Measurement of the energy gap in the compound $YBa_2Cu_3O_{9-\delta}$ on the basis of the IR absorption spectrum

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The long-wave IR absorption spectrum of the high-temperature superconducting ceramic $YBa_2Cu_3O_{9-\delta}$ has been measured by means of a bolometric effect for the first time. The energy gap of this compound has been found from the absorption threshold. The value is $2\Delta/kT_c = 0.6$.

Many studies have already been carried out to determine the energy gap 2Δ, one of the most important characteristics of a superconducting state, of the high-temperature superconductors. Various methods have been used for these measurements: tunneling spectroscopy, IR reflection and transmission spectroscopy, Raman-scattering spectroscopy, etc. The values which have been found for $2\Delta/kT_c$, however, differ greatly from study to study; in the lanthanum ceramics, for example, they range from one to ten. Each of the methods which has been used runs into some difficulties of its own.

One of the most direct measurement methods, in which the absorption threshold is determined by the value of 2Δ (Ref. 1), is IR spectroscopy. So far, either the reflection spectra or the transmission spectra have been measured for the superconducting ceramic—not the absorbed-power spectrum directly. In such an approach, a determination of 2Δ requires appealing to data calculated from the BCS theory, whose applicability to the particular material is uncertain. Furthermore, other difficulties arise in such experiments. The reflection coefficients in the superconducting and normal states differ by only a few percent; the results depend on the surface properties and the relative volume of the superconducting phase in the ceramic; the structural feature in the transmission spectrum is rather poorly defined; the porous structure of the material leads to a parasitic transmission of light; etc.

We have made use of the radiative heating of a sample to measure the absorption spectrum over the wavelength range from the short millimeter region to the IR region. From the absorption threshold we have directly determined the value of 2Δ for the ceramic $YBa_2Cu_3O_{9-\delta}$.

The test samples are disks 5 mm in diameter and 1 mm thick with $T_c \cong 94$ K and a transition width $\Delta T_c = 2$–3 K. The sample is placed in an evacuated cavity and held in place by a suspension with a selected thermal conductivity at the end of a metal waveguide with a cone. The entire structure is placed in a cryostat, in which the temperature can be varied from 1.5 to 300 K. For the measurements we use a spectrometer using backward-wave tubes[2] over the range 5–40 cm^{-1} and an IR spectrometer for the range 30–400 cm^{-1}. The incident radiation heats the sample as it is absorbed (a bolometric effect). The temperature change ΔT is proportional to the

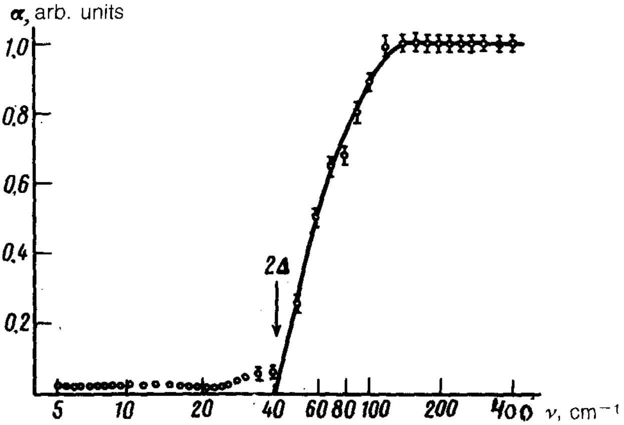

FIG. 1.

absorption coefficient. The radiation is modulated at a frequency of 10 Hz, and the value of ΔT at the modulation frequency is measured by a sensitive microthermometer: a germanium thermometer at $T = 1.5$–4.2 K and a p-InSb thermometer at $T = 80$–100 K. The thermometers are cemented to the back of the sample and are carefully shielded by metal foil from direct incidence of the radiation. The power of the incident radiation is measured with an OAP-7A optoacoustic receiver.

Figure 1 shows the behavior of the absorption coefficient for one of the samples according to measurements at $T = 1.6$ K. At $T > 90$ K, the values of the absorption coefficient in the interval 5–40 cm^{-1} and in the interval 200–400 cm^{-1} are essentially the same. The fairly sharp absorption edge at low temperatures makes it possible to determine the value of 2Δ highly accurately. For this particular sample we found $2\Delta = 5.0$ meV, i.e., $2\Delta/kT_c = 0.6$.

This value of $2\Delta/kT_c$ is significantly lower than values which have been reported so far for either lanthanum or yttrium ceramics. In this particular experimental method, we detect a minimum value of the energy gap, in contrast with the ordinary approach, in which an average value is manifested.

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