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Tuning the Electrical behaviour in LAO/STO Heterointerface

T. Shiyani[1, 2*]

[1]School of Nanosciences, Central University of Gujarat, Gandhinagar-382030, India.
[2]Shiyani Research Institute, Rajkot-360003, India.
[*]Corresponding author: E-mail: tms@outlook.in, Phone: +91-0281-2702628

ABSTRACT

High quality epitaxial $LaAlO_3$ (LAO) thin films were grown by pulsed laser deposition (PLD) technique on $SrTiO_3$ (STO, 001) with 2-10 uc thickness. LAO has a direct band gap 1.8 eV, which is optimal to separate the photo generated electron-hole pairs. Experimental evidence of electrical properties of the confined electron gas at the $LaAlO_3$-$SrTiO_3$ interface is provided by four probe transport measurements. The conductivity is two-dimensional refer to it as a two-dimensional electron gas (2DEG). Structural geometries are used to show the dependence of the resistivity with temperature and LAO thickness. LAO and STO both are non-magnetic insulators but LAO/STO interfaces with thickness 4-10 uc are conductive and insulator below 2 uc thickness. These results provide insight into the possible motivating mechanisms of the emerging properties at oxide interfaces and demonstrate a novel conducting system with promising applications in solar cells. Oxide perovskites made of transition metal oxides are an upcoming class of materials that may replace conventional semiconductors for photovoltaic applications.

KEY WORDS: LAO, STO, heterointerface, photovoltaic.

***Corresponding author**

T. Shiyani

School of Nanosciences, Central University of Gujarat, Gandhinagar-382030, India.

Shiyani Research Institute, Rajkot-360003, India.

E-mail: tms@outlook.in, Phone: +91-0281-2702628

INTRODUCTION

Lanthanum aluminate is an inorganic compound with the formula $LaAlO_3$ (LAO). It is a polar material as LaO layer has +1 charge and AlO_2 layer has -1 charge. It is an optically transparent ceramic oxide with a distorted perovskite structure, ABO_3, where A is large cation and B is a small cation. The structural phase transitions are often observed as a function of external parameters like temperature or pressure. The structure of $LaAlO_3$ is rhombohedral at room temperature and usually defined as hexagonal with space group R-3c. The lattice parameters are a = 0.536 nm and c = 1.311 nm. LAO is also structurally compatible with many functional compounds, like manganites, superconductors, ferroelectrics, and semiconductors. LAO is also a band insulator with optical band gap around 5 eV. The reasonably small lattice mismatch of 3% to STO and similarity of the thermal expansion coefficients allow the epitaxial growth of LAO films on $SrTiO_3$ (STO). STO has a relatively large, indirect band gap of 3.25 eV this implies it is a band insulator. STO can be made metallic by creating the oxygen vacancies after heating the sample to more than 800 °C in low oxygen pressures [1-2].

The class of transition metal oxide compounds exhibit a broad range of functional properties, such as piezoelectricity, ferroelectricity, superconductivity, colossal magnetoresistance, ferromagnetism and photovoltaic. All these phenomenon result from strongly correlated electronic behavior and turned out to be very sensitive to external parameters such as electromagnetic fields and internal or external pressure. Epitaxially grown thin films of LAO can serve various purposes for correlated electrons heterostructures and devices. The widespread observation of conductivity at the interface of LAO/STO has stimulated considerable interest in potential applications [3–4]. Oxygen vacancies can actually dominate the transport properties of LAO films that are fabricated at too low oxygen partial pressures. The conducting quasi-two dimensional electron system (q2DES) formed at the interface between LAO and STO band insulators is confronting the condensed matter physics community with new paradigms. Transition metal oxides and its heterostructures are future materials that may replace semiconductors for device applications. As of 2015, there are no commercial applications of the $LaAlO_3/SrTiO_3$ interface [5]. However, speculative applications have been suggested, including field effect transistors, sensors, photodetectors, thermoelectric and functional solar cell. Oxide heterostructures have been exploited with unique properties to fabricate high efficient solar cells [6-8].

EXPERIMENTAL SECTION

LAO films were grown on TiO_2-terminated (001) STO substrate by pulsed laser deposition (PLD) technique using a 248 nm excimer laser at a repetition rate of 2 Hz, an energy of 300 mJ, and a spot area of nominally 1 × 10 mm^2. A high-power laser ablates a LAO target, and the plume of ejected material is deposited onto a heated STO substrate. Substrate size was 2.5 x 5 mm for each sample. The substrate temperature was 700 ˚C and the oxygen partial pressure was maintained at 10 mTorr during deposition [9-10]. Fig. 1 shows the schematic representation of PLD method. Substrates were cooled down to room temperature in 10 mTorr O_2 immediately after the deposition of films. This anneal treatment resulted in a very smooth surface with well defined unit cell steps separating the individual terraces. LAO thin films were fabricated with thickness of 2-10 uc. Thickness measurement was performed using Veeco profilometers. Device configuration was made by depositing silver on LAO films using using thermal evaporation. Temperature dependent I-V measurements were performed by closed cycle refrigerator (CCR) from room temperature to 10K with a device geometry as shown in Fig. 2 [11-12].

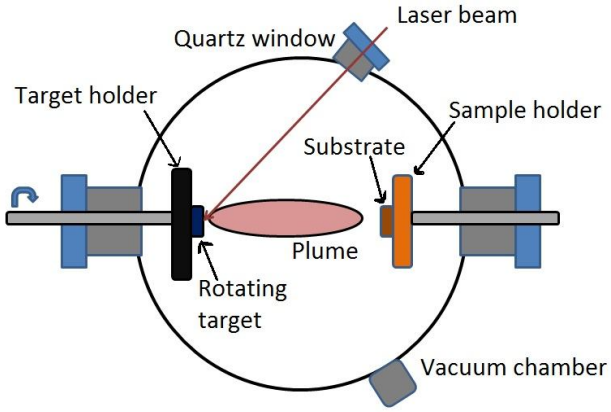

Fig. 1. Schematic representation of pulsed laser deposition method.

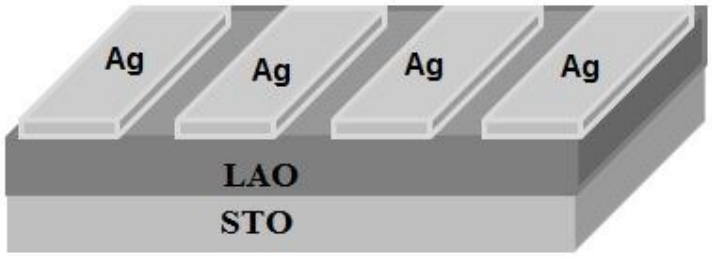

Fig. 2. The schematic representation of LAO/STO thin films for device application.

RESULT AND DISCUSSION

We have tuned the I-V behaviour with varying thickness of LAO thin films to explore the interfaces and to understand the driving mechanisms behind the emerging properties in LAO/STO thin films. The interface between LAO and STO is a notable materials interface because it exhibits properties not found in its constituent materials [13-15]. The interface of LAO and STO gives a metallic interface layer. LAO/STO interface is electrically conductive such as metal under specific conditions. All LAO/STO interfaces are not conductive. The conductivity is achieved only when the interface is along the (001) crystallographic direction and having LAO thickness at least 4 uc. Thickness and temperature dependent R(=V/I) behaviour is shown in Fig. 3. This shows that films are conducting with thickness more than 4 uc and insulating with thickness of 2 uc. The value of measured resistance is upto 140 kΩ in conducting films. The $SrTiO_3$ side of the interface is TiO_2-terminated (causing the $LaAlO_3$ side of the interface to be LaO-terminated). The LAO layer should have to be thick at least 4 uc to make conducting interface. Resistivity measurements were performed in a bar geometry by four probe method. The resistivity is plotted as a function of the temperature in Fig. 4. A photovoltaic effect has been observed in LAO in mV range without any bias at ambient temperature under the irradiation of light [16].

Polar gating was the first mechanism used to explain the conductivity at LAO/STO interfaces [17]. When the LAO layer grows thicker than 2 unit cells, its valence band energy rises above the Fermi level, causing holes (or positively charged oxygen vacancies to form on the outer surface of the LAO. The positive charge on the surface of the LAO attracts a negative charge to nearby available states. The strengths of the polar gating hypothesis are that it explains why conductivity requires a critical thickness of four unit cells of $LaAlO_3$ and that it explains why conductivity requires the $SrTiO_3$ to be TiO_2-terminated. The hypothesis has also been called the electronic reconstruction hypothesis, highlighting the fact that electrons move to compensate the building voltage [18-19]. The study of how these properties emerge at the LAO/STO interface is a growing area of research in condensed matter physics [20].

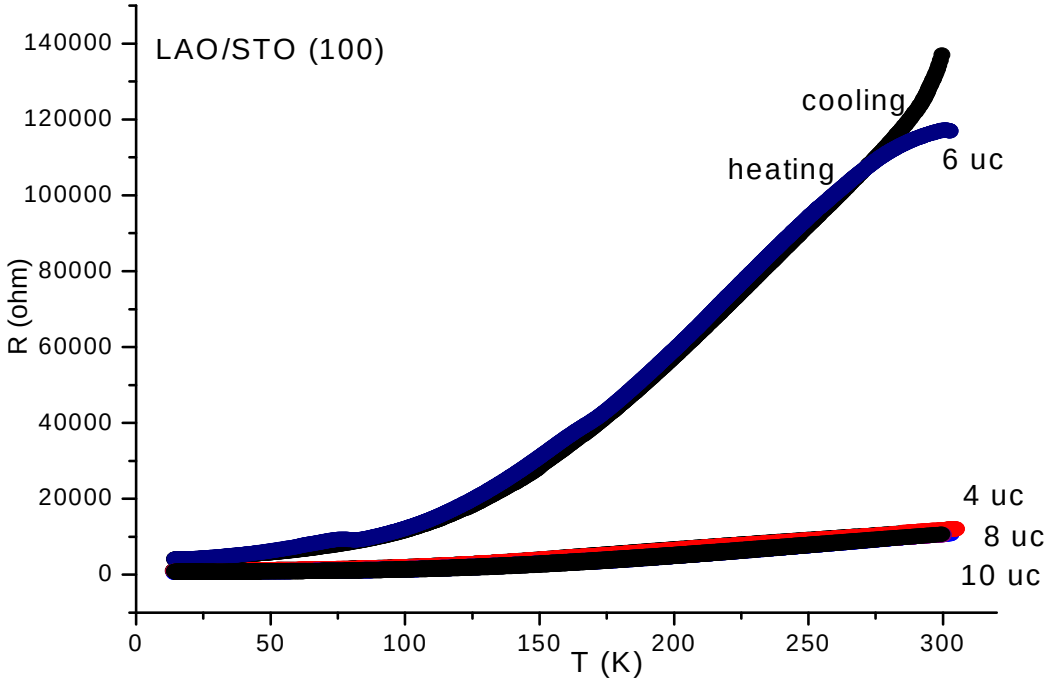

Fig. 3. Temperature dependent resistance of LAO/STO with different thickness.

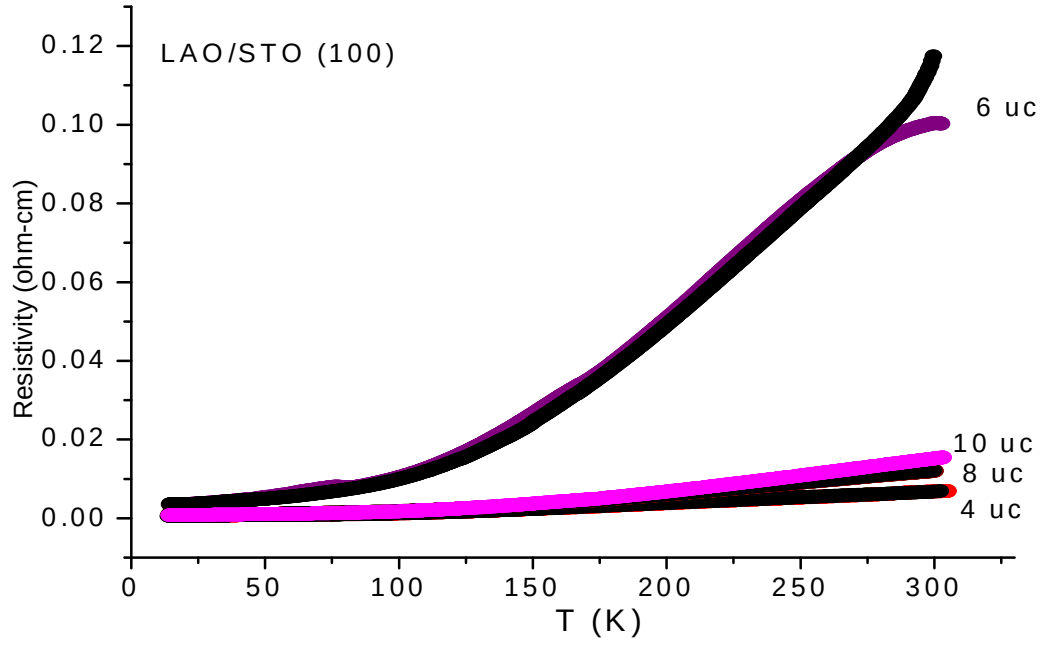

Fig. 4. Temperature dependent resistivity of LAO/STO with different thickness.

CONCLUSION

Epitaxial and stoichiometric $LaAlO_3$ films were grown on TiO_2-terminated (001) $SrTiO_3$ substrate by PLD technique. Intermixing of layers has a pronounced effect on the valence band offset, and this effect may have important implications for the mechanism of electrical conductivity at the LAO/STO interface. This represents an additional control mechanism for modification of the electrical properties of heterointerfaces. We have observed electrical transport properties for 2DEGs at the LAO/STO interface. It was found that LAO/STO interface is conducting for LAO films with thickness of 4-10 uc and insulator with thickness of 2 uc. This tuning of electrical characteristics in LAO/STO interface demonstrates the importance of controlled surface preparation. This phenomenon will enable new structures and devices that exploit nanoscale interface engineering.

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