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$_{0.7}$Ba$_{0.3}$MnO$_3$ at 10 GHz, we report a large magneto-impedance $M$=\(R_s(H_f) - R_s(H_z)/R_s(H_z)\), 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.

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Recently, large magnetotransport effects have been found near room temperature, both in conventional giant magnetoresistance multilayers\(^1\) 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$_{0.67}$Ba$_{0.33}$MnO$_3$ (LBMO).

The surface resistance of a parallelepipeds (2×2×0.5 mm$^3$) of LBMO was investigated at 9.9 GHz over the temperature range 250\(\leq T\leq 350\) 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 $h_{\text{rf}}$. Although the absolute value of $R_s$ is difficult to access, the relative values are known to within about 3\%. The applied dc field $\mu_0 H$ ranged from 0 to 1.5 T and was applied either parallel ($H_b$) to or perpendicular ($H_z$) to $h_{\text{rf}}$. In the former case one measures the magnetoresistance while for the latter geometry the magnetooabsorption 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 $H||h_{\text{rf}}$. Previously,\(^8\) we modeled the phenomenon using the dynamic permeability $\mu$ of a monodomain ferromagnet derived from the Landau–Lifschitz–Gilbert equation,

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

where $\gamma=g\mu_0/\hbar$ is the gyromagnetic ratio, $\alpha$ the Gilbert damping term, and $M_S$ the saturation magnetization. $H'=H+i\omega M'+\hbar$ with $H$ containing any stray fields, dynamic or static, and $M'=M+me^{i\omega t}$ with $m$ being the dynamic magnetization. For $M||h_{\text{rf}}$, the dynamic susceptibility $\chi = \mu - 1$ can be written as

$$\chi = \mu_0 M_0 \left[ \mu_0 H + \mu_0 M + i\Gamma \right],$$

where $\Gamma = \alpha\omega/\gamma$. If $\Gamma = 0$, $\mu = 1 + \chi = 0$ when $\mu_0 H = \omega/\gamma - \mu_0 M_0$.

This is the FMAR condition, and at that value of $H$, $R_s$ ($\propto \sqrt{-i\mu}$) $\approx 0$. The FMAR phenomenon causes a decrease in the microwave absorption which is often observed in thick samples of ferromagnetic metals. For linewidths greater than $-0.1\omega/\gamma$, 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 $\omega/\gamma = \mu_0 M_S$, and the dip in $R_s(\mu_0 H_z)$ appears at a temperature given by $\omega/\gamma = \mu_0 M_S(T) + \mu_0 M_L$. 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 $\omega$ constant and slowly increasing $T$. Therefore, from the FMAR...
and small linewidth corrections calculated from Eq. (2), one can determine the $T$ dependence of $M$ (Fig. 2).

The magneto-impedances (Fig. 3) are

$$MI' = \frac{R_s(0) - R_s(H)}{R_s(0)}$$

and

$$MI = \frac{R_s(H) - R_s(H)}{R_s(H)}$$

for $T$ varying between 270 and 310 K ($\approx T_C$); 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.

$\Gamma$ for this LBMO, like that of all ceramic CMR materials, is not small ($\sim 40$ mT), a clear sign of magnetic disorder. A $\Gamma$ value of only 25 Oe has been observed in an epitaxial LBMO film. 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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