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Superconductivity in aluminum nanoparticles

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Abstract

Nanoparticles of aluminum of 250 Å were prepared in He atmosphere. The superconducting transition temperature (T_c) was determined by magnetic susceptibility and heat capacity. Three speculated superconducting transitions were found at 3.2, 1.8 and 1.5 K in magnetic susceptibility, whereas only one broaden superconducting transition near 1.5 K can be clearly identified in heat capacity measurement, which is considerably higher than the bulk value of 1.16 K. The multiphase transitions are conjectured to be associated to the size or surface effects. The broadened superconducting peak in heat capacity is attributed to the thermodynamic fluctuation of superconductivity and particle size distribution.

Keywords: Nanoparticles; Superconductivity; Heat capacity

1. Introduction

Nanoparticles are found to be different from the bulk materials in some of the physical properties because of their discrete electronic energy levels and surface effects. Reduction of particle size produces substantial changes in the physical properties, one of the examples is the superconducting transition temperature T_c. It would be interesting to investigate the size dependent superconductivity in nanoparticles.

In Al granular thin films, the dependence of superconducting transition temperature on the crystal size and evaporation temperature has been studied [1]. Al granular films of average crystalline size about 1000, 180, and 45 Å, which were evaporated at room temperature, have superconducting transition temperature of about 1.26, 1.6 and 2.3 K, respectively. While the film was evaporated at liquid nitrogen temperature, its superconducting transition temperature becomes 3 K for 45 Å [1]. In the present investigation, Al nanoparticles of average size about 250 Å, were prepared and characterized by X-ray diffraction and HRTEM. The measurements of magnetic susceptibility and heat capacity were employed to study the size effects on the superconductivity of Al nanoparticles.

2. Experimental

Al nanoparticles were prepared by thermal evaporation of Al powder (99.9999 %) on a copper substrate at liquid nitrogen temperature in a high purity He atmosphere. According to X-ray diffraction measurements, Al nanoparticles had the same structure as the bulk and no impurity phase was detected, except the peak broadening due to reduction of the particle size. High resolution transmission electron microscopy (HRTEM) was further employed to study their shapes and size distribution as shown in the inset (a) to Fig. 1. The average particle size was estimated to be about 250 Å. Magnetization measurements were carried out as a function of temperature using the Quantum Design SQUID magnetometer for $T > 1.7$ K and a home made DC SQUID for the range 0.3 to 2 K. Calorimetric measurements between 0.3 and 8 K were performed using the thermal relaxation microcalorimeter in a ^{3}He refrigerator [2].

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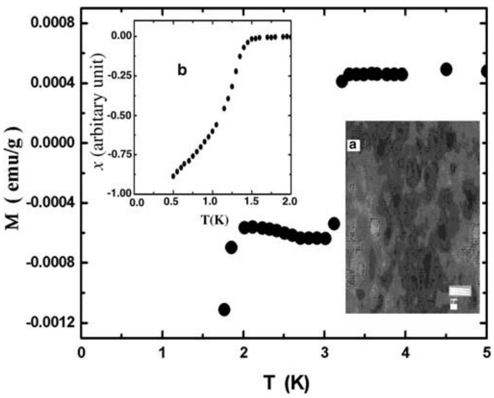

Fig. 1. Magnetic susceptibility versus T curve of Al nanoparticles (250 Å) in the range of 1.7 to 5 K. The measurements were carried out using commercial Quantum Design SQUID magnetometer. Inset (b): In the range of 0.3 to 2 K, magnetic susceptibility curve of 250 Å Al nanoparticle was obtained by our home made DC SQUID magnetometer. The inset (a) shows a HRTEM photograph of aluminum nanoparticle.

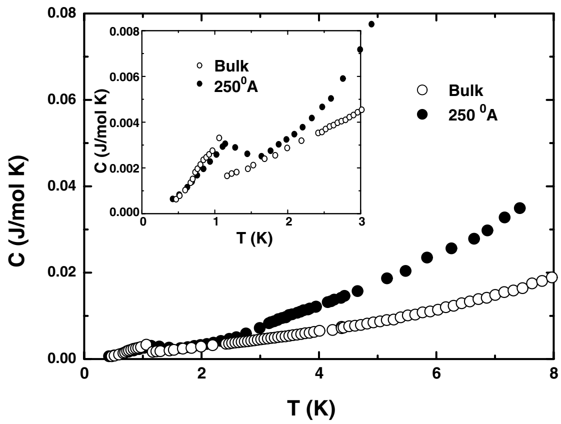

Fig. 2. Heat capacity of aluminum bulk and nanoparticles from 0.4 to 8 K plotted as C versus T. The inset shows the details of the superconducting transition region.

3. Results and discussion

The magnetic susceptibility versus temperature for 250 Å nanoparticles is shown in Fig. 1. The superconducting transitions at 3.2 and 1.8 K were observed using the commercial SQUID magnetometer. Another 1.5 K transition was also observed in the home made DC SQUID, as shown in the inset (b) to Fig. 1. These superconducting transition temperatures were considerably higher than the bulk value of 1.16 K [3]. The temperature dependence of heat capacity for bulk as well as 250 Å nanoparticles are shown in Fig. 2 as C versus T. The aluminum bulk shows a sharp transition in heat capacity, which is a characteristic of bulk supercondutors; whereas Al nanoparticles show a broadened transition, which is stretched from 1.2 to 1.6 K. This broad transition may be originated from the thermodynamic fluctuation near to the superconducting temperature and also from the size distribution of the particles in the specimen [4]. The superconducting transition of specific heat is consistent with the one observed in DC SQUID data at 1.5 K. The enhancement of the above transition temperature is probably due to the increased prominence of low-frequency surface modes. The superconducting transitions observed at 1.8 and 3.2 K in magnetic susceptibility may be due to the surface effects of the particles. The enhancement of superconductivity arises from an increased effective electron–phonon interaction near the surfaces of superconductor as postulated by Ginzburg [5]. The multiphase transitions are concluded to be associated with the size or surface effects of the particles.

4. Conclusion

We had observed that aluminum nanoparticles of 250 Å showed the multiple superconducting transitions at 1.5, 1.8 and 3.2 K, which may be due to the size or surface effects of the particles. The broadened superconducting transitions observed in heat capacity are concluded to be the result of thermodynamic fluctuation of superconductivity and particle size distribution.

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