The anisotropic magnetoresistance and planar Hall effect in tetragonal $La_{2/3}Ca_{1/3}MnO_3$ thin films

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A phenomenological model in high field limit for the anisotropic magnetoresistance (AMR) and the planar Hall effect (PHE) is developed, and the galvanomagnetic tensor based on a tetragonal symmetry $4/mmm$ (D_{4h}), applicable to epitaxial films on a substrate, has been obtained. The derived in-plane transverse resistance ρ_{xy} shows a $\sin 2\phi$ angular dependence, while the longitudinal ρ_{xx} is constituted by not only a two-fold $\cos 2\phi$ term, but also a four-fold $\cos 4\phi$ term due to the square symmetry of the lattice. $La_{2/3}Ca_{1/3}MnO_3$ Hall bars along [100] and [110] axes were fabricated on single-crystal-like films grown on $SrTiO_3$ (001) and $LaAlO_3$ (001). PHE and AMR have been studied in varied external magnetic fields and temperatures. The model is in good agreement with the experimental results in high fields, while deviations are observed near the <100> easy axes with the field decreasing. Meanwhile, in the film on LAO the contribution of the four-fold term in ρ_{xx} is much weaker, and a field dependent angle deviation in ρ_{xy} can be recognized. The fitting parameters reveals the evolution of these term weights with temperature and magnetic field, which is distinct from conventional ferromagnetic metals and cannot be explained by the phenomenological model. An alternative mechanism for AMR based on the magnetization-induced local orbit deformation through spin-orbit as previously proposed by O'Donnell *et al.*, may be prevalent in manganites and other systems of complicated crystal structures.