ peaks still exist, indicating Cu diffuses across the Mo film and reacts with Mg. However, due to the existence of the Mo buffer layer, the intensity of MgB_2 peaks enhanced. As shown in Figure 7, the surface morphology of MgB_2 film on Mo-Cu substrate is similar to that of film on Cu substrate. The film is uniform and well connected.

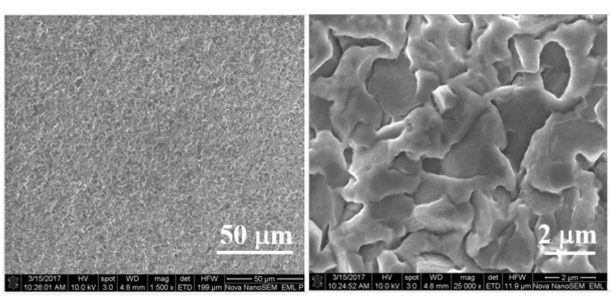

Figure 7: The morphology of MgB_2 film on Mo-Cu substrate.

DC Superconducting Properties

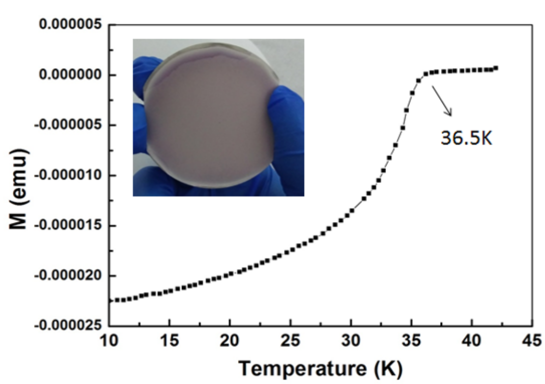

Figure 8: M-T curve of the MgB_2 film fabricated on Mo-Cu substrate. The inset shows the picture of a 50-mm diameter MgB_2 film on Mo-Cu substrate.

As shown in Figure 8, the transition temperature of the MgB_2 film on Mo-Cu substrate is about 36.5 K, slightly higher than the MgB_2 film fabricated on Cu substrate directly. The 100 nm-thick Mo film may be inadequate to suppress the Mg-Cu reaction. Sputtering much thicker Mo film to improve the quality of MgB_2 film on Cu substrate is in progress.

CONCLUSION

To study the RF properties of MgB_2 films, MgB_2 films with 50-mm diameter were fabricated on Cu substrates by using an improved HPCVD setup. The large-area film is well connected and shows clear hexagonal MgB_2 crystalline structure. The superconducting transition temperature is about 36.2 K. To suppress the Mg-Cu reaction, Mo buffer layer is introduced. With Mo buffer layer, the transition temperature of MgB_2 film on Mo-Cu substrate is about 36.5 K.

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