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The E–J characteristics of MgB_2 thin film prepared by electron beam evaporation method

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Abstract

The E–J characteristics of MgB_2 thin film prepared by the electron beam evaporation method were investigated. The film has a fairly higher T_c of 35 K and J_c of 0.48 MA/cm^2 at 20 K and 1 T among as-grown MgB_2 films prepared by various methods. The E–J characteristics at various temperatures and magnetic fields can be described by the percolation transition model. The pinning parameters and the distribution of pinning forces of the MgB_2 thin film were estimated. It was found that the MgB_2 thin film has the uniform distribution of pinning forces by grain boundaries.

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Keywords: MgB_2 thin film; E–J Characteristics; Pinning parameters

1. Introduction

The discovery of the superconductivity in MgB_2 [1], with the highest transition temperature T_c of 39 K among metallic superconductors, has attracted a great deal of notice in both fundamental studies and practical applications. MgB_2 has a great potential for practical applications because of the high transition temperature, a binary intermetallic compound with a simple crystal structure, a low material cost, no weeklinks [2] and so on. MgB_2 has been fabricated in various forms: single crystals, powder, bulk, thin films, tapes and wires.

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A fabrication of thin films is important for electronic applications and investigations of basic properties. A high quality MgB_2 thin film with J_c of $\sim 10^7$ A/cm^2 at 5 K and 0 T was obtained by the ex situ annealing process [3–5]. In this process, a boron precursor film deposited by a pulsed laser deposition (PLD) technique was sealed in Ta tube with Mg pieces and annealed at a relatively high temperature of 900 °C. On the other hand, in situ or as-grown films which do not require high temperature annealing processes have suppressed T_c's of <35 K. In the case of application to junctions or multilayers, in situ or as-grown films are desired because a post annealing with high temperatures is not favorable. In situ or as-grown films are prepared by molecular beam epitaxy [6,7], pulsed laser deposition [8], sputtering [9,10]. The upper critical field of the clean MgB_2 film without impurities is not too high in comparison with conventional metallic superconductors such as Nb_3Sn ($B_{c2} \sim 30$ T). Nevertheless in the dirty film including MgO, very high upper critical fields, $B_{c2}^{\parallel}(0) \sim 49$ T and $B_{c2}^{\perp}(0) \sim 34$ T parallel and perpendicular to the film surface, respectively, have been reported [11].

The grasp of electromagnetic properties, in particular the E–J characteristics in the magnetic field, is essential for superconducting applications. The E–J characteristics of superconductors are determined by many factors: the interaction between pinning centers and vortices, vortex–vortex interaction, the thermal agitation and so on. Therefore, it is very difficult to estimate the E–J characteristics theoretically. It has been shown that the complex E–J characteristics of high-T_c superconductors were estimated by the percolation transition model which took into account the statistical distribution of pinning forces [12–14]. The electric transport properties of MgB_2 in the magnetic field are not known in detail. In this study, we investigated the E–J characteristics of the as-grown MgB_2 thin film prepared by the electron beam evaporation technique [16]. The obtained E–J characteristics were analyzed with the percolation transition model, and then we derived the pinning parameters. Moreover, we estimated the distribution of pinning forces and considered pinning features.

2. Experimental

The MgB_2 thin film was deposited on a c-plane sapphire substrate (0 0 1) by the electron beam evaporation (EBE) method [16]. The substrate was set in the deposition chamber with a base pressure of 10^{-7} Pa and heated at 240 °C by a halogen lamp heater. A pure magnesium block (99.9%) and stuffed granular born (99.5%) were used as the evaporation sources. The flux of Mg and B that arrived onto the substrate were independently monitored using two quartz crystal monitors (QCM). The flux rates were precisely administered by an automatic control of each electron beam regulator by the feedback from the QCM's. Flux rates for Mg and B were controlled at 3 nm/s and 0.5 nm/s, respectively, to compensate for the high volatility of Mg. The thickness of the MgB_2 film was 300 nm. In order to measure E–J characteristics, the film was patterned into microbridge shape with the strip dimension of 50 μm wide and 1 mm long by a photolithography technique. The film was chemically etched by an acid solution with HNO_3. To obtain good contacts, Au contact pads were deposited on the film by a RF sputtering after cleaning the film surface with Ar-ion etching. The E–J characteristics were measured by a dc four probe method, where the magnetic field was applied perpendicular to the film surface in the range from 1 T to 7 T. The stability of temperature was ±0.03 K.

3. Results and discussion

Fig. 1 shows the typical temperature dependence of the resistivity of the MgB_2 thin film. The fairly higher superconductive transition temperatures of $T_{c(onset)} = 35$ K and $T_{c(zero)} = 34$ K among as-grown films were obtained. A structural analysis was carried out by a typical X-ray diffraction (XRD). As shown in Fig. 2, MgB_2 peaks of (0 0 1), (0 0 2) and (1 0 1) are observed and impurities such as MgO are not included.

The E–J characteristics of $B = 7$ T at various temperatures are shown in Fig. 3. An E–J curve at a low temperature region has a negative curvature in a log–log plot. As the temperature increase,