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Energy Gap of MgB_2 from Point Contact Spectroscopy

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포인트 접촉에 의한 MgB_2의 에너지 간격

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Abstract

We performed the point contact spectroscopy on newly discovered superconductor MgB_2 thin films with Au tip. In the point contact spectroscopy of the metallic Sharvin limit, the differential conductance below the gap is twice as that above the gap by virtue of Andreev Reflection. After some surface cleaning processes of sample preparation such as ion-milling and wet etching, the obtained dI/dV versus voltage curves are relatively well fitted to the Blonder-Tinkham-Klapwijk (BTK) formalism. Gaps determined by this technique were distributed in the range of 3meV~ 8meV with the BCS value of 5.9meV in the weak coupling limit. We attribute these discrepancies to the symmetry of the gap parameter and the degradation of the surface of the sample. We also present the temperature dependence of the conductance vs voltage curve and thereby the temperature dependence of the gap.

Keywords : point contact spectroscopy, magnesium diboride

The newly discovered superconductor, magnesuim diboride(MgB_2) fascinated people in the field of superconductivity with its high critical temperature of 39K[1]. The isotope effect experiment strongly implies that the phonon coupling is important for the superconducting mechanism in this material. In spite of its simple stoichiometry and structure, the value of gap parameter is currently very much in controversy. There have been many reports about the point contact and tunneling spectroscopy soon after the discovery of the superconductivity of MgB_2. But, unfortunately, gap values varied from work to work leaving little consensus on the energy gap. Schmidt et al.[2] obtained the gap values of 4.3 meV~4.6 meV from the tunneling spectroscopy and the point contact spectroscopy. Rubio-Bollinger et al.[3] used a scanning tunneling microscope to measure tunneling into small grains of MgB_2 embedded in gold matrix. A good fit was found to the BCS model with a s-wave symmetry gap value of 2meV. Sharoni et al. [4] used STM to measure a bulk sample of MgB_2 and they also found a good fit to a BCS model with an isotropic order parameter of a larger gap values of 5~7 meV. Kohen et al. [5] performed the point contact experiment to find the dI/dV curves are well

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described in the BTK formalism [6] with an s-wave symmetry and find the gap values of 3~4 meV.

One can safely obtain the energy gap and the gap anisotropy from the tunneling spectroscopy if there is such an anisotropy in the energy gap. However, surface degradation and lack of a decent size high quality single crystal limit the successful tunneling measurement in this material. On the other hand, one can get a glimpse of the energy gap from the point contact on a thin film if the surface of the MgB_2 is in decent shape.

In this report we present results of the point contact spectroscopy onto a MgB_2 thin film in the metallic Sharvin limit.

Point contact spectroscopy is the simple and direct measurement technique with high resolution for gap value of a superconductor. Different from tunneling spectroscopy, this technique uses the Andreev reflection [7] which is a well known phenomenon in superconductivity. Andreev reflection is a phenomenon that occurs at the interface between superconductor and a normal metal. In the highly simplified model, the process can be described as follows. When an electron is incident to the normal metal – superconductor (NS) interface from the normal metal with energy smaller than superconducting gap, it must condense to Cooper pair in order to transfer into the superconductor. So it combines with its partner (electron with the opposite momentum and spin) and a hole is retro-reflected into the normal metal. In this way, an electron changes to an electron pair at the NS interface and conductance below the superconducting gap becomes twice as that above the superconducting gap.

The MgB_2 films used in this experiment are fabricated in LG-Elite and the growth technique is reported already elsewhere [8]. The magnetization versus temperature curves are shown in Fig. 1. Critical temperature from the magnetization curve is about 38 K. Before the point contact measurement, we cleaned the sample surface by ion-milling the top layer of a few tenth nm and then followed by the wet etching in HCl: ethanol=1:100 solution.

The tip used in this experiment was Au with its tip diameter smaller than 5μm and the metallic contact between the tip and sample is controlled by using a differential micrometer with a resolution of 1 μm. The details of this technique and the experimental setup are found in refs. [9] and [10].

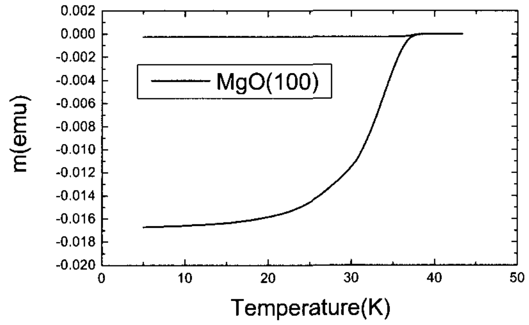

Fig. 1. Magnetization versus Temperature curve of MgB_2 thin film on MgO(100) substrate

Conductance versus voltage curves and current versus bias voltage curves were obtained simultaneously using the standard 4-probe lock-in technique. The point contact experiment was performed at 4.2 K usually. For the temperature dependence of the energy gap value, we varied the temperature from 40 to 4.2 K. We found that the I-V curves were, in general, well described by the BTK model with very low Z (related to interface transparency) and no smearing factor. The normalized conductance within the gap value is coming very close to 2 as expected from BTK model. And yet there appears a significant discrepancy such as the appearance of the dip structure at the position of the gap as shown in the figure 2. Depending on the sample, the height of the normalized conductance peak also deviated significantly from the expected value of 2. In most cases, the normalized conductance is below 2. But, sometime depending on the contact condition, it goes beyond 2, which is quite abnormal within the frame of BTK model.

In Fig. 2 we show a typical dI/dV versus V curve which shows double peaks due to the quasiparticle tunneling (Z represents the portion of quasiparticle tunneling). In addition, there appears yet unexplained dip structure at just above the gap position.

From the best fit, we obtained the temperature dependence of the energy gap as well as the contribution from the quasiparticle tunneling, Z.

Fig. 3 shows the distribution of energy gap peaks and dips over ~100 measurements in MgB_2. From the fact that the peak positions show more population at 2~3 meV and 5~6 meV, it may be thought that MgB_2

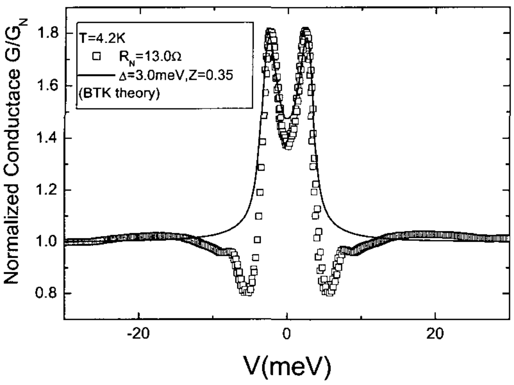

Fig. 2. Conductance versus bias voltage curve of MgB_2 thin film at 4.2 K. The solid line is BTK fitting curve with Δ=3.0 meV and Z=0.35.

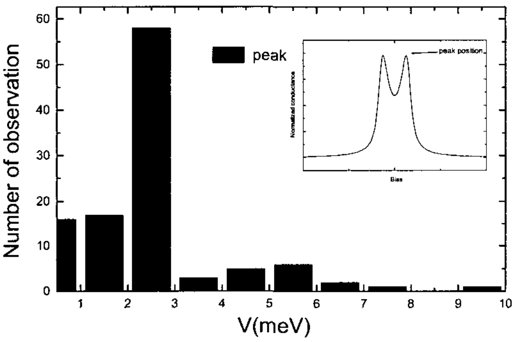

Fig. 3. Distribution of peak position (~thought as gap value) observed in a lot of point contact experiments.

has two energy gaps but we think that theory can't explain the distribution of gap value obtained at different values.

Temperature dependent variation of normalized conductance curves are shown in Fig. 4. Note the change in the height of normalized conductance peak as the temperature increases. The quasiparticle contribution for the best fit to BTK model yields Δ =3.0, 3.1, 2.9, 2.0 meV, Z=0.35, 0.31, 0.22, 0.38 for T=4.2 K, 7.4 K, 10.2 K, 16.6 K, respectively.

In Fig. 5 we show the temperature dependence of the gap value obtained from the point contact experiment and the BCS Δ(T) fitting curve for comparison. We found that the curve is well fitted to the BCS weak coupling limit but with Tc=19.8 K and Δ(0)=3 meV. This value of T_c is much smaller than

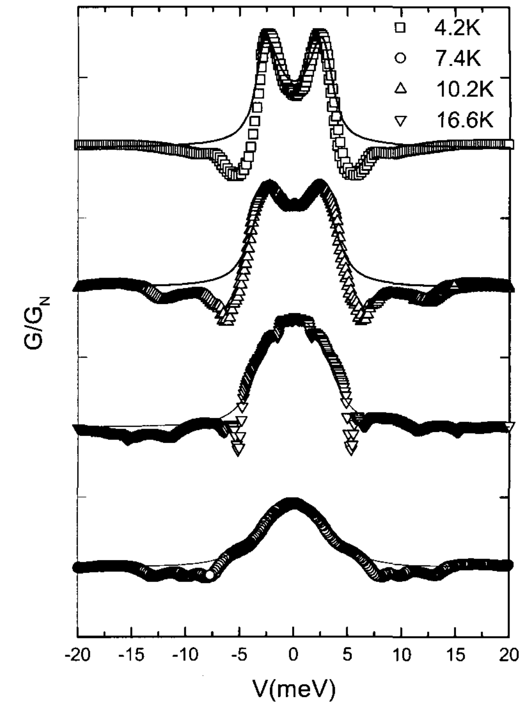

Fig. 4. Variation of normalized conductance versus bias curve (symbol) and fitting curve by BTK model at each temperature (solid line). Normalized conductance curves are shifted by 1 for clarity.

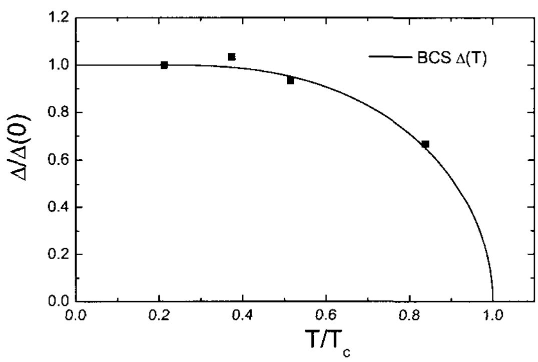

Fig. 5. Δ(T) (■) of MgB_2 and BCS calculation (solid line).

the known value of 39K but is consistent with the fact that above 20 K we could not observe Andreev and reflection hence the resulting enhancement of conductance below the gap.

For these discrepancies, we suggest two possible scenarios. One is the possibility of the anisotropic gap symmetry of MgB_2. There are several reports that discuss the gap symmetry of MgB_2 to be anisotropic s-wave. S. Haas et al.[11] proposed a model of an anisotropic s-wave superconductivity to describe the thermodynamic and optical response in sintered MgB_2 wires with the following form;

$$\Delta(\vec{k}) = \Delta(\frac{1+az^2}{1+a})$$

where the parameter a determines the anisotropy and z=cos θ, and θ is the polar angle. They assumed $\Delta_{min}/\Delta_{max}=0.5$ and found that it described those properties well. Chen et al. [12] also suggested the anisotropic s-wave gap symmetry to explain the data of tunneling spectroscopy on MgB_2 thin films. They obtained the results that $\Delta_z \sim 8.0$ meV and $\Delta_{xy} \sim 5.0$ meV from their data. From the magnetization measurement of partially oriented crystallites, O. F. de Lima et al. [13] found the anisotropy ratio H_{c2}^{ab} / H_{c2}^{c} to be 1.73. Also from the magnetization data for the c-axis oriented films, Patnaik et al. [14] obtained the anisotropy ratio of 2. And very recently, Simon et al.[15] obtained the evidence for the anisotropic gap from the experimental data of the conduction electron spin resonance (CESR) and magnetization. They obtained 6~9 for the anisotropy ratio. Also in our measurements, we found some distribution of gap values within 3 ~ 8 meV as shown in Fig. 3. In Fig. 6, spectroscopy data are shown, which is fitted well to the BTK formalism with Δ = 4.9 meV and Z=0. Because our samples are thin films with random orientation, we think that the probed gap value may be different from point to point and that this distribution is an evidence for the anisotropy of gap.

In other scenario, these differences and distribution of gap value can be explained by the degradation of the surface of the samples or the surface effect. In Refs. [2] and [3], the authors probed gap values smaller than BCS value of 5.9 meV corresponding to T_c=39 K(4.3 ~ 4.6 meV in [2] and 2 meV in [3]). They attributed the difference to the chemically-modified surface layer and degradation of samples. But because we started the measurement within 5 minute after the surface cleaning process mentioned above, we think that those surface effects were not serious.

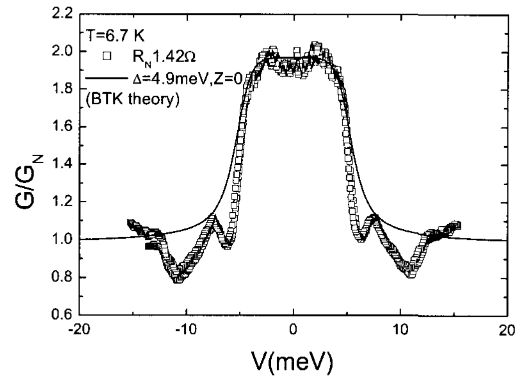

Fig. 6. Conductance vs bias curve of MgB_2 thin film at 6.7K. The solid line is BTK fitting curve with Δ=4.9meV and Z=0.

In conclusion, we performed the point contact measurement on MgB_2 thin films and obtained the temperature dependence of gap values. The spectroscopy data are rather well described by the BTK model and the temperature dependence of the gap value fits well the BCS formula with T_c=19.8 K and $\Delta(0)$ = 3 meV. And we observed some distribution of gap values in the range of 3~8 meV,which thought to be due to the anisotropy of superconducting gap of MgB_2.

Acknowledgements

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