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]. Size of the order parameter at $T = 0$ K is estimated to be $2\Delta(0) \sim 60$ cm^{-1}, if single isotropic order parameter of $2\Delta(0)/k_B T_c = 3.52$ is assumed.

Optical reflectance spectra $R(\omega)$ can be calculated using optical conductivity $\sigma(\omega) = \sigma_1(\omega) + i\sigma_2(\omega)$. 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 ϵ_0, ω_p and γ are the dielectric constant in vacuum, plasma frequency and dumping constant, respectively. The value of γ is given by $\gamma = \epsilon_0\omega_p^2\rho$, where ρ is the value of the electrical resistivity. The value of ω_p was reported to be ~ 13600 cm^{-1} [3], and the value of ρ at $T = 40$ K in our samples was ~ 8.3 $\mu\Omega$cm. Therefore, the value of γ at 40 K in our samples is estimated to be ~ 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.

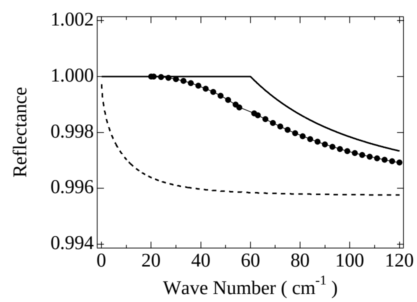

Fig. 1. Reflectance spectra at $T = 0$ K calculated for MgB_2 (solid circles). The solid and broken curves show the reflectance spectra at $T = 0$ K and 40 K calculated by the M-B theory and the Drude model, respectively.

$R(\omega)$ at $T = 40$ K was calculated using $\omega_p = 13600$ cm^{-1} and $\gamma = 30$ cm^{-1}, which is shown in Fig. 1 as a broken curve. The $\sigma_1(\omega)$ and $\sigma_2(\omega)$ at $T = 0$ K of the dirty-limit superconductors with an isotropic order parameter were given by the Mattis-Bardeen (M-B) theory [4]. Although MgB_2 is not a dirty-limit superconductor, we used the M-B theory to calculate $\sigma_1(\omega)$ at $T = 0$ K, where the value of $2\Delta(0)$ was assumed to be 60 cm^{-1}. In order to calculate $\sigma_2(\omega)$ at $T = 0$ K, we used the two-fluid model; $\sigma_2(\omega) = \epsilon_0\omega_s^2/\omega$, where ω_s is the plasma frequency of the superfluid. Since MgB_2

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is not a dirty-limit superconductor, we assumed $\omega_s = \omega_p = 13600\ \mathrm{cm}^{-1}$ 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 $\omega = 30 \sim 110\ \mathrm{cm}^{-1}$ 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 $0.5\ \mathrm{cm}^{-1}$. 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 $110\ \mathrm{cm}^{-1}$, 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 ω 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 ; $\Delta_k = \Delta_1 + \Delta_2 \cos 2\theta$, where θ 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 Δ_1 and Δ_2 were assumed to be $30\ \mathrm{cm}^{-1}$ and $20\ \mathrm{cm}^{-1}$, respectively. The results are shown in the form of the relative conductivity ratio $\sigma_{1s}(\omega)/\sigma_{1n}(\omega)$ in Fig. 3 as solid circles, where $\sigma_{1s}(\omega)$ and $\sigma_{1n}(\omega)$ are $\sigma_1(\omega)$ at $T = 0$ K and T_c respectively. The result of the M-B theory for $2\Delta(0) = 60\ \mathrm{cm}^{-1}$ 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

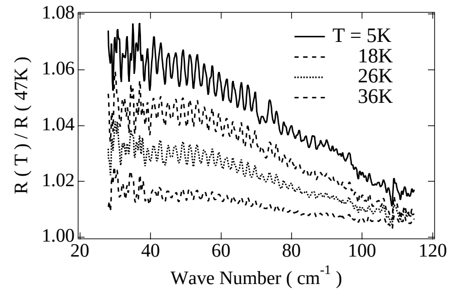

Fig. 2. Reflectance spectra observed at $T = 5 \sim 36$ K normalized by that observed at $T = 47$ K.

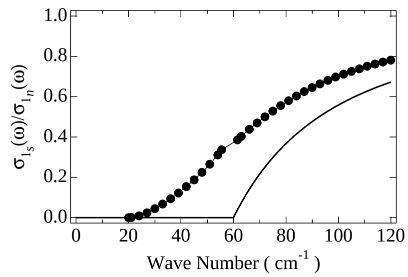

Fig. 3. The relative conductivity ratio $\sigma_{1s}(\omega)/\sigma_{1n}(\omega)$ calculated for MgB_2 (solid circles). The solid curve shows the results of the calculations by the M-B theory.

$R(\omega)$ 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 $\omega = 30 \sim 110\ \mathrm{cm}^{-1}$ 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.

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