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Spontaneous vortex glass transition in Pb/Co nanocomposites

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Abstract – Lead (Pb) films containing homogeneously distributed cobalt (Co) nanoparticles (mean size 4.5 nm) have been prepared with the help of a cluster source. The direction of the magnetic moments (μ_{Co}) of the Co nanoparticles embedded in the Pb matrix is completely random, leading to the absence of macroscopic magnetization M. In-situ resistivity measurements indicate the occurrence of spontaneous vortex phases for H_{ex} = 0 and M=0. Ex-situ magnetic measurements give further evidence for this picture. The magnetization of the films below the superconducting transition temperature depends on the relative directions of μ_{Co} and H_{ex}. This can be explained by the formation of spontaneous vortices in the sample.

Superconductor (SC)/ferromagnet (FM) nanocomposites made from FM Co clusters (mean diameter 4.5 nm) embedded in a SC Pb film (thickness:100 nm) have been prepared by co-deposition of well-defined, in-beam prepared Co clusters and Pb atoms onto a cold substrate (~ 40 K). The low temperature preparation results very high quality Pb film with the transition width of 0.04 K. The transport properties have been measured in-situ in the temperature range of 2-300 K and in external magnetic fields up to 1.2 T. The resistivity data of the films annealed at 300 K indicate the occurrence of spontaneous vortex phases [1] as shown in Fig.1. These phases occur in the absence of an external magnetic field and any macroscopic magnetization (the orientation of the Co cluster magnetic moments μ_{Co} without external magnetic field is completely random) and are caused by the stray field of the FM Co cluster moments only. The V(I) measurements show that the spontaneous vortices have a phase transition from vortex glass (solid) to vortex liquid with increase in temperature (Fig. 2).

Magnetic properties have been measured ex-situ in a SQUID magnetometer. The magnetic data give further evidence for the spontaneous vortex formation showing that the magnetization M of the films below the superconducting transition depends on the orientation of μ_{Co}, which can be changed by applying different external field before cooling down the sample below T_c [2]. These findings can only be explained if we assume that the moment caused by spontaneous vortices depends upon the orientation of μ_{Co}. The different direction of the external magnetic field (parallel or anti-parallel to the moment of the spontaneous vortices) results that we can manipulate the sample to have diamagnetic Meissner effect or paramagnetic Meissner effect.

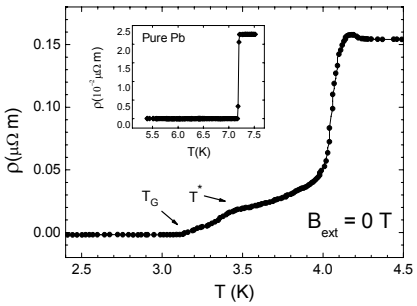

Figure 1: Resistivity as a function of temperature for the Pb/Co nanocomposite without external magnetic field. Inset: A reference sample of Pure Pb.

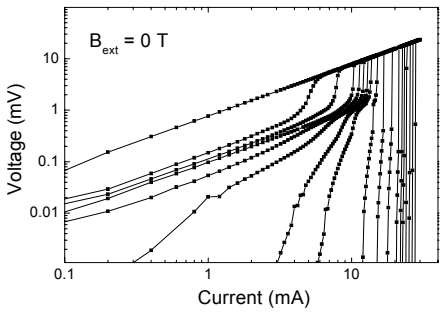

Figure 2: The isotherms of V(I) for Pb/Co nanocomposite with temperature from 2.26 K to 4.2 K without external magnetic field.

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[1] Y.T. Xing et al., Phys. Rev. B **78** (2008) 224524
[2] Y.T. Xing et al., arXiv:0812.0847v1