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Constructive interaction of d^0 ferromagnet with superconductor

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Recently, d^0 ferromagnetism in closed shell oxides containing virtually no magnetic ions has been the subject of a number of theoretical and experimental investigations as a part of the effort to develop suitable materials for spintronic devices [1]. Although its true physical origin still remains to be solved, some surface and/or grain-boundary related defects in the nanostructures are believed to be responsible for d^0 ferromagnetism [2].

In addition, although not well recognized, d^0 ferromagnetism will provide an interesting experimental system for studying superconductor/ferromagnet (S/F) proximity effect. Previously, a variety of S/F heterostructures have been used to investigate the interplay between S and F order parameters [3]. However, the design and fabrication of S/F heterostructures are quite challenging because the magnetic moments in the conventional ferromagnetic materials are usually quite strong and can easy destroy the superconducting state. However, Anderson and Suhl [4] suggested long ago that a weak ferromagnetism should not destroy the superconducting state; rather, superconductivity could survive in a ferromagnetic background provided that the magnetic direction is varied on a scale smaller than the superconducting coherence length, resulting in an inhomogeneous domain-like structure called the cryptoferromagnetic state. Thus, the inherently weak and surface-derived nature of d^0 ferromagnetism makes it an excellent candidate for realizing the cryptoferromagnetic state and the related domain wall effect. In this work, we hence investigate the magnetic properties of MgB_2/MgO composite, in which MgB_2 and MgO phases are responsible for superconductivity and d^0 ferromagnetism, respectively.

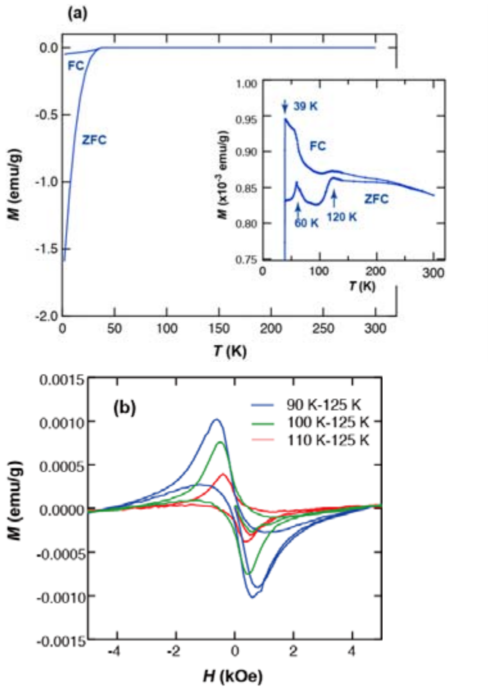

Fig. 1 (a) $M(T)$ curves of the sample measured at 50 Oe. The inset shows an expanded plot in the temperature region above 39 K.(b) Difference between the M(H) loops measured at different temperatures indicated.

The superconductor/d^0 ferromagnet composite was synthesized using solid phase reaction between Mg and B_2O_3 [5]. Figure 1(a) shows the temperature dependent irreversibility of the zero-field-cooling (ZFC) and field-cooling (FC) magnetization (M) curves measured at 50 Oe. In addition to the superconducting transition of the bulk MgB_2 at 39 K, one notices two additional characteristic features at ~60 K and ~120 K in the ZFC magnetization curve, suggesting the existence of certain magnetic transitions at these temperatures. To highlight possible changes in the magnetization in these temperature regions, we took a difference between the M(H) loops measured at different temperatures [see Fig. 1(b)]. The difference $M(H, T)–M(H$, 125 K) (T=90, 100, 110 K) tends to reveal a hysteresis loop characteristic of superconducting materials with weak bulk pinning. It is hence most probable that the observed drop in M at ~120 K in the ZFC curve shows the appearance of the superconducting phase at that temperature because of the constructive interaction between d^0 ferromagnet and superconductor. Furthermore, the sharp peak at ~60 K seen in the ZFC curve is indicative of the existence of a spin-glass-like transition, which most likely results from the rearrangement of ferromagnetic domain caused, directly or indirectly, by the superconducting order occurring at temperatures below ~120 K. We consider that the extremely high critical temperature of ~120 K obtained in this work results from the inherently weak and inhomogeneous (domain-like) nature of defect related d^0 ferromagnetism, which may induce a local increase of T_c in the vicinity of a domain wall.

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