2 K superconductivity in pyrochlore oxide $Cd_2Re_2O_7$

Zenji Hiroi [a,1], Masafumi Hanawa [a,2]

[a] *Institute for Solid State Physics, University of Tokyo, Kashiwa, Chiba 277-8581, Japan*

Abstract

Superconductivity at $T_c = 2$ K is observed on the polished surface of $Cd_2Re_2O_7$ single crystals which exhibit a bulk superconductivity at 1.0 K. It is suggested that chemical degradation occurred at the surface gives rise to a change in the density-of-state at the Fermi level so as to raise T_c.

Key words: $Cd_2Re_2O_7$; pyrochlore oxide; superconductivity

$Cd_2Re_2O_7$ is the first and only one superconductor found in the family of pyrochlore oxides which have been studied extensively in terms of geometrical frustration on the pyrochlore lattice. Hanawa *et al.* prepared single crystals of $Cd_2Re_2O_7$ and found a sharp superconducting transition at $T_c = 0.97$-0.98 K in their specific heat measurements [1]. In contrast, Sakai *et al.* [2] and Jin *et al.* [3] reported slightly higher T_c values of 1.1 K and 1.2 K on their polycrystalline and single crystal samples, respectively. Moreover, they reported an upper critical field H_{c2} of 0.5-0.8 T, which is much larger than our estimation of 0.29 T [1]. These discrepancy in T_c and H_{c2} may come from the difference in samples and the experimental methods to determine them. We have already reported that the sample dependence of T_c determined by specific heat measurements is small, 0.97-1.04 K, while resistivity measurements give a sccatter between 1 and 2 K [4]. Moreover, the T_c of samples prepared in the polycrystalline form exhibited a broad transition with $T_c = 1.0$ - 1.5 K in the specific heat measurements. Here we report that the T_c of $Cd_2Re_2O_7$ can be raised up to 2 K on the polished surface of the crystal: Bulk superconductivity at about 1.0 K occurs inside the crystal, while the surface layer can become superconducting at higher temperature.

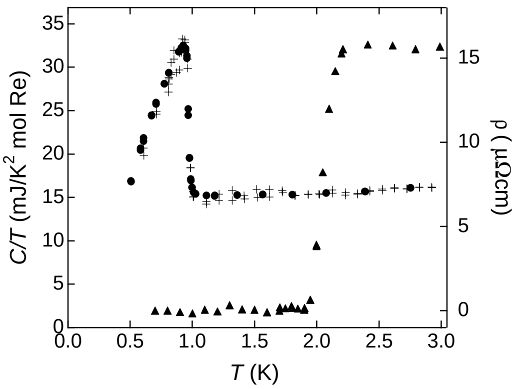

Fig. 1. Specific heat divided by temperature C/T (circles and crosses) and resistivity ρ (triangles) of $Cd_2Re_2O_7$ single crystals showing superconducting transitions at $T_c = 1$ K and 2 K.

Figure 1 shows the temperature dependence of specific heat divided by temperature C/T as well as resistivity ρ. The C/T shows a well-defined λ-type transition at $T_c = 0.97$ K which is defined as the midpoint of the jump. On the other hand, the resistivity measured on a bar-shaped crystal of 1 mm × 2 mm × 0.06 mm that was obtained by polishing another crystal from the same batch exhibits a sharp drop at $T_c = 2$ K. Then, after removal of Au electrods, this polished crystal was examined by specific heat measurements. The results shown in Fig. 1 (marked with cross) exactly traces on

[1] Corresponding author. E-mail: hiroi@issp.u-tokyo.ac.jp
[2] Present address: Department of Applied Physics, Nagoya University, Nagoya, 464-8603, Japan

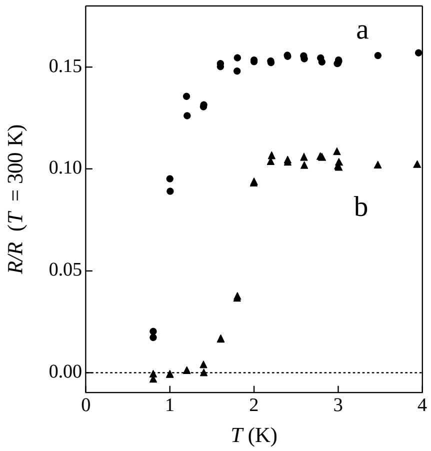

Fig. 2. Resistivity normalized to the value at T = 300 K from a polished crystal. The measurements were performed with a current flow perpendicular (a) and parallel (b) to the polished plane. The latter gives a higher T_c due to surface superconductivity.

the first measurements, giving $T_c = 0.97$ K. There is no anomaly in the C/T curve at 2 K. This fact implies that the T_c of the bulk inside the crystal is always about 1 K, and the 2 K superconductivity must be filamentaly, probably occurs on the polished crystal surface. In contrast, a resistivity drop near 1 K was always observed for as-grown crystals without polishing.

More direct evidence for surface superconductivity was obtained when resistivity was measured in two different electrode configurations with a current flow parallel or perpendicular to the polished surface, as shown in Fig. 2. The T_c was apparently 2 K for the former case, while about 1 K for the latter. This strongly suggests that the voltage drop around 2 K is due to thin surface layers. Therefore, we conclude that the 2 K superconductivity occurs only at the polished crystal surface.

The upper critical field H_{c2} is also dependent on the treatment of crystals. Figure 3 shows the temperature dependence of H_{c2} determined by resistivity measurements on two polished crystals (p1 and p2) and on three non-polished crystals (a1, a2, and a3), as well as that determined by specific heat measurements on an as-grown crystal (a4). The polished crystals show higher T_c and H_{c2} compared with the bulk value for crystal a4, while the as-grown crystals with slightly high T_c also exhibit a large enhancement in H_{c2}. Note that the curve for crystal a3 resembles with that for crystal a4: Before resistivity measurements crystal a3 was chemically etched in a diluted HCl solution, possibly which have taken away a degraded suface layer with a higher T_c.

The origin of the observed enhancement of T_c on the crystal surface is not known. Probably even the surface of as-grown crystals is degraded chemically, and this is

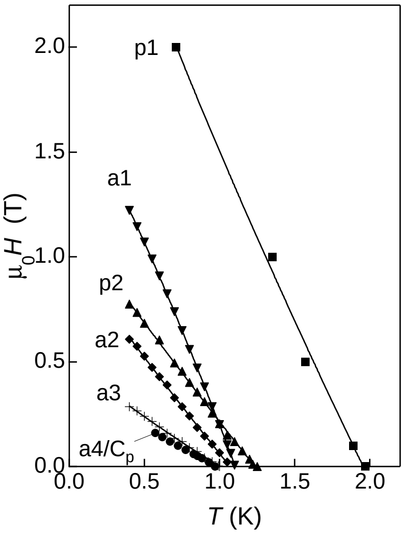

Fig. 3. $H - T$ phase diagram showing the upper critical field determined by resistivity measurements for two polished crystals (p1 and p2) and as-grown crystals (a1, a2, a3), as well as that determined by specific heat measurements (a4).

increased by polishing the crystals. A slight modification of the crystal structure or chemical composition would result in the change of the density-of-state at the Fermi level and thus T_c.

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