Thermodynamic properties of $MgCNi_3$ superconductor

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Abstract

We have measured the magnetic properties on the high quality polycrystalline sample of the recently discovered ternary carbide superconductor $MgCNi_3$. The lower critical field, the upper critical field and the thermodynamic critical field were estimated. The coherence length, penetration depth, and the Ginzburg-Landau parameter were calculated, respectively.

Key words: $MgCNi_3$ superconductor; magnetic property; thermodynamic parameter

1. Introduction

The discovery of 39 K superconductivity in MgB_2[1] initiated a new round of research fever to search new superconductors in the category of intermetallic compounds. Recently He *et al.*[2] reported the superconductivity in $MgCNi_3$ at critical transition temperature 8 K. Structurally $MgCNi_3$ provides the chance to compare the overall perovskite-like superconductor including HTSC and the conventional $Ba1 - xK_xBiO_3$[3]. The large ratio of Ni (60% in molar ration) makes $MgCNi_3$ an intriguing compound to investigate the possible magnetic interaction with superconductivity [4]. S. Y. Li *et al.* measured the transport properties of the $MgCNi_3$ at the applied magnetic field and calculated the Hall coefficient, density of states, and the upper critical field. Their experiments suggest that the $MgCNi_3$ is a conventional type-II superconductor with coherent length $\xi_0 \sim 47$Å[5]. The NMR experiment [6] showed $2\Delta/K_BTc$ is 3.2 comparable to the weak-coupling BCS value 3.53, suggesting that $MgCNi_3$ might be an isotropic s-wave superconductor. The thermodynamic property of the superconductor in many ways manifests the pairing symmetry at the low-lying states at the temperature region below Tc. Here we report the magnetic measurements on $MgCNi_3$ superconductor from which the critical field $Hc1$, $Hc2$, and Hc were obtained and the coherence length, penetration depth and the G-L parameter were calculated.

2. Experimental

The $MgCNi_3$ compounds were prepared using the solid reaction method similar to that described in ref [2]. The starting materials were magnesium powder (2N purity, 80mesh), glass carbon (Alfa, 3N purity), fine nickel powder (3N purity, > 300 mesh). The raw materials were carefully mixed and pelletized, then sealed in an evacuated quartz tube. The compounds were sintered at 600°C for a short time (30 min) before further treated at 900°C for 3 hr. The phase is pure as checked by powder x-ray diffraction. The microstructure, composition and morphology were studied by HRTEM, SEM-EDAX. The superconducting properties were qualified and measured magnetically using dc SQUID or Mag-Lab magnetometer and electrically using the four-probe method.

3. Results and Discussion

Figure 1 shows the superconducting transition curves of the $MgCNi_3$ sample. Magnetic moment mea-

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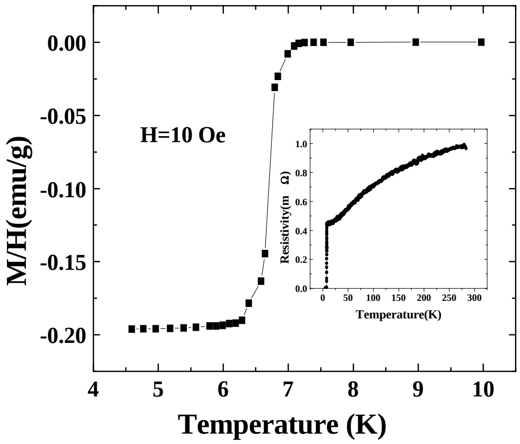

Fig. 1. The superconducting transition of the $MgCNi_3$ sample.

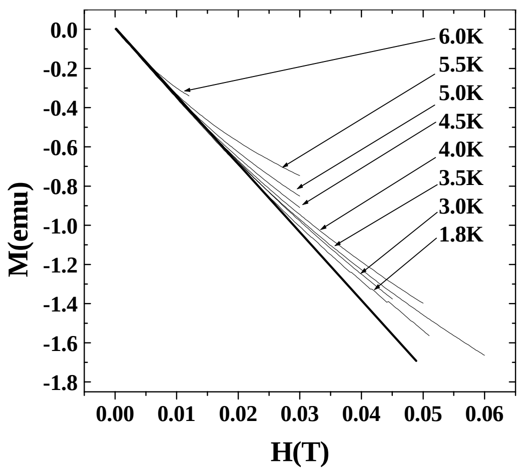

Fig. 2. The initial magnetization of the $MgCNi_3$ compound.

surements of the sample in ZFC model indicate a rather steeper superconducting transition. The inset of Fig.1 is the R-T curve showing a sharp superconducting transition with the critical temperature around 8 K. The nearly flat shielding signal at low temperature indicates the high quality of the sample in terms of homogeneity and improved intergrain links, which make the sample more suitable to conduct the bulk property measurements. Figure 2 provides the initial magnetic moments versus applied field at various temperatures. Employing the first ten points, a Meissner line was drawn using the least-square fit. This sets the linear base line to determine the $Hc1$ where the experimental data deviate from the extrapolated Meissner relation. The value of thus obtained $Hc1$ is threshold dependent. Choosing criteria 0.3×10^{-4} emu deviation from the linearity, the $Hc1$ data of $MgCNi_3$ can be obtained from the initial M-H curve, and thus extrapolated $Hc1(0)$ is 126 Oe.

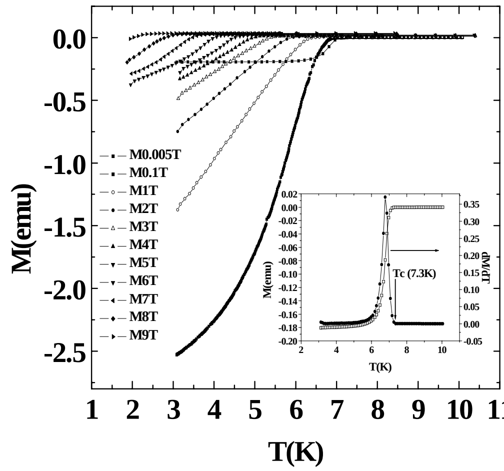

Fig. 3. The dc susceptibility of the MgCNi3 superconductor.

Figure 3 shows a set of measurements of magnetic moment as function of temperature at various of applied field in ZFC model. To define the upper critical field $Hc2$, the magnetic data were differentiated. The Tc value was chosen as the jump point of the dM/dT as shown in the inset of Figure 3. Using the WHH formula, $Hc2(0) = 0.69Tc\,|dHc2/dT|_{T=Tc}$, $Hc2(0)$ = 16 T with Tc =7.3 K is obtained. Assuming an isotropic superconductivity, the coherence length was calculated using the G-L relation $Hc2 = \Phi_0/2\pi\xi^2$. The obtained $\xi(0)$ is 45Å, in good agreement with the result of 47Å from the magnetoresistance measurement[5]. According to $Hc1 = (\Phi_0/4\pi\lambda^2)\ln(\lambda/\xi)$, the penetration depth $\lambda(0)$ was calculated to be $\sim$ 2300 Å. Consequently the Ginzburg-Landau parameter, $\kappa = \lambda/\xi$, is calculated to be about 51. Using the relation $Hc1Hc2 = Hc2\ln\kappa$, the thermodynamic critical field Hc was calculated to be 0.6T.

Acknowledgements

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References

[1] J. Nagamatsu, N. Nakagawa, T. Muranaka, Y. Zenitani, and J. Akimitsu, Nature 410 (2001)63

[2] T. He et al., Nature, 411 (2001)54

[3] R. J. Cava et al., Nature 332 (1988)814

[4] H. Rosner, R. Weht, M. D. Johannes, W. E. Pickett, E. Tosatti, Phys. Rev. Lett., 88 (2002)27001

[5] S.Y. Li et al., Phys. Rev. B 64 (2001)135205

[6] P. M. Singer, T. Imai, T. He, M.A. Hayward and R. J. Cava, Phys. Rev. Lett. 87 (2001)257601