

Summary

This thesis describes the structural and magnetic properties of epitaxial $\text{La}_{0.67}\text{Sr}_{0.33}\text{MnO}_3$ (LSMO) thin films and nanostructures on single crystalline substrates. As LSMO is a half-metallic ferromagnet with almost 100% spin polarization and high curie temperature ($T_C = 360$ K), a detailed analysis of different properties of LSMO thin films and nanostructures is essential in realizing magnetic devices based on this material. For the direct measurement of strain state and magnetic anisotropy of this material, it is necessary to grow LSMO thin films on different substrates which have different lattice mismatch with the film. As future spintronic devices ultimately have to be fabricated at nanoscale lateral dimensions, it is also important to study the magnetic properties of nanostructures of LSMO.

In the beginning of this thesis, the selection criteria for the model system of LSMO to prepare thin films and nanostructures are given. A brief survey of different fundamental properties of LSMO and pre-existing studies on magnetic behavior such as the magnetic anisotropy and domain structures of LSMO thin films grown on different substrates are given in chapter 2. Different experimental techniques and characterization methods which are used in this thesis for fabrication and investigation of these thin films and nanostructures are discussed in chapter 3.

In order to study the effect of different strain state on structural and magnetic properties of epitaxial LSMO films, we have grown these films on different substrates namely, SrTiO_3 (STO) of (001) orientation and NdGaO_3 (NGO) of different orientations (eg. (100), (010), (110) and (001)). First, in chapter 4, we discuss epitaxial LSMO films which were grown on STO(001) substrates by pulsed laser deposition (PLD). Structural analysis of these films showed that LSMO grows in two dimensional growth mode resulting in an epitaxial film replicating the step-terrace structure of the substrate up to the film surface. Here LSMO experiences an in-plane tensile strain on STO substrate. The magnetic anisotropy

measurements of these films of different thicknesses at different temperatures were carried out by both Vibrating sample magnetometer (VSM) and Torque magnetometry. A combination of uniaxial anisotropy and biaxial anisotropy is observed in these films. Detailed analysis showed that vicinal steps on the film surface induce a uniaxial anisotropy with magnetic easy axis lying along the step direction. The biaxial anisotropy which is found to be crystalline in nature have easy and hard axes lying along [110] and [100] crystal directions respectively. When the temperature is decreased, biaxial anisotropy dominates over uniaxial step induced anisotropy. At room temperature, uniaxial step induced anisotropy become prominent. More quantitative measurements carried out by torque magnetometry on films of different thicknesses shows that biaxial anisotropy constant (K_1) decreases with temperature and it has no dependence on the film thickness. Also, uniaxial anisotropy constant (K_u) does not appear to scale with volume of the film, indicating that the step induced uniaxial anisotropy is mainly originated from the surface or interface of the film.

It is known that LSMO film experiences an un equal in-plane compressive strain on NGO substrates. In chapter 5, LSMO films grown on NGO substrates of different orientations by PLD are analyzed for the dependence of strain state on its magnetic anisotropy properties. The films grow coherently on NGO substrates of all orientations and in each case LSMO and NGO having equal in-plane lattice parameters with known strain state. LSMO films grown on NGO(100), (010), (110) and (001) oriented substrates reveal that all these films shows in-plane uniaxial crystalline anisotropy with easy and hard axes lying along the crystalline directions of the substrates, at room temperature and low temperature (160K). The unequal in-plane compressive strain modifies the crystal lattice of the film, which thereby modifies the magnetic crystalline anisotropy so that the easy and hard axes lie along the in-plane crystal directions. Compared to LSMO films on STO substrates, the surface steps have no influence on the magnetic anisotropy of the film on NGO substrates. The magneto-crystalline anisotropy in LSMO/NGO is found to be much stronger than that of LSMO/STO films. Magnetization reversal mechanism of LSMO/NGO(100) were studied and compared to both curling model and modified Kondorsky model. It is realized that the magnetization reversal mechanism can be well explained by modified Kondorsky model for these LSMO films.

Arrays of LSMO nanodots and wires were fabricated by Laser Interference Lithography (LIL) technique and they are discussed in chapter 6. The minimum dimension of nanodots and wires fabricated on STO substrates were 80nm (diameter) and 125nm (width) respectively. Nanowires fabricated on NGO(010) substrates were having width down to 146nm.

Magnetic anisotropy measurements of the nanowires on STO substrates show the domination of magneto-static (shape) anisotropy with easy axis lying along the wire direction. A small contribution from the biaxial magneto-crystalline anisotropy of LSMO also was

found to be present in these nanowires. Double switching behavior is seen in hysteresis loops of nanowires fabricated with wire direction lying along the crystal hard direction [100] of LSMO. This is found to be because of the competition between two magnetic anisotropies present in these wires which are namely shape anisotropy and magneto crystalline anisotropy. Torque measurements of these nanowires at different temperature show that both magneto static and magneto crystalline anisotropy constants decreases with temperature. The LSMO dots and nanowires were also studied with Magnetic force microscopy.

Interestingly, LSMO nanowires on NGO(010) and NGO(110) substrates show domination of magneto-crystalline anisotropy over magneto-static (shape) anisotropy. Compared to nanowires on STO substrates, the nanowires on NGO(110) and NGO(010) substrates have easy axis not along the wire direction, but along 55° or even 90° (perpendicular) away from the wire direction respectively as defined by the strong crystal anisotropy induced by the NGO substrates. The properties such as curie temperature and magnetization values of these nanodots and wires are not found to be degraded with patterning and dry etching. For LSMO nanowires, it is possible to tune the magnetic anisotropy axes determined either by shape anisotropy or crystal anisotropy by selecting the appropriate substrates (either STO or NGO) on which the wires are fabricated. This is useful in the fabrication of spintronic devices and nanostructures based on LSMO.

