Far-infrared optical conductivity of superconducting MgB_2 films

M. A. Carnahan, R. A. Kaindl, and D. S. Chemla
Dept. of Physics, University of California at Berkeley, and Materials Sciences Division, Berkeley National Laboratory, Berkeley, California 94720, USA. Email: RAKaindl@lbl.gov

H. M. Christen, H.Y. Zhai, M. Paranthaman, and D. H. Lowndes
Oak-Ridge National Laboratory, Oak Ridge, TN 37931-6056

The recent discovery of superconductivity in MgB_2 by Akimitsu and coworkers [1] has spawned intense research efforts which are aimed both at realizing applications, possibly easier to achieve than with high-T_C cuprates, and at understanding the nature of the remarkably high superconducting transition temperature. Here, we present first results of far-infrared transmission studies of thin MgB_2 films in the vicinity of the superconducting gap 2Δ. Such measurements allow us to probe fundamental low-energy excitations of the superconducting condensate and the superconducting gap. Terahertz time-domain spectroscopy is employed, which provides directly the complex transmission function without the need for Kramers-Kronig transformations.

Through optical rectification, femtosecond pulses from a Ti:sapphire laser system generate pulsed far-infrared radiation in a broad spectral range up to 12 meV. The electric field transients transmitted through the sample are detected in a 0.5 mm thick ZnTe crystal using electro-optic sampling. Thin films of MgB_2 are grown on Al_2O_3 substrates through e-beam evaporation of boron and subsequent ex-situ annealing in Mg vapor [2]. We present results on a film only 80 nm thick, which exhibits a smooth surface and sharp transition onset (width < 1 K) at $T_C = 30$ K.

The experiments performed at normal incidence and for T = 6 - 50 K reveal the dramatic changes of the far-infrared optical response in MgB_2. As the samples are cooled below T_C, a strong transmission decrease occurs for photon energies < 5 meV, whereas a marked increase takes place at higher photon energies. This behaviour mimics characteristic far-infrared spectral changes of metallic superconductors around their gap energy, as observed for instance in lead films by Palmer and Tinkham [3]. From the complex transmission coefficient $t(\omega)$ we obtain the frequency-dependent complex conductivity $\sigma(\omega)$ using thin-film electrodynamics [4]. As expected for the superconducting state, the imaginary part shows an inverse-frequency response which can be explained by the inductive response of condensed carriers. The temperature dependence follows a shape proportional to that deduced from the penetration depth. The real part of conductivity - connected with absorption processes - exhibits a strong depletion of oscillator strength resulting from the opening of the superconducting gap. Our data show that the absorption onset occurs already for photon energies > 6 meV. This corresponds to a superconducting gap 2Δ about 2 times smaller than expected from BCS theory, imposing severe constraints on proposed simple descriptions for this novel superconductor.

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