RF Electrodynamics in Small Particles of Oxides—A Review

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Abstract. RF electrodynamics, particularly, the low field rf absorption in small superconducting and manganite particles is reviewed and compared with their respective bulk counterparts. Experimental and theoretical aspects of the small particle electrodynamical response which is qualitatively different as compared to its bulk form, atleast in the high-T_c superconducting $YBa_2Cu_3O_{7-x}$ (YBCO) cuprate superconductor and in the CMR manganite family members are discussed. We focus attention on fascinating new phenomena like rf power induced 'anomalous rf absorption' in the small particle system of YBCO and room temperature 'Colossal Magneto Impedance' (CMI) in the micron size particles of manganites occurs, illustrating rich physics and paving way for new device applications.

Keywords: Small Particle Electrodynamics, RF properties, Colossal Magneto Impedance, CMR manganites, High-T_c Cuprate Superconductors.
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INTRODUCTION

Functional Oxide materials such as High-T_c cuprates and CMR manganites have interesting dc electrical and magnetic properties which paved way for the emergence of the exciting field now known as 'Oxide Electronics'. However these materials also have very interesting 'bulk' and 'small particle' zero field and low field rf properties, which can be used in novel RF devices. While a few reviews and review-like long original articles are available for the rf properties of the bulk form of these materials [1-5], we believe that no review is available in the area of the small particle rf range electrodynamics in these materials and this article shall fill the gap to some extent.

(a) High-T_c Cuprate Superconducting Materials

High-T_c cuprate superconducting materials (HTSC) in the bulk form (thin films, single crystals and polycrystalline pellets) show an intense low field dependent RF absorption signals, generally known as 'Non-resonant RF and microwave absorption (NRMA) [6-13]. This absorption can originate from fraction of free fluxons and weak links [14-16]. Further many novel features are observed in the bulk form of these cuprates, such as 'anomalous hysteresis' [17], 'Temperature dependent phase reversal' [18,19], 'Oscillations in the line spectra' [20], 'periodic fine structure' particularly in single crystals [21], 'Paramagnetic Meissner effect' [22] and microwave power induced evolution of the second peak in Bi-2212 single crystals [23], to name the

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temperature and field and treating the bulk granular HTSC sample as an 'effective medium' with effective conductivity and permeability expressed in terms of the meissner fraction. The cross over from 'normal' to 'anomalous' rf absorption also depends on the normal state conductivity of the sample and the rf frequency too. A model developed by Bhat-Srinivasu-Kumar [19] explains all these features naturally.

In the case of micron size YBCO powders, a new feature as compared to bulk form is observed, namely, rf power dependent cross over from 'normal' to 'anomalous' NRMA signals. Such a behavior is totally new and only has been observed in the micron size powders of YBCO [24]. In Fig.1(a) (reproduced from ref.[24]) one can see that as the rf field value is increased from about 4 milli gauss to 16 milli gauss, the phase of the NRMA signal reversed as compared to that of the ^{1}H NMR signal. Here the in phase and out of phase signals corresponds to the 'anomalous' and the 'normal' NRMA signals respectively. One can also see the 'transition' signals with structure, at intermediate rf power levels. Full experimental details can be found in ref. [24].

In the model developed by Srinivasu-Bhat-Kumar [24] the 'normal' and 'anomalous' NRMA rf absorption and the cross over can be explained in the following way:

'Normal' NRMA absorption

The micron size YBCO powder consists of many weakly connected loops. For the situation where the parameter $\beta = 2\pi L_g J_c/\varphi_o > 1$ (where φ_o is the flux quantum, L_g is the geometric loop self inductance, J_c is the junction critical current density.) the energy of the loop becomes a multi valued function, leading to an irreversible hysteretic Josephson-Junction characteristic.

Thus, for the rf amplitude beyond a threshold value, the YBCO powder system makes transitions between flux states, as the dc flux is ramped. The associated phase-slippage induces impulsive emf causing ohmic dissipation, through the junction normal resistance [24, 40]. This response when averaged over a distribution of loop area and orientation shall give an rf absorption that increases with increasing dc field (H_{dc}) [3].

'Anomolous' NRMA absorption

The rf field induced anomalous NRMA absorption occurs only in micron size powder samples of YBCO and is experimentally absent in well sintered bulk samples. This means the weak links involved are expected to be mostly the Josephson junctions between the micron-sized irregularly shaped particles of the powder. These weakly-linked superconducting loops can be non-hysteretic, i.e. $\beta = 2\pi L_g J_c/\varphi_o < 1$ as the critical current in these inter particle contact weak links is expected to be very small. Further as the H_{c1} (junction) << H_{c1} (bulk), these junctions are well suited for nucleating fluxons and which are weakly pinned.

cosine factor and replace AH_ω by its average value in the argument of Bessel function, Eq.1 takes the form:

$$\frac{<P>}{P_o} = \left[1 - \left(\frac{1-16\pi^2\eta^2}{1+16\pi^2\eta^2}\right) J_o\left(\frac{4\pi A H_\omega}{\phi_o}\right)\right] - \left[\left(1 - \left(\frac{1-16\pi^2\eta^2}{1+16\pi^2\eta^2}\right)\right) J^2{}_o\left(\frac{2\pi A H_\omega}{\phi_o}\right)\right] \quad (2)$$

Where $\eta = \frac{H_{dc} A_o}{\phi_o}$. Figure 1(b) shows the simulation of Eq. 2 (reproduced from ref. [24]). It can be seen that the power dissipation <P> is a monotonically decreasing function of H_{dc}, which is the 'anomalous' NRMA. A cross over to the 'normal' NRMA at lower rf levels occurs because of the hysteretic-rf-squid behavior as discussed above.

There is another possible explanation, which is based entirely on the conventional rf SQUID response. The reduction of J_c with field can make a fraction of the junctions non-hysteretic (non-dissipative). This hysteretic to non-hysteretic conversion of the junctions can also lead to the 'anomalous' NRMA. However if this mechanism is playing a role, one expects this to happen in the bulk granular HTSC samples too. But in the bulk granular YBCO the rf power induced anomalous NRMA is experimentally proved to be absent [24]. We have to note that in an rf SQUID response, only hysteretic junction loops are multivalued in their energies and flux states, leading to phase slippage and dissipation. Non-hysteretic junction loops can not give any dissipation in this picture. Thus with a strong experimental proof that the anomalous NRMA is absent in bulk YBCO and with the above argument, it can be ruled out that the 'anomalous' NRMA to be originating from the rf-SQUID response. So the only dissipative mechanism is due to the above model of Srinivasu-Bhat-Kumar, where weakly pinned single fluxons in the non hysteretic junctions giving rise to the 'anomalous' low field rf absorption (NRMA), from Eq.2. The non-hysteretic junction nature is ensured because of the very weak inter particle contacts in the powder.

Microwave Absorption and Colossal Magneto Impedance (CMI) in the Micron size Manganite powders

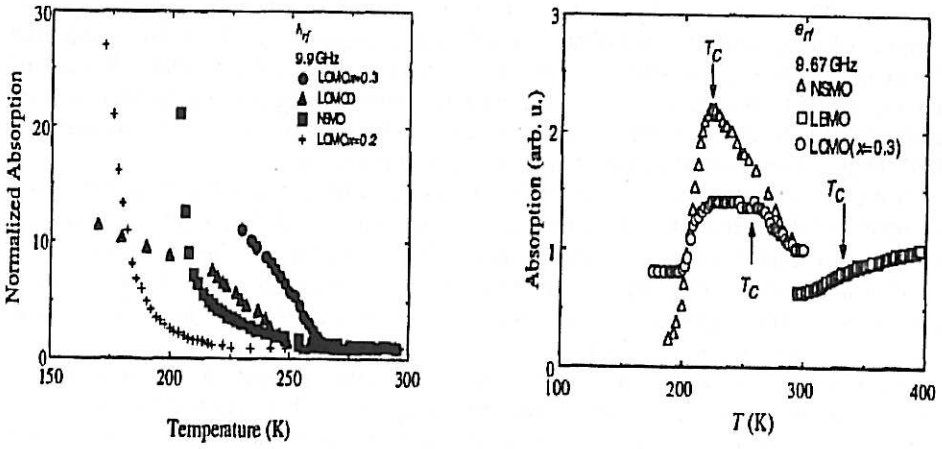
Infact there are only a few reports on the rf impedance measurements in manganite small particle powder samples [35-39] as compared to that of bulk. In the nanometric manganites, Nath et al [39] have shown that the MI percent increases with nanometric grain size. In the micron size La_{1-x} Sr_xMnO_3 powders, Li et al [37,38] found that microwave loss peak corresponds to the maximum dielectric loss tangent tan δ_e near 10.5 GHz, while the measurements being carried out by network analyzers. In this type of measurements it is difficult to separate the loss contributions from e_{rf} and h_{rf} fields.

compared with the situation when the sample is located in the e_{rf}. Data (reproduced from ref. [36] is shown in Fig. 2(b). Here in this case the absorption seems to follow the resistivity. Thus the micron size powders of the manganite family shows qualitatively different behavior as compared to their bulk form. The peculiar h_{rf} behavior, namely a rise of microwave loss as the sample is cooled down, was explained by Srinivasu et al [35] as in the following.

As the low-T rise in the microwave loss occurs only when the powder sample is in h_{rf} field and not when it is in e_{rf} field, the microwave loss is purely a magnetic effect. In as much as the loss is essentially attributed to the joule heating arising due to the rapidly varying rf flux, the loss is then proportional to $|\mu^2|$, where μ is the dynamic permeability,

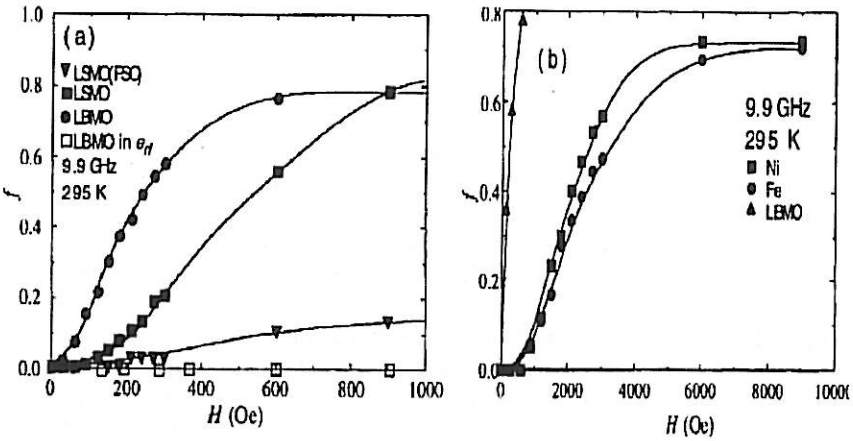
$$\mu - 1 = 4\pi\chi = \frac{4\pi M\left[H + 4\pi M + i\Gamma\right]}{\left(H + i\Gamma\right)\left[H + 4\pi M + i\Gamma\right] - \left(\frac{\omega}{\gamma}\right)^2} \tag{3}$$

This is the Gilbert's form of dynamical permeability for the spin system. M is the magnetization and Γ the resonance width parameter. Other symbols have their usual meanings. These powders are found to be magnetically inhomogeneous as their FMR line widths are very large (~ kOe). Therefore it is possible that a vestige of resonance absorption remains even at zero field. Assuming that line width increases rapidly as M increases when the temperature is decreased, which is the case actually observed



(a) (b)

FIGURE 2. Temperature dependence of microwave absorption in the micron size manganite powders when placed in (a) h_{rf} field and (b) e_{rf} field. The behavior in the two cases is qualitatively different as discussed in the text. "Reprinted with permission from AIP, ref. [36] Copyright [1999], American Institute of Physics."



(a) (b)

FIGURE 3. Figure of merit vs applied field for (a) LSMO, LBMO and Single crystal piece of LSMO placed in h_{rf} field. Note that polycrystalline powder samples show the largest effect as compared to that of bulk single crystal piece. Also almost no effect when and LBMO placed in e_{rf} field. (b) A comparison of figure of merit between LBMO powder and the conventional Ni and Fe powders. "Reprinted with permission from AIP, ref.[36]. Copyright [1999], American Institute of Physics."

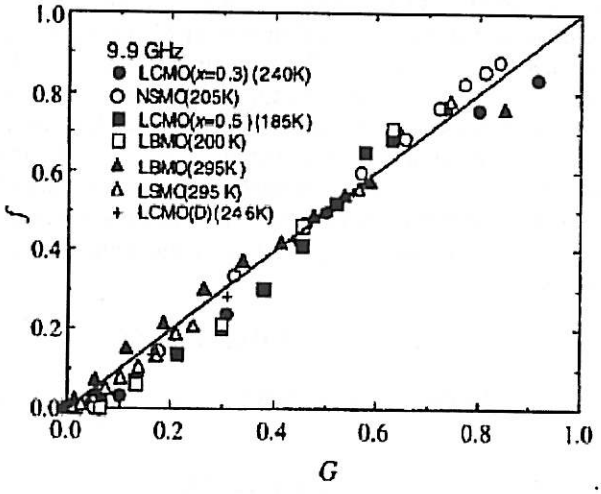


FIGURE 4. For most of the manganite family members, the observed figure of merit follows an empirical function $G(x) = x^2/(1+x^2)$, as explained in the text. "Reprinted with permission from AIP, ref. [36]. Copyright [1999], American Institute of Physics."

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