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# $d^0$ 強磁性体/超伝導体ナノ複合体における磁気ピンニング

## Magnetic Pinning in a $d^0$ Ferromagnet/Superconductor Nanocomposite

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Recently, magnetism in nanoscale materials has attracted increasing attention since unexpected room-temperature ferromagnetisms has been observed in nanoscale oxides containing virtually no magnetic ions with partially-filled d or f shells. This so called $d^0$ ferromagnetism opened a new direction in the research field of dilute magnetic oxides and challenged the conventional paradigm of magnetism. The true origin of $d^0$ ferromagnetism still remain to be clarified, but some surface and/or grain-boundary related defects are believed to play a leading role in the appearance of the long-range ferromagnetic ordering [1]. We here investigate the interaction between superconductivity and defect-induced $d^0$ ferromagnetism using a composite consisting of $MgB_2$ and MgO nanocrystals [2]. The composite exhibits a ferromagnetic hysteresis behavior in the temperature region from 40 to 300 K (see Fig. 1a). Defective MgO nanocrystals (~20 nm) embedded in the composite are considered to be responsible for the observed ferromagnetism. The zero field cool and field cool magnetization curves show that the superconducting transition occurs at $T_c$ = 38.6 K, in agreement with $T_c$ of pure $MgB_2$. In the temperature region from $T_c$ to 0.9$T_c$ (~35 K), the magnetization hysteresis curves show a superposition of ferromagnetic (F) and superconducting (S) signals (see Fig. 1b). When the temperature of the system is decreased below 0.65$T_c$ (~25 K), the S signals dominate over the F signals (see Fig. 1c). The resulting magnetic hysteresis loops are highly asymmetric and the descending filed branch is nearly flat, as predicted in the case of surface pinning. At temperatures below 0.5$T_c$ (~20 K), a sharp peak is developed near zero field in the magnetization hysteresis curves (see Fig. 1d), implying an enhancement of superconducting vortex pinning. The observed pinning enhancement most likely results from magnetic pinning due to randomly distributed magnetic MgO grains, which yield the magnetic inhomogeneity and the related pinning potential in a length scale of ~100 nm. Thus, the present ferromagnetic/superconducting composite provides an ideal model system that demonstrates the availability of $d^0$ ferromagnetism as a source of magnetic potential for effective vortex pinning.

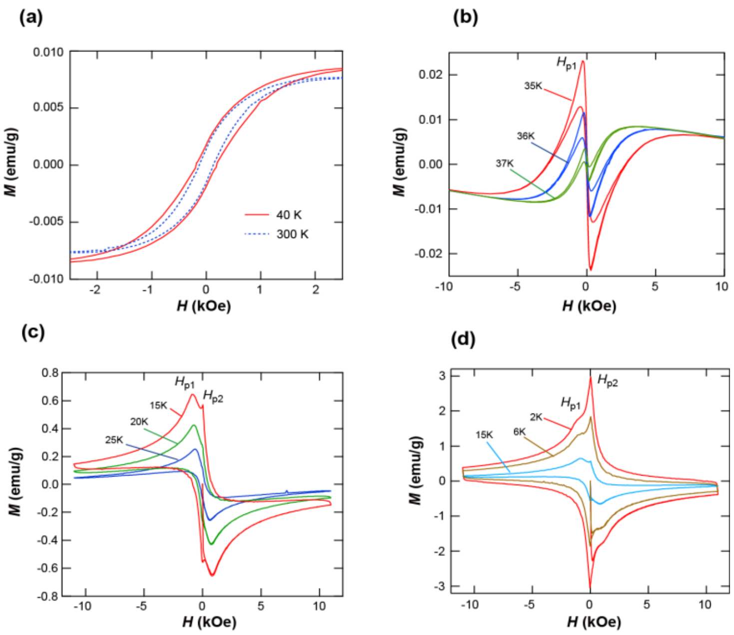


**Fig. 1 Magnetic-field ($H$) dependence of magnetization ($M$) measured at (a) $T$ = 40 and 300 K, (b) $T$ = 35, 36, and 37 K, (c) $T$ = 15, 20 and 25 K and (d) $T$ = 2, 6 and 15 K. $H_{p1}$ indicates a temperature-dependent peak field, whereas $H_{p2}$ designates a temperature-independent peak field occurring near zero field.**

[1] T. Uchino and T. Yoko, *Phys. Rev. B* **85**, 012407 (2012); *Phys. Rev. B* **87**, 144414 (2013).
[2] T. Uchino, Y. Uenaka, H. Soma, T. Sakurai, and H. Ohta, *J. Appl. Phys.* **115**, 063910 (2014).