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# RECENT ADVANCES IN LSMO THIN FILMS: FABRICATION, CHARACTERIZATION, MAGNETIC PROPERTIES AND SPINTRONIC APPLICATIONS

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## Abstract
This review is envisioned to update the recent progress in LSMO thin film development for electronic and magnetic applications. The fabrication, structure, and properties of LSMO are the primary focus of this review. The LSMO is of significant significance in electronic devices due to its Colossal Magnetoresistance (CMR), which results from high spin polarization. The paper provides a review by looking at how LSMO research evolved over history and then summarizing its theoretical background along with different deposition techniques. It emphasizes the key characterization methods for thin film evaluation. Various factors influencing the magnetic properties of LSMO thin films have been discussed. Additionally, the efficacy of LSMO thin film for spintronic application has been discussed, emphasizing the importance of surface treatment and process parameters to enhance the performance of LSMO thin film.

**Keywords:**LSMO,Thin films, Literature review, electrical and magnetic properties, spintronics applications

## Introduction
Perovskite oxides have been of huge importance in condensed matter physics and material science due to their interesting and wide span of properties. An important one is that of $La_{0.67}Sr_{0.33}MnO_3$ (LSMO) thin films, which gained great importance because of a huge magnetoresistance effect; therefore, they could be interesting for spintronics and magnetic sensors in other electronic multifunctional applications. This literature review aspires to give an all-rounded overview of the present state of research on LSMO thin films by outlining a theoretical background and historical development of the current advancement and flaws in literature. The effect of colossal magnetoresistance mechanism isexplaining the effect of CMR, as the material resistivity changed highly by the effect of an external magnetic field applied across the material. Besides, the Jahn-Teller effect and electron-phonon interactions contribute the physical properties of LSMO, as suggested by Maezono&Nagaosa in 2003.
Chahara et al. (1993) reported that manganites and especially CMR began to grow $La_{1-x}$Cax$MnO_3$magnatoresistance. In fact, the work of Helmolt et al. on $La_{1-x}Ca_xMnO_3$highlighted the practical applicability of the material. Another study of LSMO thin films came in with the thin film deposition with DC magnetron sputtering. Some of the deposition PLD, MBE, and sputtering used to deposit thin films; however, DC magnetron sputtering is more common since it offers atomic-level control in film thickness and composition. According to the work of Thoma et al., (2018) additional post-deposition annealing improved the general crystallinity and phase purity of LSMO films.Specifically, LSMO thin films are often characterized using XRD and SEM, respectively. It is reported that the increase in deposition time enhances crystallinity, and post-deposition annealing makes the transition from an amorphous state to a crystalline state with hexagonal lattice structure. On the other hand, AFM studies reveal a uniform, dense surface morphology with columnar growth that may be useful in electronic applications.

**Electrical and magnetic properties of LSMO thin films**

Determination of electrical and magnetic properties of LSMO thin film is essential. The XPS study was used to determine the surface profile of the LSMO thin film. The colossal magnetoresistance effect has been supported by the double-exchange mechanism in LSMO thin films and is known to show a strong dependency on temperature and the concentration of doping. Mukherjee et al studied epitaxial $Mn_3O_4$/LSMO bilayer thin films in 2012 in order to study the magnetic properties. Here, it describes mainly the effects of microstructure and interfacial strain. Deposited films have been prepared by pulsed laser deposition and grown on both $SrTiO_3$ and MgO substrates in such a way that it maintains lattice matching between the two films. XRD and HRTEM analysis revealed that the $Mn_3O_4$ layer induced compressive strain in LSMO within the plane, which left the lattice of LSMO distorted to a tetragonal structure. The magnetic measurements indicated that the saturation magnetization was depressed by the $Mn_3O_4$ layer at temperatures higher than the ferrimagnetic ordering temperature of $Mn_3O_4$ ($T > 50$ K) but increased at $T < 50$ K. This effect characterizes the interfacial ferromagnetic-ferrimagnetic coupling as a factor of enhancing surface magnetism in LSMO films.Another research concerns the magnetic and magnetotransport properties of $Nd_{0.6}Sr_{0.4}MnO_3$ (NSMO) thin films grown with different surface morphologies, including rod-type structures and granular structures grown on the oriented (100) $SrTiO_3$ substrates. By varying the post-growth annealing conditions, they achieved a rod-type morphology that increased in-plane magnetic anisotropy and colossal magnetoresistance nearly up to 97% at a 3 T magnetic field. The granular films showed butterfly-shaped low-field magnetoresistance, while rod-type films displayed an increase in anisotropic magnetoresistance peaking near the temperature of the metal-insulator transition by approximately 30%. Such morphological dependence on magnetoresistance provides guidelines for oxide-based sensing and magnetic devices.EpoxidicCrN ultrathin films epitaxially grown on the $La_{0.67}Sr_{0.33}MnO_3$ template layers by molecular beam epitaxy demonstrate high crystalline quality. Thus, such an epitaxial thin film opens the possibility for achieving epitaxial precision in epitaxial growth of thin films regarding the development of devices with advanced functional properties.Their work on CrN/LSMO heterojunctions, both experimentally combining techniques with density functional theory, revealed that saturation magnetization was much higher than that found in LSMO alone. The Neél temperature obtained for CrN/LSMO was 281 K, and the magnetic properties were driven mainly by the coupling between the CrN and LSMO layers through their interface. The conclusions allow an insight into the mechanism of interface-induced magnetic interactions in manganite-based heterostructures.

G. Z. Liu et al. (2016) reported the preparation of $La_{0.7}Sr_{0.3}MnO_3$ films and its magnetic, optical and electrical properties. From the results, it was found that substrate effects have little influence on electrical conductivity and the temperature for a paramagnetic-ferromagnetic phase transition of LSMO films. However, for the LSMO films deposited on LAO substrates, Liu et al. (2016) found higher coercive fields and slower photoinduced relaxation processes, indicating that substrate-related factors influence magnetization direction of the LSMO films and their crystalline quality. E. Annese et al. investigated the role of growth parameters in modulating the electronic and magnetic properties of $La_{0.67}Sr_{0.33}MnO_3$ thin films by the pulsed laser deposition technique. In this work, dramatic changes in the tetragonality, surface morphology, and magnetism of films with laser fluence and post-annealing conditions were shown. Larger fluences, in concert with low-oxygen-pressure annealing, cause lattice parameter decreases and both surface and bulk magnetism changes. These research findings provide an understanding of how LSMO thin films could be optimized for a wide range of applications by modifying their growth conditions. Danyan Cao et al. (2015) prepared thin films of $La_{0.7}Ca_{0.3-x}Sr_xMnO_3$ by the sol-gel route and measured their structural, magnetic, and transport properties. They have shown that with increased Sr doping, magnetic properties were improved, while the transition temperature shifted from 235 K to 343 K. Also, from this research, it was pointed out that lattice and physical properties demonstrated strong coupling among them; resistivity drastically reduced with higher Sr content. It was concluded that Sr doping could modulate magnetic and resistive properties of the manganite film.

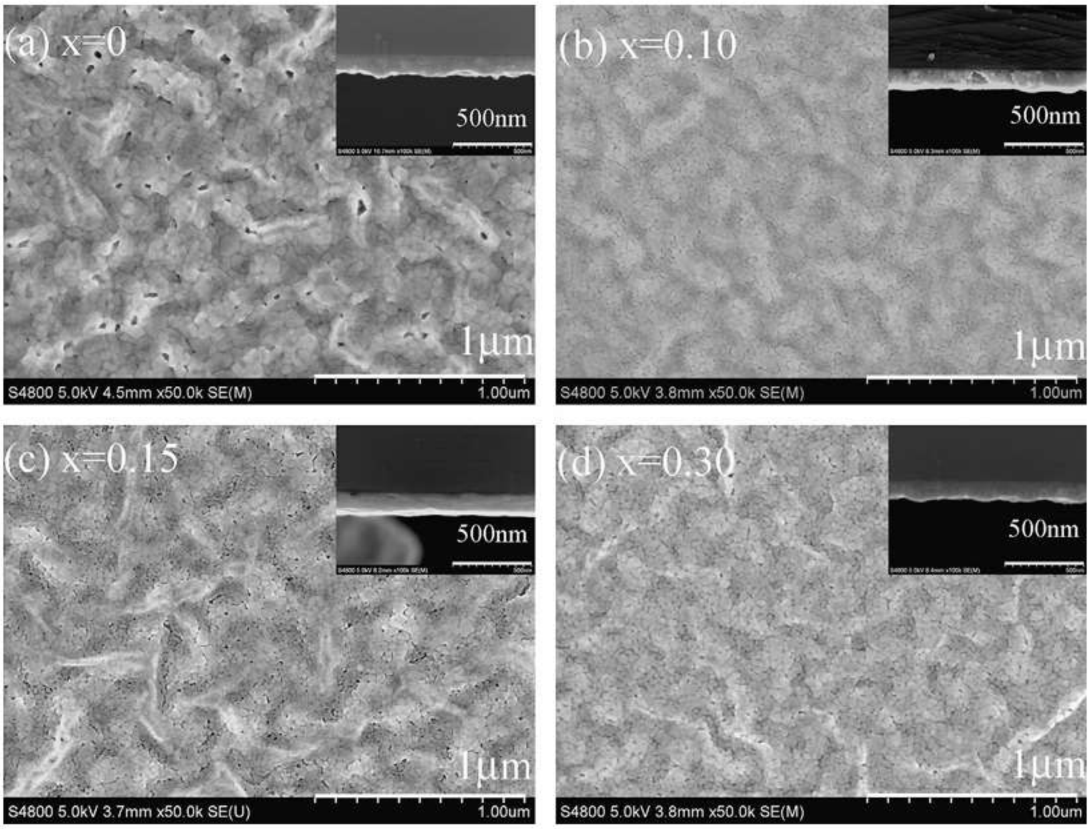


**Figure 1: SEM images of $La_{0.7}Ca_{0.3}xSr_xMnO_3$film** (Cao et al., 2015).

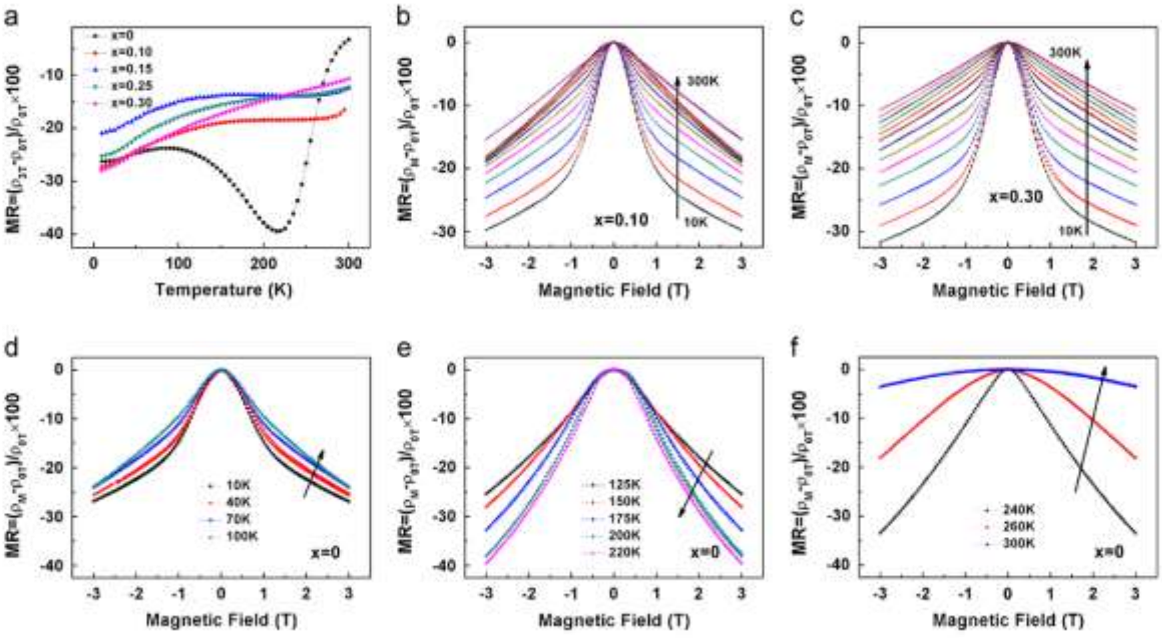


**Figure 2: (a) Magneto-resistance results obtained for LCSMO films with temperature, (b) Magneto resistance at x¼0.10 (b) and Magneto resistance at x¼0.30 (c) Magneto resistance at different temperature(d)–(f)**(Cao et al., 2015).

Pooja Narwat et al. (2023) explored the magnetic properties α-$Fe_2O_3$ (antiferromagnetic) and $La_{0.7}Sr_{0.3}MnO_3$. Their study identified two anomalous magnetic transition temperatures in the bilayer and a higher negative magnetoresistive response for the LSMO film compared to previous reports. The bilayer exhibited positive magnetoresistive response, suggesting potential for spintronic applications. The results emphasize the significance of magnetic interactions across heterostructures for device performance(Narwat et al., 2023).Md Abdullah-Al Mamun et al. (2019) studied LSMO thin films with palladium free layer for their dynamic magnetic properties. Ferromagnetic resonance spectroscopy was applied to the heterostructures on $LaAlO_3$ and Platinum substrates. On LAO, the highly oriented (0 0 l) films and randomly oriented on Pt were found. Gilbert damping parameters of the heterostructure grown on the LAO substrate show polarization in the perpendicular direction to the film plane and very low values in the presence of the optimized FMR parameters. These findings confirm that the BZT-BCT/LSMO composite system may be a potential multifunctional device for future spintronic functionalities with both low damping and giant magnetoelectric coupling. The study done by Md Abdullah-Al Mamun et al. in (2018) is rather very informative about the possibility of making efficient ferroelectric-ferromagnetic heterostructures in the case of BZT-BCT and LSMO layers. In the current research, the Hollywood layer showed forth its ferromagnetic nature and its Curie temperature was quite high (350 K). Their undertaking stressed out the prospect of combining multiferroic applications between have the ferroelectric and ferromagnetic high-quality properties heterostructures.Most of the conducted research on LSMO thin films were spintronics and magnetic sensor applications. In this regard, various surface treatment methods have been explored to modify these properties for better performance. In 2011, Li et al. conducted research on $La_{0.6}Sr_{0.4}MnO_3$ thin films and evaluated magnetic properties. The treatment of thin films involves dipping in a solution of H2O, NH4OH, and H2O2 at 85°C for various periods, ranging from 10 to 40 minutes. Photoemission spectroscopy, X-ray absorption spectroscopy, and X-ray magnetic circular dichroism were used to probe the evolution of surface properties ensuing from the SC1 treatment. Results show that SC1-treated LSMO thin films have been strongly modified at the surface level concerning their electronic properties. This increase in work function is characteristic of changes in the surface electronic structure that can affect the interaction of these films with other materials in device applications. This change in morphology may indicate that cleaning is a process that does not only alter the electronic properties, but also affects the physical topography of the films.

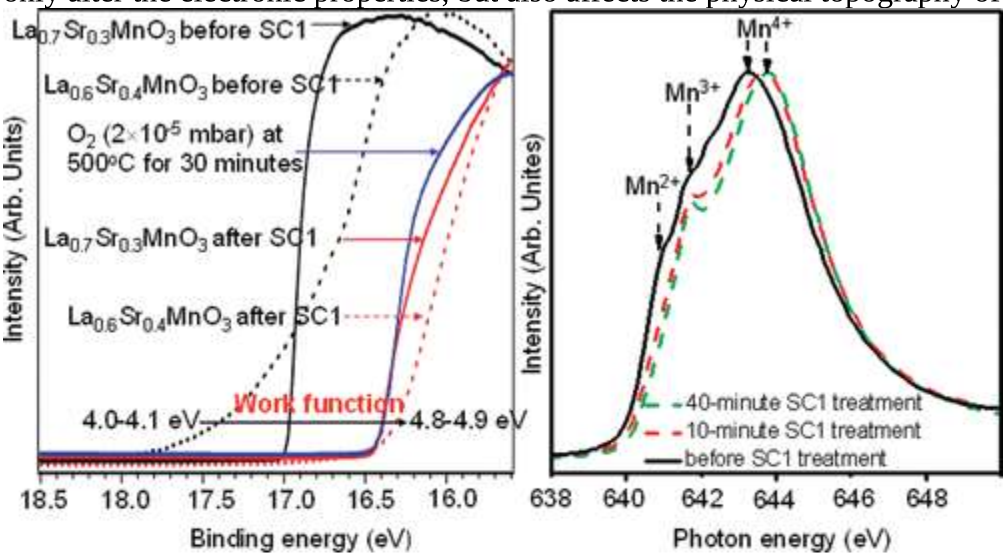


**Figure 3: XPS spectroscopy results obtained for surface-modified $La_{0.6}Sr_{0.4}MnO_3$ (**(Li et al., 2011)**).**

Surface chemical changes, as identified in core-level XPS studies, show that the SC1 treatment on LSMO thin films reduces manganese and strontium ion concentrations and shifts manganese to a higher valence state (Mn valence 3.7), which means an increase in $Mn^{4+}$ concentration. Similarly, the increase in hybridization due to the treatment as seen in the XAS results can affect electron mobility and thus lead to enhancement in conductivity. However, XMCD results demonstrate that the surface magnetic properties are hardly changed, indicating the electronic structure modification does not change the magnetic ordering selectively via SC1 treatment. It shows this selective modification as a path to functionality in enhancing the performance of LSMO thin films for spintronic and other applications by tuning electronic properties while keeping the magnetic characteristics intact(Li et al., 2011).

Room temperature strongly conductive, magnetic, and opto-electronic ferromagnetic material is highly in demand in the study of spintronic device development. Lanthanum strontium manganite, LSMO, is considered an ideal candidate due to its fully spin-polarized carrier and complex magnetic phase and transport mechanism. Generally, properties of LSMO thin films are extremely sensitive to growth temperature, oxygen stoichiometry, substrate matching, film thickness, and defects. LSMO needs structural order which could be realised with PLD to keep its ferromagnetic and conductive behaviour. The possibility of tuning conditions allows controlled deposition to optimize structural, magnetic, and conductive properties in LSMO with PLD. More notably, it observed perpendicular exchange bias in hetero-structures with LSMO and NiO, where a PEB field as large as 230 Oe was reached. This exchange bias has been attributed to disorder-induced effects at the NiO-LSMO interface, where uncompensated NiO moments are ferromagnetically coupled with LSMO, thus affecting magnetic behavior and improving the spintronic potential of LSMO-based devices.

**Electronic Structure and Strain Effects**

It introduces systematic variations in the electronic structure within the vertical interface due to variation in Mn3+/Mn4+ content arising from out-of-plane tensile strain. Changes in electronic structure can thus be directly associated with the enhancement in magnetic properties and functional performance for these VAN thin films.The possibility to control and optimize these properties by means of precise deposition techniques like PLD reflects the potential of LSMO:NiO nanocomposite thin films for advanced spintronics. Synthesis and characterization of VAN thin films of LSMO:NiO have given an example of how such microstructural control may dramaticaly affect the magnetic and electronic properties in these materials. The present study underlines, therefore, the priority that has to be placed on understanding and manipulating microstructures in order to enhance the performance of spintronic devices.

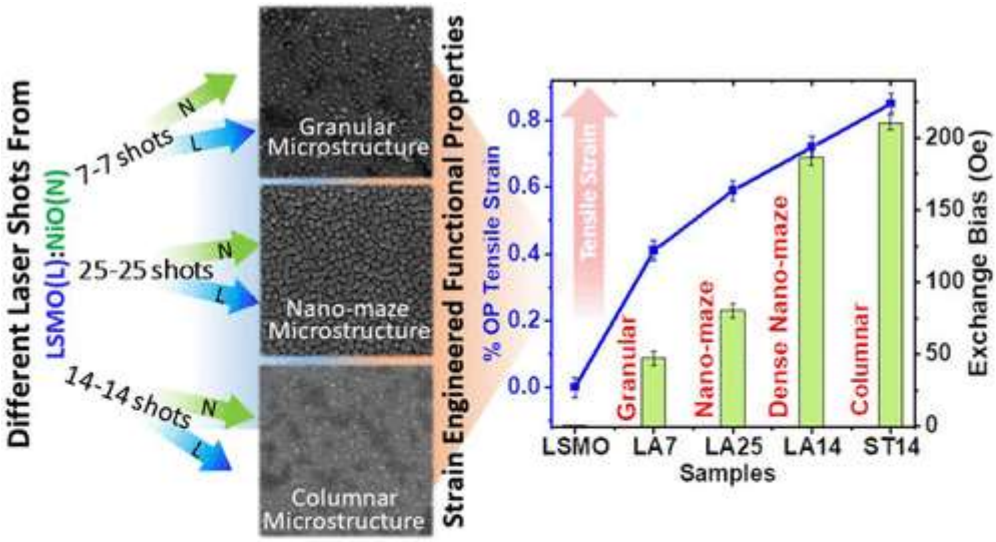


**Figure 4: Vertically Aligned $La_{0.7}Sr_{0.3}MnO_3$:NiO Nanocomposite for spintronics applications** (Panchal et al., 2020)

**Synthesis and Microstructural Control**

In designing and offering multifunctionality to spintronic devices, the microstructures and interfaces of two-phase vertically aligned nanocomposite (VAN) thin films hold paramount importance. Panchal et al., 2021 demonstrated the capability to precisely tune the microstructures of $La_{0.7}Sr_{0.3}MnO_3$ and NiO VAN thin films using PLD. This work was an extension of their previous work. Microstructures can be engineered into configurations such as nanogranular, nanocolumnar, or nanomaze patterns by controlling the number of laser shots from each phase target during PLD. The structural modifications induce strains that improve the magnetoresistance over a broad temperature range from 10–240 K and affect the in-plane EB, while the highest EB is achieved for structures under maximum strain. This research highlights the importance of deliberate microstructural design in optimizing magnetic and electronic properties in spintronic devices.

**Influence of Preparation Conditions on LSMO Thin Films**

In an exhaustive study, Annese et al. investigate the role of preparation conditions on the electronic and magnetic properties of LSMO thin films, discussing their dependence on the conditions of laser fluence and oxygen partial pressure post-annealing in thicker and thinner films prepared using PLD. Indeed, thicker films exhibit tensile strain that causes MnO_6 octahedra deformation, as evidenced by Raman spectroscopy. Thinner films reveal a pronounced in-plane magnetic anisotropy, showing very strong dependence on the conditions of preparation, with evident effects on surface morphology and electronic properties.

**Influence of Deposition Parameters**

It has been tested that $La_{0.7}Sr_{0.3}MnO_3$ is under consideration as a possible candidate for multifunctional devices, memory applications, and spintronics. K. Kumari et al. (2020) have investigated change in magnetic properties of LSMO thin film upon change in oxygen concentration. Their films were deposited at various oxygen partial pressures between 10 and 250 mTorr and are all uniform in thickness of approximately 30 nm. The XRD patterns of the corresponding films indicate the synthesized materials are of high quality because they only show (00l) reflections and no secondary peaks:. The analysis of the surface morphology shows that the films are rather smooth. The film grown at 150 mTorr gives the lowest average roughness. It was observed that an increase in the oxygen concentration leads to enhancement of magnetic Tc. Phase transition improvement also observed upon $O_2$ increase concentration. This improvement is likely associated with a reduction in the amount of oxygen deficiencies and inhomogeneities at the higher oxygen growth pressures. In particular, the magnetization in 150 mTorr proved to have the highest absolute value among the others and a value T\(_C\)=340 K and this could be reasoned by the very smooth surface and a minimal number of oxygen vacancies and other defects. Furthermore, this research work directs to the fact that NRM is related to the oxygen gas pressure during growth. The films grown under different pressures in this gas exhibited differing intensities of NRM; therefore, the interplay between oxygen content, structural integrity, and magnetic properties might be very complex. These results thus impress that the optimization of performance in LSMO thin films for spintronics should focus on oxygen partial pressure. Optimization of oxygen stoichiometry is essential during thin film preparation. The research by Kumari et al. conducted research on thin film LSMO preparation while change in oxygen pressure and influence the magnetic properties. Controlled fine-tuning of these properties by the oxygen partial pressure, hence, opens new routes towards the development of advanced spintronic devices.

Boschker et al. (2011) were giving an extensive review LSMO thin film, physicochemical properties and highlighting the characterization tools such as XPS, HRTEM, XRD etc. The LSMO films showed a saturation magnetization of 4.0 μB/Mn and exhibited a Curie temperature of 350 K, along with residual resistivity as low as 60 μΩ·cm, which has already qualified the realization of high-quality films that can possess large magnetization with low residual resistivity at the same time. This reinforces the fact that optimization of the deposition process cannot be achieved by just considering one property. This requires, in turn, that all the important properties must be satisfied to obtain good films, properly adapted to device applications. These studies unanimously established the fact that the quality of thin films determines the performance. Well-grown LSMO films with their magnetic and electronic properties well optimized are very crucial for successful implementation of these materials into spintronics and multifunctional devices. In this respect, the comprehensive characterization approach by Boschker et al. is nothing but a guideline for further research and development in this field, ensuring that all relevant properties are taken into account when the deposition process is optimized. In short, the contribution by Boschker et al. throws important light on the realization of high-quality LSMO thin films. The results strongly underline the need for a detailed, comprehensive strategy of characterization in obtaining optimized films with respect to the properties sought for sophisticated device applications. This study is of critical help to further the use of LSMO in a wide variety of technological applications, more so in the field of spintronics by Boschker et al. 2011.

**Orientation-Dependent Properties of LSMO Thin Films**

Majumdar et al. 2013 review the influence of crystalline orientation on electronic structure and magnetic properties in $La_{0.7}Sr_{0.3}MnO_3$ (LSMO) films, using two orientations, namely, (001) with a c-axis out-of-plane and (110) with a c-axis in-plane. This (110) orientation does not exhibit a dead layer because of the lack of polar discontinuity at the substrate-film interface, hence showing better ferromagnetic interactions. X-ray diffraction, XPS, and magnetic analyses revealed that the more complete lattice relaxation in the (110)-oriented films reduces the electronic deformation around the La atoms and $MnO_6$ octahedra. This improved structural quality increases the Curie temperature by approximately 15 K and makes the (110)-oriented LSMO films more appropriate for applications in spintronics. However, substrate strain generates magnetic anisotropy, which is favorable for the out-of-plane domain creation-problematic for practical integration into a spintronic device. Thus, while the orientation of (110) enhanced the ferromagnetic properties, effective application in the area of spintronics demands control over magnetic anisotropy and domain structure.

**Flexible Integration of LSMO Thin Films**

Below, Huang et al. (2018) seek to apply $La_{0.67}Sr_{0.33}MnO_3$ (LSMO) thin films on flexible mica substrates with the goal of extending their use in flexible electronics and spintronic applications. PLD-prepared epitaxial LSMO films possess high crystallinity and microstructural quality and good ferromagnetic and magnetoresistance properties, with the saturation magnetization Ms at 10 K lying in the range of 125 to 400 emu/cm³ and MR ~ 45% at 5 K in a 1 T field for films deposited at 50 mTorr. Importantly, these films retain their properties even after mechanical bending-a clear indication of their very good flexibility and stability. Such properties are indispensable for flexible spintronic and electronic applications. The above study underlines the possibility to use functional oxides together with flexible substrates without any loss in performance, opening the route for a number of future applications in flexible electronics which require substrate flexibility while retaining robust magnetic and electronic properties.

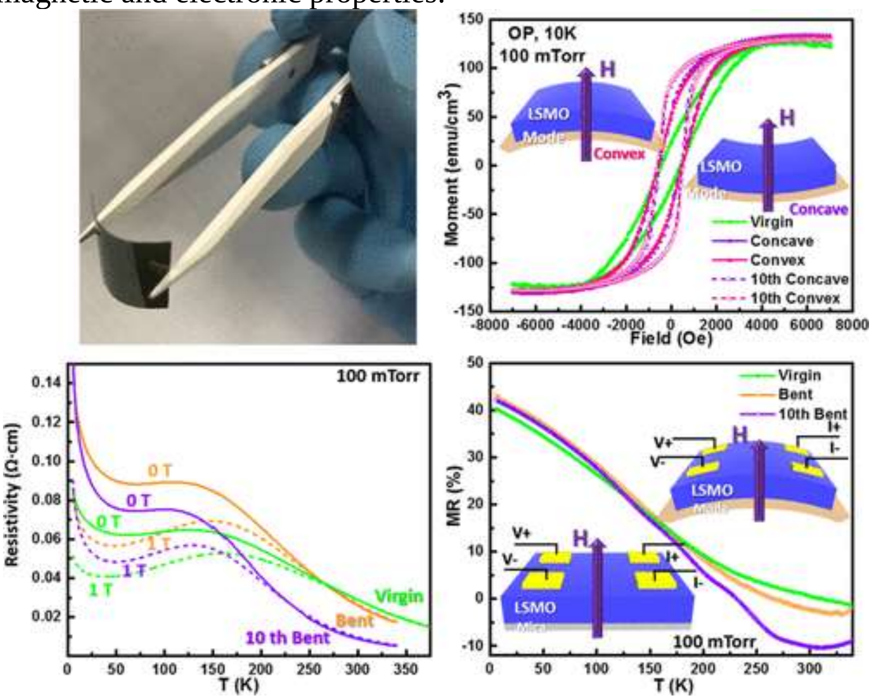


**Figure 5: Flexible $La_{0.67}Sr_{0.33}MnO_3$and its magnetic properties**(Huang et al., 2018).

**LSMO thin film properties by varying the film thickness**

Pradhan et al. 2008 present thickness-dependent properties of the $La_{0.67}Sr_{0.33}MnO_3$ (LSMO) films within a thickness range from 12 nm to 55 nm deposited by the pulsed-laser technique onto single-crystalline $SrTiO_3$ (STO) and STO-buffered Si substrates. It is observed that T_C is suppressed considerably more in LSMO films deposited on STO-buffered Si substrates compared to the films grown on STO with decreasing film thickness. In particular, a 55 nm LSMO/STO film maintains a T_C ~ 360 K near bulk values, whereas the similarly grown film on STO-buffered Si has a lowered T_C of 320 K. The T_C reduction was thus attributed to strain and interfacial disorders in LSMO on STO/Si. Similarly, surface morphological characteristics vary with film thickness, as will be seen next. Indeed, post-deposition oxygenation and annealing improve the overall magnetization of LSMO films on STO-buffered Si, mainly because of increased oxygen content, while these treatments do not significantly affect T_C. Thermomagnetic history effects evidence inhomogeneities, especially at interfaces, which are strongly affecting magnetic behavior. The substrate choice, thickness, and interfacial quality are the main parameters influencing the magnetic properties of LSMO thin films, as underlined in this paper.

**Biaxial Magnetic Anisotropy in LSMO Thin Films**

Chaluvadi et al. (2018) discussed magnetoresistance and magnetic anisotropy of half-metallic $La_{0.67}Sr_{0.33}MnO_3$ (LSMO) films deposited on MgO (001) substrates with a $SrTiO_3$ (STO) buffer layer. Vectorial Magneto-Optical Kerr Magnetometry applied within the study reveals that films at room temperature possess purely biaxial magnetic anisotropy, free of uniaxial anisotropies that may be detrimental in spintronic applications. The magnetization reversal angular evolution, as well as that of the critical fields-like coercivity and switching fields, was analyzed, showing that the magnetocrystalline anisotropy exhibits a fourfold symmetry, rather well defined, in temperature, too. Control of magnetic anisotropy is an essential task for the improvement of magnetoresistance effects; for this reason, LSMO films are particularly suitable for spintronics applications. It points out that the optimization of the magnetic and electronic properties clearly depends on critical parameter tuning, such as film thickness, substrate, and oxygenation treatments; hence, biaxial anisotropy is of crucial advantage for the engineering of spintronic devices.

**Tunable Multiferroic Heterostructures: CFO/LSMO/LAO**

Haque et al. present an investigation into the structural and magnetic properties of LAO/LSMO/CFO heterostructures grown by PLD. XRD confirms crystalline growth, and the rocking curve gives a full-width at half-maximum of 0.37° for the LSMO (200) peak, indicating excellent out-of-plane orientation. As verified by TEM, the structural composition is homogeneous, while SEM-EDX confirms homogeneity in the elemental composition. Static magnetization experiments show a ferromagnetic hysteresis loop with a coercive field of 327 Oe for LSMO films at room temperature. The thickness dependence of the CFO layer has been further investigated, and as a result, obtained the optimum CFO thickness of ~40 nm with a coercive field of 792 Oe. Dynamic magnetism measurements by ferromagnetic resonance spectroscopy give, in addition, evidence that the Gilbert damping parameter is low, ~0.037, in the LSMO/LAO structure due to spin-orbit coupling, with a gyromagnetic ratio of 0.002 GHz/Oe-values commensurate with applications in spintronics. The present work underlines the great possibilities offered by LSMO/LAO/CFO heterostructures for engineering magnetic properties toward optimized performance in spintronics.

**Silicon-based thin film**

Carrero et al. discussed a detailed nanoscale structural characterization of $La_{0.66}Sr_{0.33}MnO_3$ thin films deposited by PLD on buffered Si (100) substrates. The thin film composed of $Y_{0.13}Zr_{0.87}O_2$ and $CeO_2$. XRD, HRTEM analysis confirmed the thin film characteristics. Magnetic and electric measurements show ferromagnetic and metallic behavior at low temperatures across various film thicknesses, with strain and defects notably affecting films thinner than 15 nm.

**Superparamagnetic State in LSMO**

Ramírez Camacho et al. present the presence of superparamagnetic state in high-quality $La_{0.7}Sr_{0.3}MnO_3$ (LSMO) thin films deposited on $SiO_x$ /Si (100) substrates by using RF sputtering. In such nanostructured films, no grain boundary is observed, though they contain locally epitaxial nanoregions with an out-of-plane (012) orientation. The thick films of 140 nm are ferromagnetically ordered, whereas the thinner films exhibit superparamagnetic behavior for 40 and 60 nm, which is attributed to interacting ferromagnetic monodomain nanoregions due to surface spin-glass structures. The large coercive fields obtained for these films signal great prospects of this system in integration with Si-based nanodevices for spintronic application. This finding opens a new way towards tuning magnetic properties in LSMO thin films for next-generation spintronic devices.

**LSMO/LaFeO$_3$ Bilayer**

Gopalarao et al. report on the magnetic and electrical transport properties of LSMO/LaFeO3 bilayers grown on (001) oriented LaAlO3 substrates by RF magnetron sputtering: Gopalarao et al. (2017). XRD analysis reveals an out-of-plane tensile strain that decreases with film thickness. Magnetic measurements yield a ferromagnetic transition temperature ranging from 290 K for a film thickness of 30 nm to 332 K for a 200 nm thick film. M - H loops measured at 50 K exhibit increased saturation magnetization with thickness. Electron magnetic resonance spectra display ferromagnetic resonance peaks that sharpen and shift to lower field for increasing thickness.

**Epitaxial LSMO Thin Films on Silicon**

Vila-Fungueiriño et al. describe the elaboration of high-quality $La_{0.7}Sr_{0.3}MnO_3$ (LSMO) epitaxial thin films grown on silicon substrates by combining chemical solution deposition and molecular beam epitaxy. They show the possibility of precise tuning of coercive fields by mosaicity control of the STO/Si buffer layer. This work is just one way to merge physical and chemical deposition techniques. The approach here is prescriptive of a path toward low-cost, oxide-based devices compatible with CMOS technology and emphasizes the possibility to scale up the fabrication of functional devices for applications within and outside spintronics.

**Applications in Spintronics**

The review article by Cesaria et al. (2011) covers a wide array of applications for LSMO thin films in the emerging field of organic spintronics. As LSMO is a fully spin-polarized charge carrier material, there are huge possibilities for it to be used in spintronic devices exploiting the spin in addition to the charge of the electrons to enhance the functionality and performance. Given the unique properties of LSMO, spintronics, a field aimed at creating more efficient and versatile electronic devices, greatly benefits from it, thus driving ongoing research and development in this area (Cesaria et al., 2011). In growing LSMO thin films, there exist large opportunities for PLD to help with improvements in spintronics. Control and optimization of the different properties of such films by deposition are regarded as key techniques for the development of next-generation spintronic devices. Manuel Bibes and Agnès Barthélémy reviewed advances in oxide spintronics connected with the growth of high-quality oxide thin films and heterostructures. They highlighted the initial motivation behind oxide spintronics due to high-temperature superconductivity in perovskite copper oxides and the subsequent discovery of colossal magnetoresistance in manganite films. The review emphasizes the significant role of manganites in magnetic tunnel junctions and the latest developments in diluted magnetic oxides and multiferroics, providing a comprehensive overview of the field's progress and future directions(Bibes& Barthelemy, 2007).

**Gaps in the Literature**

Despite significant advancements in the study of LSMO thin films, several gaps in the literature remain that hinder the full realization of their potential in spintronic applications. One of the primary gaps is the limited understanding of the interplay between the microstructural characteristics and the resulting magnetic and electronic properties of LSMO thin films. While numerous studies have focused on individual aspects such as film thickness, oxygen stoichiometry, and substrate effects, a comprehensive understanding that integrates these factors holistically is still lacking. Additionally, most research has been conducted on rigid substrates, leaving a substantial gap in the exploration of flexible and stretchable substrates which are crucial for the development of next-generation flexible electronics.

Another critical gap is the limited exploration of the long-term stability and reliability of LSMO thin films in practical device environments. While laboratory studies have demonstrated promising properties, the behavior of these films under prolonged operational conditions, including exposure to varying temperatures, humidity, and mechanical stresses, remains underexplored. This gap is particularly pertinent for applications in wearable and flexible electronics, where materials are subjected to continuous deformation and environmental fluctuations.

Surface treatment and incorporating with other material tailor the thin film properties. In addition, many investigations reported in the literature deal with bulk properties and hardly touch on interfacial phenomena, very relevant for the performance of spintronic devices. Moreover, only a few studies have been conducted on the scalability of deposition techniques for industrial-scale applications to commercialize LSMO-based technologies. Only by a multidisciplinary approach will it be possible to overcome these shortcomings by state-of-the-art characterization and theoretical modeling combined with test devices. Future studies should therefore be focused on establishing a much deeper understanding of microstructural-property relationships, long-term reliability in different environments, and the scalable fabrication routes for LSMO films. It is only by filling these gaps that the full potential for LSMO thin films within spintronics and other state-of-the-art electronic applications will be realized.First, it is eventually possible to control the deposition and post-deposit annealing parameters of LSMO thin films so as to engineer their structural, morphological, and electronic properties. Second, in an effort to understand this, the changes of magnetoresistance behavior by cobalt doping were elaborated, providing new insight into the optimization of such materials for state-of-the-art technological applications.

**Conclusion**

The literature review gives an overview of LSMO thin film fabrication and electronic and spintronics application. LSMO thin films remain one of the key focal points in materials science research due to their interesting magnetic and electronic properties. Advances in thin film deposition techniques and surface treatments have contributed greatly to enhancing the properties and functionality of LSMO based thin films. The literatures clearly indicate that the control of the fabrication parameters, atomic precision, is required for desired properties, such as oxygen stoichiometry and film thickness. Characterization techniques have been instrumental in gaining deep insight into both the structural and magnetic behaviors of LSMO thin films and have opened the way toward integration into spintronic devices. The optimization of these properties is desirable, and new applications in spintronics and beyond can be realized. These gaps and challenges further reflect that additional research in this area is required.

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