Conference Paper

Superconductivity in Nanostructured Ga-Ag Eutectic Alloy

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Abstract

The dc and ac magnetizations were studied for the eutectic Ga-Ag alloy embedded into a porous glass with 7 nm mean pore size. The measurements were performed within a temperature range of 1.9 to 10 K which covers the superconducting transition for the nanocomposite. The onset of superconductivity at the magnetic field 10 Oe was found at about 7.1 K which is much higher than in bulk gallium. The phase diagram showed a positive curvature at low magnetic fields. The activation energy of vortex mobility was calculated at different magnetic fields using the ac data.

Keywords: Ga-Ag eutectic alloy, superconductivity, nanoconfinement

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1. Introduction

Superconductivity in low-dimensional systems is in a focus of modern physics because of various promising applications. Nanostructured conventional superconductors can be fabricated by embedding metals or metallic alloys into hard mesoporous matrices such as silica porous glasses and opals. Recently many new and fascinating features were observed for superconducting pure metals under nanoconfinement (see [1, 2] and references therein). In contrast, properties of metallic eutectic alloys embedded into porous matrices were not studied. To overcome this lack of information on superconductivity in confined metallic alloys we performed studies of the dc and ac magnetizations for the eutectic gallium silver alloy embedded into a porous glass with 7 nm mean pore size near the superconducting transition.

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2. Samples and Experiment

The porous glass was obtained by acid leaching of a phase separated soda borosilicate glass. The mean pore size of 7 nm was measured using nitrogen porosimetry. The alloy of the eutectic composition (97% Ga, 3% Ag) was embedded into the porous matrix in liquid state under pressure up to 10 kbar. The filling factor calculated from weighing the empty and loaded matrix was near 85%. The sample for studies was cut in the shape of a plate and thoroughly cleaned from traces of bulk alloy. The sample weight was 12.08 mg.

The dc and ac magnetizations of the glass-alloy nanocomposite were measured using Quantum Design MPMS 3 and PPMS-9, respectively. The temperature dependences of the dc magnetization were monitored with the zero field cooling (ZFC) and field cooling (FC) protocols under different external magnetic fields. Temperature variations of the ac magnetization were monitored with the FC cooling procedure under different bias fields, amplitudes and frequencies of the ac driving field. The ac driving field for measurements under different frequencies was set to 1 Oe.

3. Results and Discussion

The temperature dependences of the dc ZFC susceptibility χ obtained at different magnetic fields from 10 Oe to 7 T are shown in Fig. 1. At 10 Oe the magnetic screening is near full which shows that almost the whole sample is enveloped by superconducting currents. With increasing magnetic field the critical temperature T_c decreases and screening weakens. Such behavior is typical for type II superconductors. The critical field line found from Fig. 1 is depicted in Fig. 2.

As can be seen in Fig. 1, the onset of superconductivity in magnetic field 10 Oe was observed at a temperature which is much higher than in bulk α gallium. We suggest that the increase of T_c is due to different structure of the gallium rich phase in the crystalline alloy [3].

The ZFC and FC curves were found to merge together at a temperature of irreversibility T_{irr} which depends on magnetic field. The irreversibility line is also shown on the phase diagram in Fig. 2. One can see that both the critical field line and irreversibility line show a positive curvature at low fields which then transforms to the ordinary negative curvature with increasing magnetic field. The positive curvature was observed earlier in many unconventional superconductors [4, 5]. Several theoretical

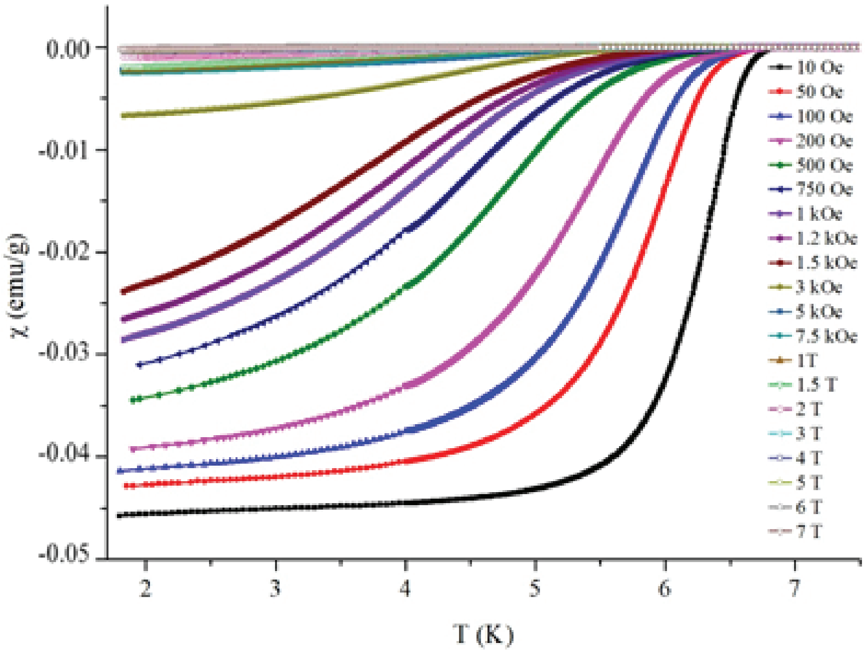

Figure 1: Variations with temperature of the dc susceptibility obtained under the ZFC protocol at magnetic fields shown on the panel.

models were suggested to tread this anomalous sign of curvature (see [6] and references therein). For our nanocomposite sample the most suitable one is related to the geometry of the pore network [6].

The temperature dependences of the real χ' and imaginary χ'' parts of the ac susceptibility are shown in Fig. 3, a and b, respectively. From the data presented in Fig. 3, we found the temperature of the onset of superconductivity T_c' and temperature of the middle of screening T_m at different magnetic fields. Fig. 3, b allowed us to find the temperature of the onset of losses T_c'' and temperature of the χ'' maxima T_p. The corresponding lines are also shown in Fig. 2. One can see that the positive curvature at low fields remains for all the lines. The temperatures T_m and T_p agree well with each other in accordance with the thermally activated creep model of vortex mobility.

The peak position T_p was found to change with frequency. The frequency dependence of T_p follows the Arrhenius law. This allows us to evaluate the activation energy of the vortex creep U_a for various magnetic fields. The field dependence of the activation energy is shown in Fig. 4. At low fields the activation energy decreases weakly with increasing magnetic field. At higher fields U_a drops down, which can be treated as a change from mobility of single vortices, located on the alloy confined particles, to collective movement of vortices.

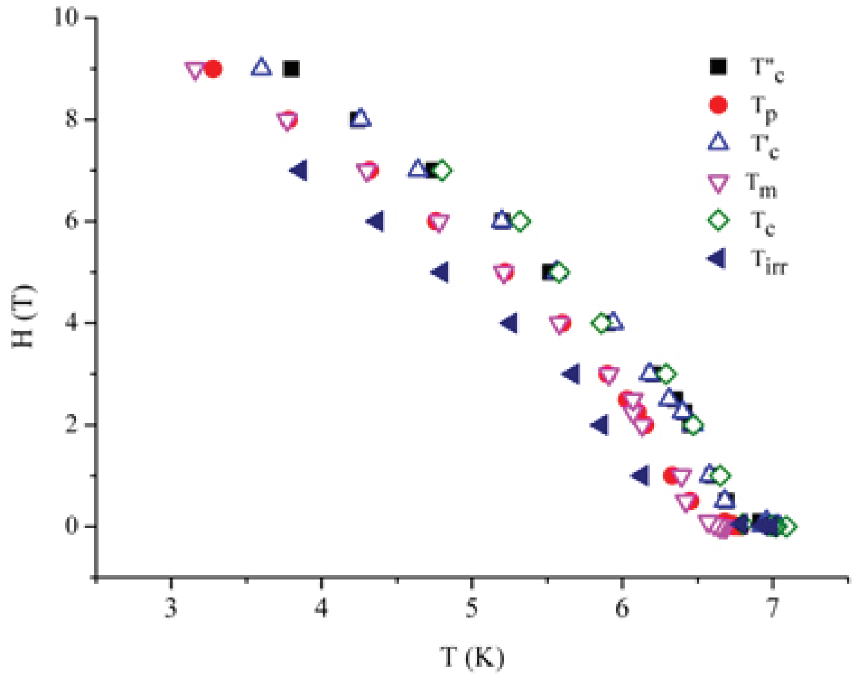

Figure 2: The phase diagram for the lines indicated on the panel.

4. Summary

Studies of the dc and ac magnetizations for the eutectic Ga-Ag alloy embedded into a porous glass yield a complex T-H phase diagram with a positive curvature of the critical and other lines at low magnetic fields. The drastic increase in the temperature of superconducting transition was ascribed to structural changes under nanoconfinement. The activation energy of the vortex mobility was calculated using the ac measurements at various frequencies and was shown to decrease weakly with increasing magnetic field up to about 5 kOe and then to drop down at higher magnetic fields.

Acknowledgements

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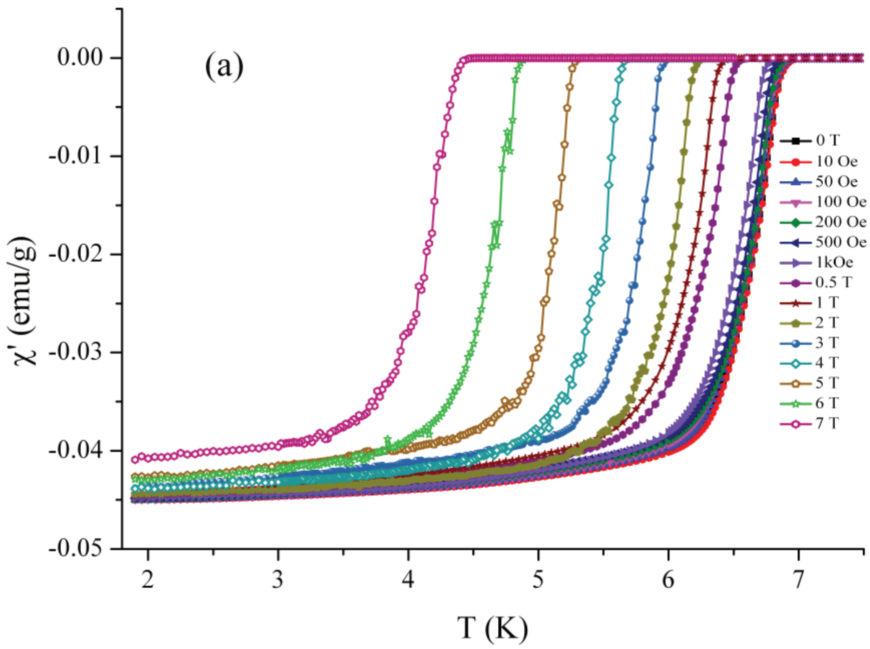

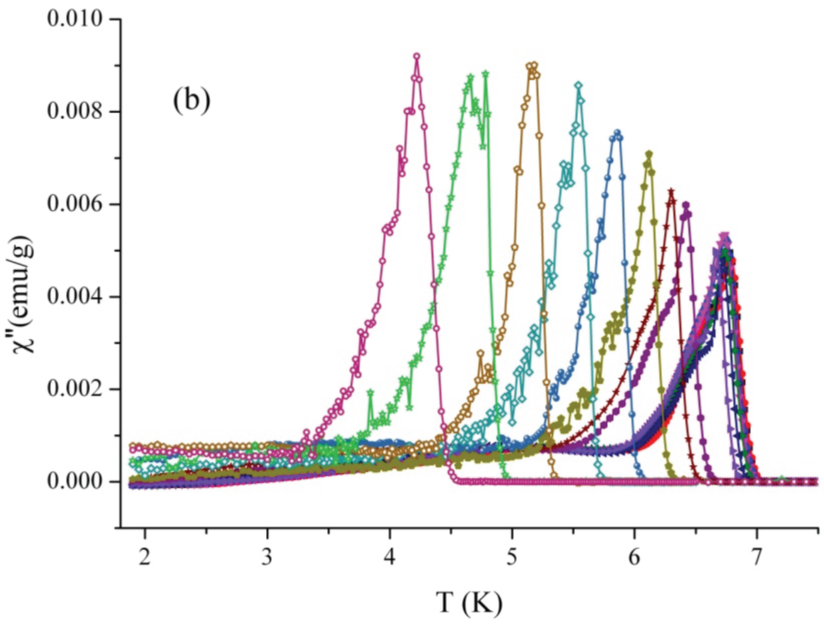

Figure 3: Temperature dependences of the real (a) and imaginary (b) parts of the ac susceptibility obtained at the frequency of driving field 1 kHz and the amplitude 1 Oe.

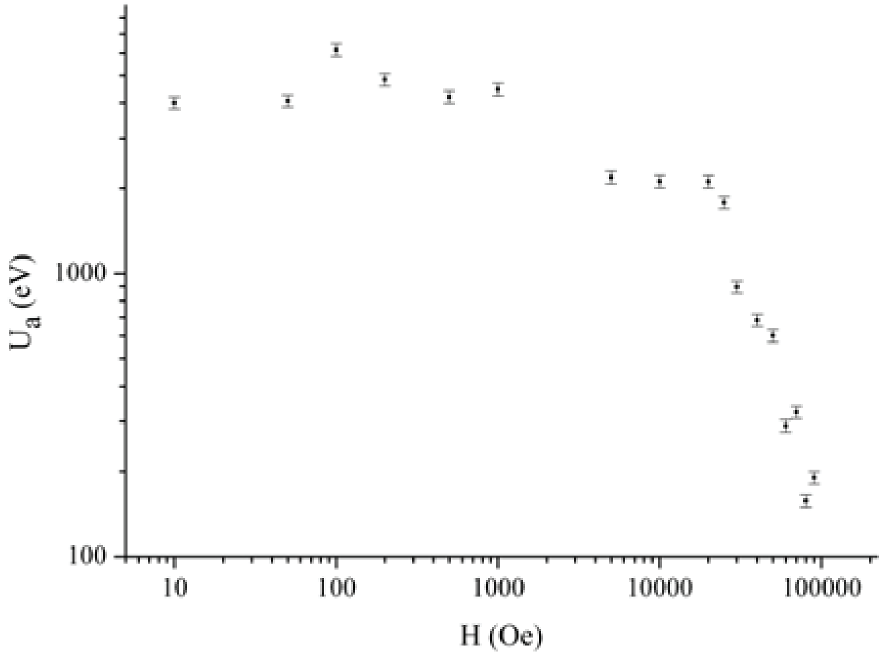

Figure 4: Dependence of the vortex activation energy on the bias magnetic field.

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