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Properties of MgB_2 Intragrain Nanobridges

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MgB_2 결정립 나노브릿지 특성에 관한 연구

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Abstract

Inter-grain nanobridges of the MgB_2 superconductor have been fabricated by focused-ion-beam (FIB) and their electrical transport properties were studied. The MgB_2 film was prepatterned into microbridges by a standard argon ion milling technique and then FIB-patterned into 100 nm x 100 nm bridges. Current-voltage characteristics showed a strong flux-flow type behavior at all temperatures with a trait of Josephson coupling near T_c. At low temperatures, the curves showed a two-step resistance-doubled transition with occasional hysteresis. The resistance-doubling transition is believed to be due to a two-channel flux-flow effect. The temperature-dependent critical current data showed $I_c(T) \propto (1-T/T_c)^2$ near T_c, same as a normal barrier junction, and $I_c(T) \propto (1-T/T_c)^{1.2}$ at low temperatures, similar to that of a film.

Keywords : MgB_2, superconducting nanobridge, focused-ion-beam

I. Introduction

The feasibility of new superconducting materials in the active electronic application depends on whether the Josephson junction can be produced from them. Since the first discovery of MgB_2 superconductors [1], many groups have studied fabrication of Josephson element in various types. Standard trilayer junctions with an insulating barrier [2-4] and a normal metal barrier [5, 6] have been reported. However, materials problem of MgB_2, such as a naturally-formed thick insulating top layer, did not allow an easy and reliable tri-layer fabrication

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technology in spite of the relatively long coherence length. Such a restriction naturally turned the researchers' attention toward alternative solutions. Among them were weak link type Josephson elements fabricated by focused ion beam (FIB) or electron beam (EB). Nanoscale scratch [7] or contamination [8] across microbridges have been made. FIB-patterned nanobridges have also been reported [9]. However, even though traits of quantum effects, such as SQUID modulation, were observed in some of those weak links, current-voltage curves were far from the resistively-shunted-junction (RSJ) type Josephson junction characteristics. In this work, we have studied fabrication of MgB_2 nanobridges by FIB and their superconducting transition properties: the current-voltage characteristics and the temperature dependent critical current.

II. Experimental results and discussion

Our films were made by a hybrid physical chemical vapor deposition (HPCVD) method and the detailed fabrication procedure and the film properties are described elsewhere [10]. For the nanobridge fabrication we used highly granular and columnar films with a typical grain size of 200 nm ~ 1 μm across and a thickness of 600 nm.

To save the beam time of FIB, prior to the nanobridge patterning a standard photolithography with an argon ion etching technique was used to pattern the MgB_2 film into 8 μm-width lines, which were subsequently milled to nanobridges by focused ion beam (FIB). The nanobridge was of the size of 100 nm in width and length and was confined within a grain. Unlike our previous study on the intergrain nanobridge, in this work we deliberately avoid grain boundaries in the bridge to investigate the properties of intragranular nanoconstriction. Fig. 1 shows a scanning electrom microscope (SEM) image of the FIB-fabricated intra-grain nanobridge. As shown in the figure the bridge is well-defined with edges whitened due to FIB damage and redeposition.

Current-voltage (I-V) curves of the bridge measured at different temperatures are shown in Fig. 2. The

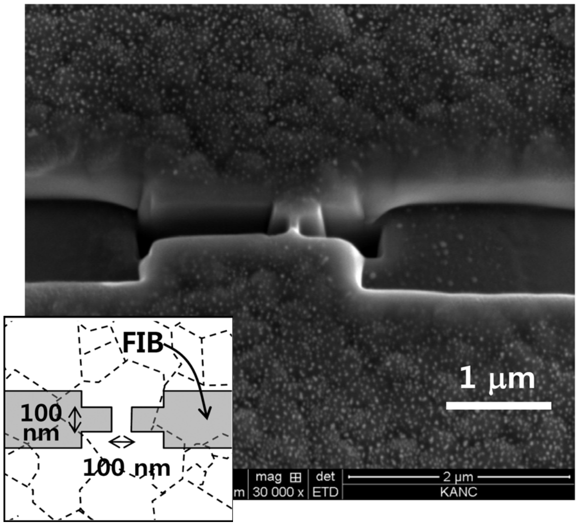

Fig. 1. Scanning electron microscope (SEM) image of the FIB-fabricated intragrain nanobridge. The lower left insert is the plan for the FIB etch.

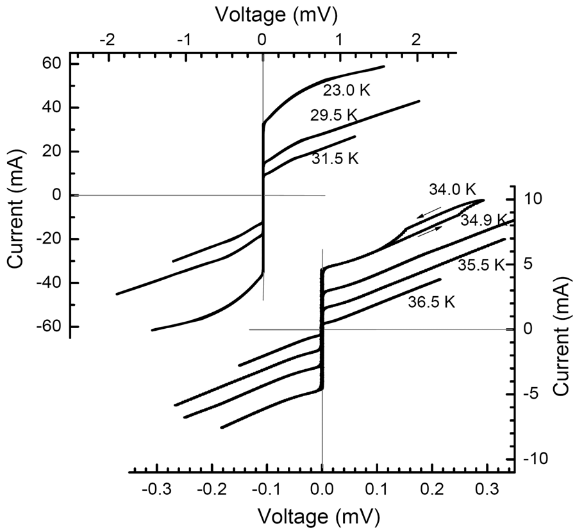

Fig. 2. Current-voltage curves of the nanobridge measured at different temperatrures. The curve shows RSJ-like behavior at 36.5 K and flux-flow effects with two-step transition in the resistive state.

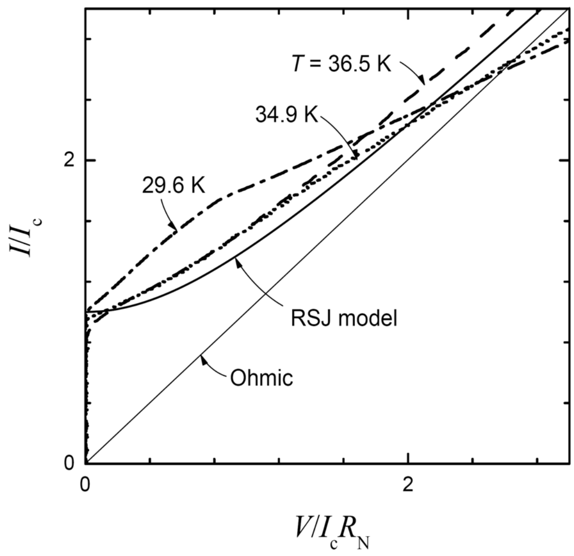

Fig. 3. Current-voltage curves normalized with respect to the critical current, I_c, and the normal state resistance, R_N.

curve resembles the RSJ model at 36.5 K, and shows a typical flux-flow type behavior with decreasing temperature. At low temperatures, a two step transition in the resistive state is shown, which is believed to be due to a multichannel flux flow effect.

To investigate the details of I-V characteristics, the curves were normalized with respect to the critical current I_c, and the normal state resistance, R_N, and some of them are shown in Fig. 3. I_c and R_N are 0.43 mA and 57 mΩ at 36.5 K, 3.0 mA and 44 mΩ at 34.9 K, and 14.4 mA and 41 mΩ at 29.6 K, respectively. R_N at 29.6 K was obtained from the slope of the first transition in the I-V curve. As described above, at 36.5 K the curve is very close to the RSJ model over all the voltage range. With decreasing temperature, the curve shows heating effect at 34.9 K and a two-step resistance transition at 29.6 K. Except near T_c, all the curves showed large excess currents due to the flux flow effect. The flux flow effect has also been observed in our previous study on the I-V curves of strongly-coupled intergrain nanobridges [11].

At low temperatures, the bridge width is much larger than the coherence length, thus vortex and antivortex pairs are generated by the transport current on both edges, at which the current distribution is peaked, and accelerated toward the middle of the bridge by the Lorentz force. The flux flow I-V has the form of $I = I_p + V/Z$ [12]. I_p is the barrier current for the flux entry into the bridge and is equal to the excess current. Z is the impedance of the flux flow which is determined by the normal state conductivity and the coherence length, and is measured as R_N. As shown in Fig. 2 and 3, the curves at low temperatures are determined by the flux flow effect. Traits of Josephson coupling through the bridge are shown only very near T_c.

In Fig. 2, the I-V curve shows a two-step resistive transition below 31.5 K. The two resistive states have slopes differing approximately by a factor of 2: 47 mΩ and 77 mΩ at 31.5 K, and 41 mΩ and 83 mΩ at 29.6 K. This two-step resistive transition is believed due to development of two flux-flow channels with approximately equal impedance.

We also obtained the temperature-dependent critical current data (Fig. 4). Near T_c, where traits of Josephson effect are observable, the data are more like a normal barrier junction. As T approaches T_c,

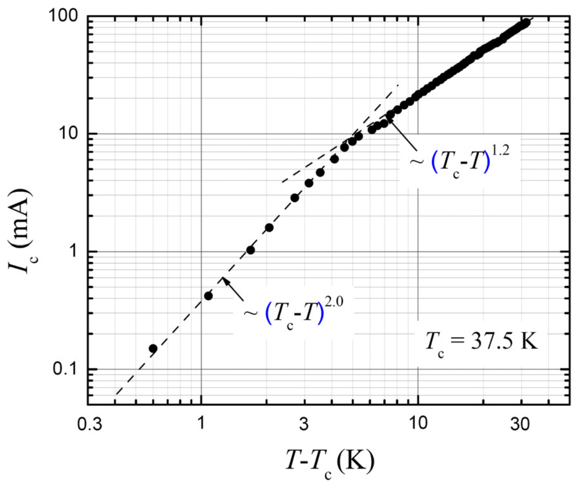

Fig. 4. Critical current versus temperature. Note that the data show a normal barrier junction property near T_c, and a film-like property at low temperatures.

the coherence length becomes comparable to the bridge dimensions and thus the bridge enters the single-phase regime, in which Josephson effect has a significant contribution to the transport. The 'single-phase state' near T_c in our sample shows a normal barrier property. At low temperatures, the data show a film-like behavior for which the exponent is 1.5 [13]. At low temperatures the bridge dimensions are much larger than the superconducting coherence length and the bridge is the same as a wide film in the dimensional point of view.

III. Conclusion

We have fabricated intragrain nanobridges from MgB_2 films by a focused-ion-beam etching technique and studied their transport properties. Measured current-voltage characteristics of the bridge showed a large flux-flow effect at all temperatures with a small contribution from the Josephson coupling near T_c. Low-temperature curves showed a two-step resistive transition which is believed to be due to a two-channel flux-flow effect. The temperature- dependent critical current data showed a normal barrier property near T_c and a film-like behavior at low temperatures.

Acknowledgments

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