Far-Infrared Optical Reflectance Spectra in Sintered MgB$_2$ Ceramics

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Abstract

Optical reflectance spectra $R(\omega)$ of sintered MgB$_2$ ceramics were observed for $\omega = 30 \sim 110$ cm$^{-1}$ at $T = 5 \sim 47$ K. A significant raise in $R(\omega)$ below 110 cm$^{-1}$ is observed below $T_c$, which can be attributed to the evolution of the superconducting energy gap. The results of the calculation of $R(\omega)$ at $T = 0$ K for anisotropic superconductors qualitatively reproduce the observed spectral shape, which suggests that MgB$_2$ is an anisotropic superconductor.

Key words: MgB$_2$; optical properties; far-infrared spectra; anisotropy

1. Introduction

The recently discovered superconductor MgB$_2$ with $T_c$ of 39 K is of great current interest [1]. However, there is no consensus yet about the nature of its superconductivity such as size, number and anisotropy of the order parameter [2].

Optical reflectance spectra $R(\omega)$ can be calculated using optical conductivity $\sigma(\omega)$. In order to describe $\sigma(\omega)$ of MgB$_2$ in the normal state, we used the Drude model; $\sigma(\omega) = \epsilon_0 \omega_p^2 / (\gamma - i\omega)$, where $\epsilon_0$, $\omega_p$ and $\gamma$ are the dielectric constant in vacuum, plasma frequency and dumping constant, respectively. The value of $\gamma$ is given by $\gamma = \epsilon_0 \omega_p^2 \rho$, where $\rho$ is the value of the electrical resistivity. The value of $\omega_p$ was reported to be $\sim 13600$ cm$^{-1}$ [3], and the value of $\rho$ at $T = 40$ K in our samples was $\sim 8.3 \ \mu\Omega cm$. Therefore, the value of $\gamma$ at 40 K in our samples is estimated to be $\sim 30$ cm$^{-1}$, which is smaller than the value of 2$\Delta(0)$ estimated above. This result suggests that MgB$_2$ is not a dirty-limit superconductor.

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is not a dirty-limit superconductor, we assumed $\omega_n = \omega_p = 13600$ cm$^{-1}$ at $T = 0$ K. The calculated $R(\omega)$ spectrum at $T = 0$ K is shown in Fig. 1 as a solid curve.

A prominent feature of a solid curve in Fig. 1 is the evolution of a sharp reflectance edge at $\omega = 2\Delta(0)$. Therefore, it can be expected that $R(\omega)$ of MgB$_2$ also exhibits the reflectance edge at $\omega = 2\Delta(0)$ at sufficiently low $T$, if it has an isotropic order parameter. In this paper, we report on a study of the $R(\omega)$ of sintered MgB$_2$ ceramics for $\omega = 30 \sim 110$ cm$^{-1}$ at $T = 5 \sim 47$ K.

2. Experimental

MgB$_2$ ceramics were sintered under high pressure of 3.5 GPa at 1200 C for 2 hours. $T_c$ of the samples was 39 K. The sample surface was polished mechanically to obtain mirror-like surface. FIR optical reflectance spectra $R(\omega)$ were measured using a BOMEM DA8 Fourier-transform interferometer with a Hg arc lamp source and a Si:B bolometer. The spectral resolution was 0.5 cm$^{-1}$. The incident FIR radiation was nominally unpolarized, and was introduced normal to the sample surface for the measurement.

3. Results and Discussion

$R(\omega)$ observed at $T = 5 \sim 36$ K normalized by that observed at $T = 47$ K are shown in Fig. 2. Interference fringes in the spectra are due to multiple internal reflections within the optical window of the Si:B bolometer. A significant raise in $R(\omega)$ below $T_c$ is observed in Fig. 2 below 110 cm$^{-1}$, which can be attributed to the evolution of the superconducting energy gap. However, we could not observe the emergence of the significant reflectance edge within the region of $\omega$ explored in this work. Therefore, the results suggest that the order parameter of MgB$_2$ is not isotropic.

In this work, we assume that the order parameter of MgB$_2$ has the following uniaxial anisotropy; $\Delta_2 = \Delta_1 + \Delta_2 \cos 2\theta$, where $\theta$ is the angle of $k$ relative to $k_z$. Recently, a new theory to calculate $\sigma(\omega)$ of anisotropic superconductors has been developed [5]. We have applied the theory to calculate $\sigma_1(\omega)$ of MgB$_2$ at $T = 0$ K, where the value of $\Delta_1$ and $\Delta_2$ were assumed to be 30 cm$^{-1}$ and 20 cm$^{-1}$, respectively. The results are shown in the form of the relative conductivity ratio $\sigma_1(\omega)/\sigma_{1n}(\omega)$ in Fig. 3 as solid circles, where $\sigma_{1n}(\omega)$ and $\sigma_{1s}(\omega)$ are $\sigma_1(\omega)$ at $T = 0$ K and $T_c$, respectively. The result of the M-B theory for $2\Delta(0) = 60$ cm$^{-1}$ is also shown in Fig. 3 as a solid curve. By using the result of $\sigma_1(\omega)$ shown in Fig. 3, we have calculated $R(\omega)$ of MgB$_2$ at $T = 0$ K, where the two-fluid model were used for $\sigma_2(\omega)$. The results are shown in Fig. 2 as solid circles, which does not exhibit the significant reflectance edge at $\omega \sim 2\Delta_1$, and qualitatively reproduce the spectral shape of $R(\omega)$ shown in Fig. 2. Therefore, it is suggested that the order parameter of MgB$_2$ is anisotropic.

4. Conclusion

We have measured the $R(\omega)$ of sintered MgB$_2$ ceramics for $\omega = 30 \sim 110$ cm$^{-1}$ at $T = 5 \sim 47$ K. The results of the calculation of $R(\omega)$ at $T = 0$ K for anisotropic superconductors qualitatively reproduce the observed spectral shape, which suggests that MgB$_2$ is an anisotropic superconductor.

References