Probing magnetic anisotropy and phase transitions in $Pr_{0.5}Sr_{0.5}MO_3$ (M = Mn, Co) using RF transverse susceptibility

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The half-doped magnetic oxides $Pr_{0.5}Sr_{0.5}MnO_3$ and $Pr_{0.5}Sr_{0.5}CoO_3$ exhibit rich complexity in their fundamental physical properties determined by the intricate interplay between structural, electronic and magnetic degrees of freedom. $Pr_{0.5}Sr_{0.5}MnO_3$ undergoes a paramagnetic (PM) to ferromagnetic (FM) transition at T_C~250K followed by a ferromagnetic to antiferromagnetic (AFM) transition at T_N~150K [1]. Noticeably it possesses relatively large one-electron bandwidth (W) and exhibits a metallic layered A-type AFM state at low temperature. Since the A-type AFM state is related to the intrinsic $d(x^2\text{-}y^2)$-type orbital order, this compound is found to show orbital order-induced strong magnetic anisotropy [2]. In another case of interest, $Pr_{0.5}Sr_{0.5}CoO_3$ undergoes a PM-FM phase transition at T_C~230K and a magnetic anomaly is observed at T_A~120K. This anomaly occurs at the same temperature where the structural change is observed, and it is attributed to a coupled structural/magnetocrystalline anisotropy transition driven by Pr-O hybridization [3]. Since magnetic anisotropy plays a significant role in both systems, it is vitally important to systematically study the magnetic anisotropy and its variation with temperature, particularly in the vicinity of the magnetic phase transitions.

In this study, we demonstrate that radio frequency transverse susceptibility (TS) is a very powerful method for probing magnetic anisotropy and magnetic phase transitions in $Pr_{0.5}Sr_{0.5}MnO_3$ and $Pr_{0.5}Sr_{0.5}CoO_3$ compounds prepared using the conventional ceramic route. Magnetic measurements were conducted using a commercial Physical Property Measurement System (PPMS) from Quantum Design with a temperature range of 5 – 300 K and applied fields up to 7 T. A sensitive tunnel-diode oscillator (TDO) operating at 12-15MHz was used to measure the radio-frequency (RF) transverse susceptibility of this material [4]. Since the presence of the electromagnetic fields on the sample is associated with the RF currents, the TS technique is sensitive to both resistive and magnetic transitions that often simultaneously occur in charge-ordered manganites [5]. In particular, the magnetic screening length of the material is determined by both the effective permeability (μ_{eff}) and the electrical conductivity (σ) via the skin depth, $\delta = (\mu_{eff}/\sigma)^{1/2}$, where these parameters (μ_{eff} and σ) abruptly vary at a temperature at which a magnetic ordering transition or electronic phase transition takes place. Therefore, the RF TS technique is useful for probing coexisting magnetic, electronic and structural phase transitions.

Magnetic measurements reveal that the $Pr_{0.5}Sr_{0.5}MnO_3$ system undergoes a transition from the PM to FM state at T_C~250K followed by another transition from the FM to AFM state at T_N~150 K. The system exhibits a metamagnetic state in the vicinity of the FM-AFM phase transition. TS experiments reveal that there is an abrupt change in magnetic anisotropy at the FM-AFM phase transition temperature (T_N~150K). It is interesting that the signature of magnetic anisotropy is present even in the PM and AFM states, although the magnitude is much smaller in the PM and AFM states than in the FM state. As the temperature is decreased from T_C, the effective magnetic anisotropy increases in the FM region and decreases in the AFM region. The sharp change of magnetic anisotropy at T_N is likely associated with the structural phase transition that occurs at this temperature. This implies a strong coupling between the magnetism and the lattice in $Pr_{0.5}Sr_{0.5}MnO_3$. The signature of magnetic anisotropy fields revealed in the TS experiments, in both the PM and AFM states, points to the existence of ferromagnetic clusters in these states. This is consistent with the previous observation of split electron paramagnetic resonance (EPR) spectra at temperatures far above T_C [2]. The TS is also shown to be a very useful technique for probing magnetic field-induced phase transitions (the change from AFM to FM state) in this system.

In the case of $Pr_{0.5}Sr_{0.5}CoO_3$, the TS data also reveal that there is a sharp change in magnetic anisotropy at T_A~120 K, and that magnetic anisotropy persists above T_C~230K. The change in magnetic anisotropy at T_A is related to the coupled structural/magnetocrystalline anisotropy transition [3], while the presence of magnetic anisotropy above T_C indicates existence of ferromagnetic clusters in the PM range. It is worth noting that unlike the $Pr_{0.5}Sr_{0.5}MnO_3$ system, the magnetic anisotropy of $Pr_{0.5}Sr_{0.5}CoO_3$ increases with decreasing temperature below T_A and its magnitude is relatively large. This contrasting difference can be reconciled with the fact that the $Pr_{0.5}Sr_{0.5}CoO_3$ system undergoes a transition from the high-temperature FM state to the low-temperature FM state at T_A, while the $Pr_{0.5}Sr_{0.5}MnO_3$ system enters the AFM state below T_N. Overall, we provide fundamental insights into the physics of manganites and cobaltites and demonstrate RF transverse susceptibility as a very powerful method for probing the ground state magnetic properties in these systems.

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