Ferromagnetic antiresonance in $La_{0.7}Ba_{0.3}MnO_3$ traced out by temperature variation

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Using the phenomenon of ferromagnetic antiresonance (FMAR) in ceramic samples of $La_{0.67}Ba_{0.33}MnO_3$ at 10 GHz, we report a large magneto-impedance $\mathrm{MI}=R_s(H_\parallel)-R_s(H_\perp)]/R_s(H_\parallel)$, where R_s is the microwave surface resistance and H the applied field. The MI reaches 30% at a field of 30 mT near room temperature. The FMAR also lets us measure $M(T)$ by following R_s as a function of T and H. *© 1997 American Institute of Physics.* [S0021-8979(97)31408-X]

Recently, large magnetotransport effects have been found near room temperature, both in conventional giant magnetoresistance multilayers[1,2] as well as colossal magnetoresistance (CMR) manganites.[3,4] Large changes in resistivity attendant upon moderate applied fields have been observed even at microwave frequencies.[5] The goal of these investigations has been to maximize the response, especially at low fields. Very recently,[6] we have demonstrated that in a high-quality single crystal of $La_{0.7}Sr_{0.3}MnO_3$ (LSMO), more than a 60% change in the microwave surface resistance R_s near room temperature can be obtained in fields of a few tens of mT by appealing not to its magnetoresistance but to the phenomenon of ferromagnetic antiresonance (FMAR). Here we show, for the first time, that more than a 30% change in R_s can be obtained in a modest (30 mT) field for a ceramic sample of $La_{0.7}Ba_{0.3}MnO_3$ (LBMO).

The surface resistance of a parallelepiped ($2\times2\times0.5$ mm^3) of LBMO was investigated at 9.9 GHz over the temperature range $250<T<350$ K using a cavity perturbation technique.[7] The T_C of the specimen was determined to be 340 K from an ac susceptibility measurement. The sample was placed on a side of a rectangular cavity in the region of the maximal microwave magnetic field h_{rf}. Although the absolute value of R_s is difficult to access, the relative values are known to within about 3%. The applied dc field $\mu_0\mathbf{H}$ ranged from 0 to 1.5 T and was applied either parallel ($H_\parallel$) to or perpendicular ($H_\perp$) to $\mathbf{h}_{\mathrm{rf}}$. In the former case one measures the magnetoresistance while for the latter geometry the magnetoabsorption is controlled largely by FMAR and ferromagnetic resonance (FMR).

Figure 1 shows a set of field and temperature scans of R_s. A minimum is observed for $\mathbf{H}\perp\mathbf{h}_{\mathrm{rf}}$. Previously,[6] we modeled the phenomenon using the dynamic permeability μ of a monodomain ferromagnet derived from the Landau–Lifschitz–Gilbert equation,

$$\frac{d\mathbf{M}'}{dt}=\gamma(\mathbf{M}'\times\mathbf{H}')+\frac{\alpha}{M_S}\left(\mathbf{M}'\times\frac{d\mathbf{M}'}{dt}\right), \qquad (1)$$

where $\gamma=g\mu_B/\hbar$ is the gyromagnetic ratio, α the Gilbert damping term, and M_S the saturation magnetization. $\mathbf{H}'=\mathbf{H}+\mathbf{h}_{\mathrm{rf}}e^{i\omega t}+\tilde{\mathbf{H}}$ with $\tilde{\mathbf{H}}$ containing any stray fields, dynamic or static, and $\mathbf{M}'=\mathbf{M}+\mathbf{m}e^{i\omega t}$ with $\mathbf{m}$ being the dynamic magnetization. For $\mathbf{M}\perp\mathbf{h}_{\mathrm{rf}}$ the dynamic susceptibility χ $(=\mu-1)$ can be written as

$$\chi=\frac{\mu_0M[\mu_0H+\mu_0M+i\Gamma]}{(\mu_0H+i\Gamma)(\mu_0H+\mu_0M+i\Gamma)-(\omega/\gamma)^2}, \qquad (2)$$

where $\Gamma=\alpha\omega/\gamma$. If $\Gamma\cong0$, $\mu=1+\chi\equiv0$ when

$$\mu_0H=\omega/\gamma-\mu_0M. \qquad (3)$$

This is the FMAR condition, and at that value of H, R_s $(\propto\sqrt{-i\mu})\cong0$. The FMAR phenomenon causes a decrease in the microwave absorption which is often observed in thick samples of ferromagnetic metals. For linewidths greater than $\sim0.1\omega/\gamma$, the FMAR is not so marked and a linewidth correction to Eq. (3) is required.

The interpretation of the zero-field observations is far from straightforward since Eq. (2) holds only for a single domain state; however, detailed calculations show that qualitatively all of the observed features are reproduced, independent of the assumed domain configuration. In each case the minimum in $R_s(0)$ occurs when $\omega/\gamma=\mu_0M_s$, and the dip in $R_s(\mu_0H_\perp)$ appears at a temperature given by $\omega/\gamma=\mu_0M_s(T)+\mu_0H_\perp$. Clearly, the location of the FMAR is controlled by M even for $H=0$. Since M varies rapidly when T is changed close to T_C, one can trace out FMAR by holding ω constant and slowly increasing T. Therefore, from the FMAR

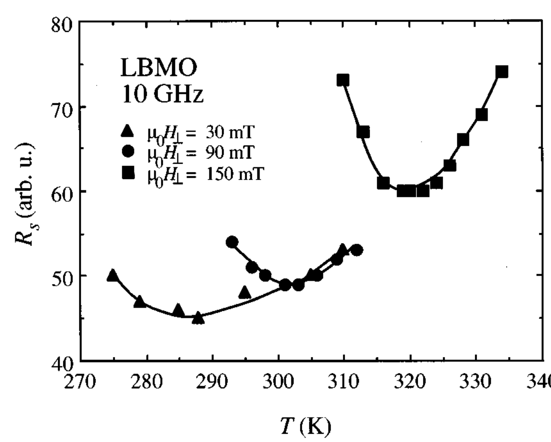

FIG. 1. Temperature dependence of the surface resistance at 10 GHz of a LBMO ceramic for fields of 30 mT (triangles), 90 mT (circles), and 150 mT (squares). The minima correspond to point where Eq. (3) is satisfied.

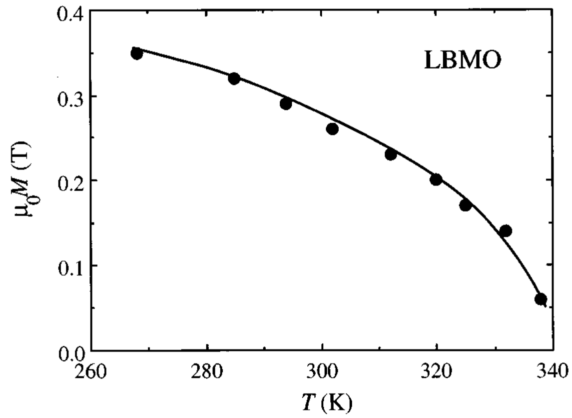

FIG. 2. Temperature dependence of the magnetization of a ceramic LBMO sample. The magnetization was inferred from Eq. (2).

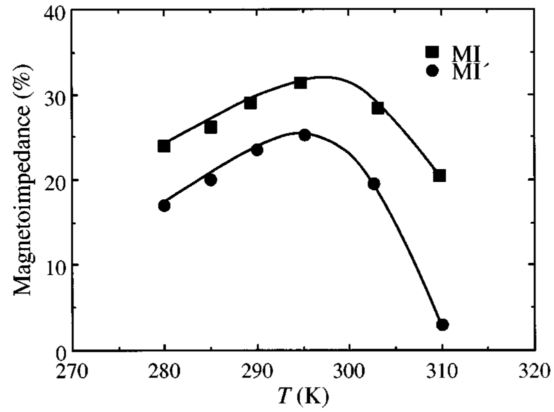

FIG. 3. Temperature dependence of the magneto-impedances MI and MI′ at 30 mT for a sintered LBMO sample at 10 GHz. MI, which reaches its maximum near 300 K, is the more meaningful quantity since the sample is measured in a monodomain state.

condition[8] [Eq. (3)] and small linewidth corrections calculated from Eq. (2), one can determine the T dependence of M (Fig. 2).

The magneto-impedances (Fig. 3) are

$$\mathrm{MI}' = [R_s(0) - R_s(H_\perp)]/R_s(0))$$

and

$$\mathrm{MI} = [R_s(H_\parallel) - R_s(H_\perp)]/R_s(H_\parallel)$$

for T varying between 270 and 310 K ($\cong T_C$); however, it is crucial to note that this is not a result of magnetoresistance, rather, we are observing a magneto-impedance effect at microwave frequencies.

Γ for this LBMO, like that of all ceramic CMR materials, is not small (~40 mT), a clear sign of magnetic disorder. A Γ value of only 25 Oe has been observed in an epitaxial LBMO film.[9] Considering the sizable magnetic inhomogeneity, the MI is quite impressive.

To conclude, a sizable magneto-impedance resulting from ferromagnetic antiresonance has been obtained in rather small applied fields of ceramic LBMO at 10 GHz. Although not optimized, the MI is as large as 30% at room temperature and 30 mT. The observation of a large MI in a sintered material further enhances the possibility of technological applications since single-crystal manganites are difficult to manufacture. More uniform ceramics with narrower linewidths will enhance the MI.

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