Research Matters SPRING 2005 Sc

The colossal potential of tiny magnets

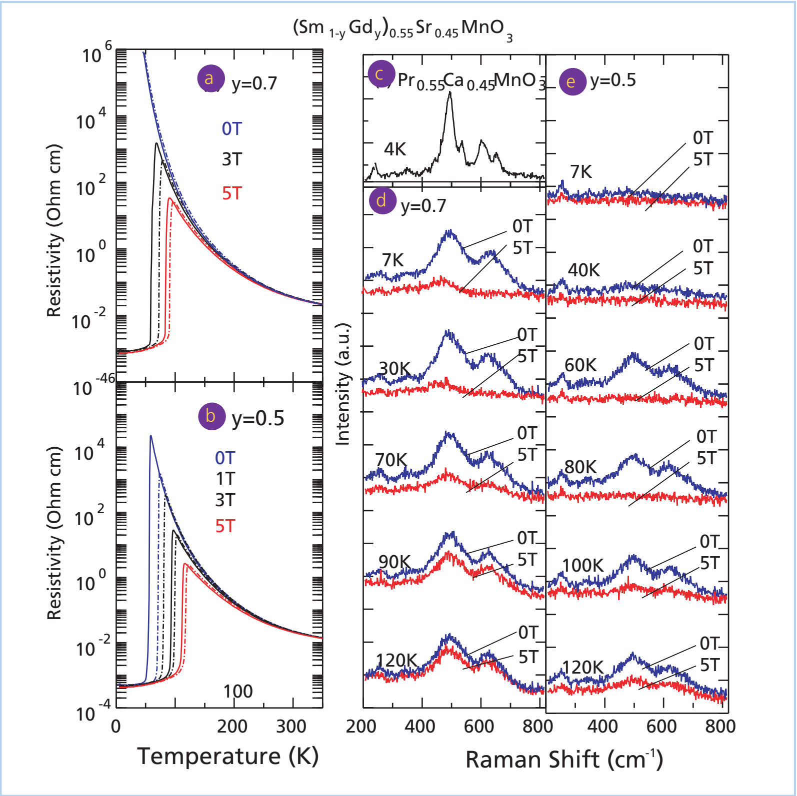


Figure 1 Temperature profiles of resistivity in magnetic fields for the crystals of (a) y=0.7 and (b) y=0.5 of $(Sm_{1-y}Gd_y)_{0.55}Sr_{0.45}MnO_3$ and temperature profiles of Raman phonon spectra at zero field and 5 T for the crystals of $(Sm_{1-y}Gd_y)_{0.55}Sr_{0.45}MnO_3$ with (d) y=0.7 and (e) y=0.5. For comparison, the spectra of the $Pr_{0.55}Ca_{0.45}MnO_3$ crystal are also shown in (a).

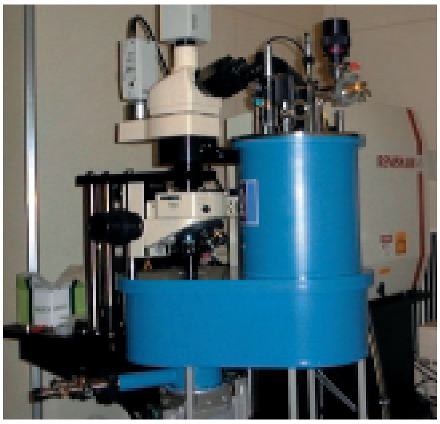
Hard drives, floppy disks and other information storage devices, all rely on magnetic storage. Each 'bit' of information is stored in the form of a tiny magnet that produces a field pointing in one of two directions corresponding to the ubiquitous 0's and 1's of the binary code. Although incremental advancements in hard drive technology occur regularly, major leaps forward require critical breakthroughs in how computing components work or, more significantly, in what they are made of. The next evolutionary step in hard disk technology may be found in the phenomena of colossal magnetoresistance (CMR).

Mainly found in perovskite oxides, CMR is a property that allows these materials to experience dramatic changes in resistance – a quality important to the read heads used to detect the patterns of magnetic fields stored on hard disks. This effect cannot be satisfactorily explained by current physical theories, including magnetic scattering or the double exchange mechanism. It has thus been suggested that Jahn-Teller distortion effects (in which the unstable molecular systems in a degenerate state undergo distortion to form systems of lower symmetry and energy to remove the degeneracy) might play an important role in producing the CMR effect.

Answering fundamental questions

To study the origins of CMR, Yoichi Okimoto, PhD, Research Scientist from the Correlated Electron Research Center (CERC), National Institute of Advanced Industrial Science and Technology (AIST) in Japan, performed Raman spectroscopy on manganese oxides, typical perovskite structures. These oxides are of the general formula $R_{1-x}A_xMnO_3$, where R is a trivalent rare earth element and A, a divalent alkaline earth ion. The physics of the manganese octahedral structure in these systems are governed by competition between ferromagnetism and charge/orbital ordering (CO/OO). That is, the antiferromagnetic and insulating CO/OO state can transform into a metallic ferromagnetic state upon the application of a sufficient magnetic field, leading to the CMR effect.Raman spectroscopy was used to detect the degree in structural shift between these states.

The research team prepared cleaved structures of single crystals of $(Sm_{1-y}Gd_y)_{0.55}Sr_{0.45}MnO_3$, with y=0.7 and 0.5, for the measurements of the Raman Spectra and a He-Ne laser was focused on the samples. To induce the CMR effect, a superconducting magnet (Oxford Instruments' Microstat BT) was used to apply magnetic fields of up to 5 T. The scattered light was then collected through a notch filter and dispersed by a single monochromator equipped with a charge-coupled device (CCD) detector. The Microstat BT combines a 5 T superconducting magnet with a pillared Microstat Hires enabling optical measurements to be perfomed with sub-micro m spatial resolution on samples cooled down to 4.2 K.



The MicrostatBT

Figures 1a and 1b show the temperature-profiles of resistivity in magnetic fields for the crystals of $(Sm_{1-y}Gd_y)_{0.55}Sr_{0.45}MnO_3$ with y=0.7 and 0.5. As shown in the resistivity at zero field, a ferromagnetic metallic (FM) state is seen as the ground state for y=0.5, while an insulator for y=0.7. In the case of y=0.7, however, a metallic state starts to appear at 3 T and below ~50 K. As the magnetic field is intensified, the metallic state is relatively stabilized in common to the cases of y=0.5 and 0.7. These profiles thus show typical examples of the CMR phenomena, with the occurrence of effect dependant on both temperature and the strength of the applied magnetic field.

Figures 1d and 1e show the temperature-profiles of the Raman phonon spectra for the crystals of $(Sm_{1-y}Gd_y)_{0.55}Sr_{0.45}MnO_3$ (y=0.7 and 0.5) taken at zero field and 5 T. For comparison, the spectra of a $Pr_{0.55}Ca_{0.45}MnO_3$ crystal with static Jahn-Teller distortion as well as the CO/OO below ~220 K is displayed in Figure 1c. In the spectra, two major peaks are seen at ~490cm-1 (Jahn-Teller mode) and ~600cm-1 (breathing mode). In the case of y=0.5, the intensities of the phonon modes at zero field show a slight increase as temperature is lowered from 120 K to 60 K. Below the Curie temperature, Tc, of ~50 K, however, the spectra peaks decrease in intensity and the phonon bands quickly disappear. In contrast, in the case of y=0.7, both phonon modes at zero field seem to increase in intensity with the decreasing temperature, keeping finite intensities even at the lowest temperature.

The impact of an applied external magnetic field also appears in Raman phonon spectra. In the case of y=0.5, the phonon peaks at ~490cm-1 and ~ 600 cm-1 are distinctly seen at 60 and 80K at zero field, while they disappear at 5 T. At 100 K, they are strongly suppressed at 5 T, though still discernable. In the case of y=0.7, similarly to the case of y=0.5, the phonon modes are seen at 7 and 30 K at zero field, while they also disappear at 5 T. At 70 K, they are again strongly suppressed at 5 T. For both y=0.5 and 0.7 crystals, the observed changes in the Raman phonon spectra by variations of temperature and magnetic fields nicely agree with the resistive transitions in magnetic fields as shown in Figures 1a and 1b.

These results of Raman spectroscopy study strongly indicate that the relaxation of Jahn-Teller distortion of MnO_6 octahedra (or melting of the charge/orbital ordering) is important for the explanation of CMR effects in manganites. This pivotal conclusion is likely to inspire the future research in determining the multi-factorial mechanisms of the metal-insulator phenomenon in single crystals. Elucidating a precise mechanism for the CMR phenomenon offers tremendous opportunities for the development of new technologies in read/write heads for highcapacity magnetic storage and spintronics. The unique characteristics of the Microstat BT enabled these experiments to be in a magnetic field and low temperature environment at microscopy level.

References

1. Tomioka, Y., Okimoto, Y., et al. The American Phys Soc, Phys Review, 68,094417 (2003).

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