Thermal Conductivity Study on the Borocarbide Superconductor $LuNi_2B_2C$ under Applied Magnetic Fields

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Abstract

Applied magnetic field dependence of thermal conductivity and the temperature dependences of resistivity and magnetization on the nickel borocarbide superconducting compound $LuNi_2B_2C$ have been measured in the temperature range from 4.2 K to 30 K, under the applied magnetic field range of 0∼80 Tesla. The magnetic field dependence of the thermal conductivity showed characteristic behavior at the lower and the upper critical fields at temperatures below T_c. We present the first temperature dependence curve of upper critical field derived from the results of thermal conductivity measurement of $LuNi_2B_2C$.

Key words: Superconductivity, Thermal Conductivity, Upper Critical field, $LuNi_2B_2C$

The discovery of superconductivity in the quaternary nickel borocarbide compounds, RNi_2B_2C (R=Y or rare-earth), has attracted large interest duo to the coexistence of superconductivity and magnetism in some of these compounds containing rare earth elements[1,2]. Among them, $LuNi_2B_2C$ is the one which has the highest superconducting transition temperature T_c, with no magnetic transition. Since thermal conductivity (*T.C.*) has nonzero value in both normal and superconducting states, investigations on *T.C.* can provide various information on the interplay between electrons and phonons and scattering of the both by defects and impurities. Therefore, the heat transport property in nickel borocarbide superconductors is intimately related to the mechanism of superconductivity. However, there are only several published reports, such as [3], on *T.C.* study for RNi_2B_2C series. In this paper, we present the results of *T.C.* together with those of resistivity and magnetization for $LuNi_2B_2C$, and the first upper critical field curve obtained from the results of *T.C.* measurement.

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Polycrystalline samples of $LuNi_2B_2C$ were prepared by arc-melting method in argon atmosphere. The resulting ingots were then carefully annealed for 72 hours at 1373 K. Powder X-ray diffraction measurement confirmed that the samples were predominantly single phase. Resistivity was measured by the four-probe technique. Magnetization measurement was conducted by using a SQUID (the MPMS-7 made by Quantum Design). Thermal conductivity was measured by the steady-state heat flow method[4] in a twofold vacuum system. Temperature of the whole system was controlled using a Lake Shore Model 340 Temperature Controller with temperature stability better than ±0.05K. The typical size of sample is of $1.50\times1.50\times10.0$ mm^3. Two Cernox thermometers were used to measure the temperature gradient of both ends of the samples. The sensitivity of *T.C.* measurement in the set up was about 0.1 mWcm^{-1}K^{-1}.

Figure 1 shows the temperature dependences of resistivity and magnetization of $LuNi_2B_2C$. The sample has a rather sharp superconducting transition, a low residual resistivity of 2.5$\mu\Omega$cm at the temperature just above T_c and a high residual resistance ratio $RRR =$

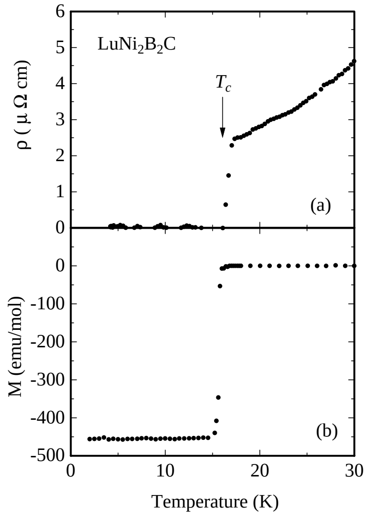

Fig. 1. Temperature dependences of resistivity and magnetization for the sample $LuNi_2B_2C$.

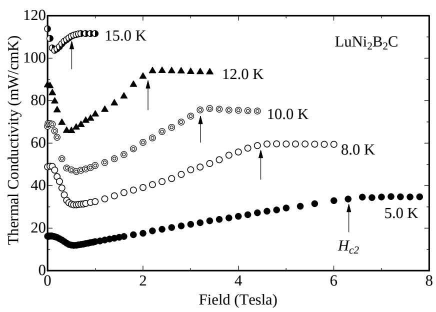

Fig. 2. Magnetic field dependence of thermal conductivity of $LuNi_2B_2C$. The arrows indicate the upper critical fields H_{c2} at different temperatures.

$\rho(300\text{K})/\rho(17\text{K}) \approx 39$, which is almost the same as that reported by Narozhnyi $etal.$[5], indicating that our sample is well prepared and high quality. $T_c = 16.5$ K derived from the resistivity curve is in excellent agreement with that from magnetization measurement, and is in consistent with most of the prior reports[6].

Figure 2 gives the applied magnetic field dependence of thermal conductivity for the sample $LuNi_2B_2C$. At constant temperatures below the superconducting transition T_c, The magnetic field dependence of the thermal conductivity shows characteristic behavior at the lower and the upper critical fields. At very low applied magnetic fields of $H < H_{c1}$, the value of thermal conductivity remains almost constant in the Meissner state. When $H > H_{c1}$, flux vortexes begin to appear in the sample, and as the result of the scattering to the phonons, the thermal conductivity decreases rapidly in the early mixed state. As H increases, the electron

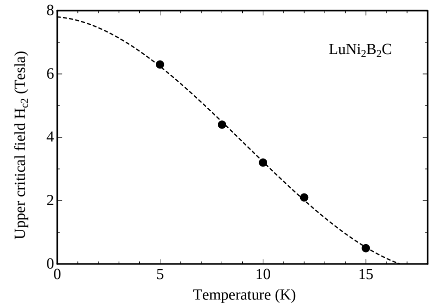

Fig. 3. Temperature dependence of upper critical field derived from the thermal conductivity results of $LuNi_2B_2C$.

contribution to the the thermal conductivity increases, resulting in the increase of total thermal conductivity of the sample. Furthermore, when the applied magnetic field is greater than the upper critical field H_{c2}, the behavior of thermal conductivity is the same as that of normal state. Therefore, it is easy to determine the H_{c2} from the magnetic field dependence of thermal conductivity, as indicated by the arrows in Fig.2.

Figure 3 shows the temperature dependence of H_{c2} curve of $LuNi_2B_2C$ obtained from Fig.2. The dashed line is drawn to guide the eyes by fitting the experiment data with the least square method. The curve of H_{c2} is almost the same as that of $LuNi_2B_2C$ single crystal measured resistively for fixed T adopting the midpoint criterion, reported by Shulga $etal.$[6]. Our result shows the typical features of the nickel borocarbide superconducting compounds RNi_2B_2C, such as $H_{c2} \sim 8 - 10$ Tesla (for R=Lu, Y) and the unusual positive curvature of H_{c2} for $T \geq 0.5T_c$, which could be explained by the two-band model (TBM) approach[6]. This proves that thermal conductivity measurement is of great important in the investigation of superconducting mechanism as well as other effective experiments, such as the resistivity, Hall effect, and magnetization.

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