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# Pulsed laser deposition of $LaNiO_3$ and $YBa_2Cu_3O_{7-\delta}/LaNiO_3$ on $SrTiO_3$ buffered (100) MgO

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**Abstract**

Multilayer structure $YBa_2Cu_3O_{7-\delta}$ (YBCO)/$LaNiO_3$ (LNO)/$SrTiO_3$ (STO)/MgO has been carefully studied in the hope that it can be used for applications such as quasiparticle injection or Josephson junction fabrication. Deposited by pulsed laser, LNO on STO-buffered (100) MgO has low resistivity, good metallic characteristics, and very smooth surface (with a mean-square-root roughness of less than 3 nm). After the deposition of LNO, YBCO film can be grown in situ on it, showing good superconducting properties with a critical temperature above 81 K and a narrow transition width below 1.5 K. X-ray diffraction analyses have indicated that all the deposited films are highly *c*-axis-oriented.



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*Keywords:* Laser ablation; Multilayers; Oxides; Electronic devices

## 1. Introduction

Multilayer heterostructures, containing high temperature superconducting (HTS) films and/or ferroelectric films and/or conducting films, have been fabricated for possible electronic applications. For example, the ferroelectric film in a ferroelectric/superconducting multilayer can be used to tune the filter made of the superconducting film; a conductive film in a similar structure can be used as an electrode through which quasiparticles are injected into the superconducting film; a multilayer can be the candidate for a Josephson junction (such as a superconductor–normal metal–superconductor junction); etc. Obviously, in any multilayer structures, the interfaces between various layers and their epitaxial growth are the most important issues, and these topics have attracted the interest of many researchers. In particular, much attention has been paid to the conductive oxide $LaNiO_3$ (LNO) for a few more reasons in addition to what were mentioned above [1]: first, LNO is of perovskite-type possessing a pseudo-cubic lattice parameter of 0.383 nm, which matches well with those of $YBa_2Cu_3O_{7-\delta}$ (YBCO) ($a=0.382$ nm, $b=0.389$ nm) and those of ferroelectric films such as $PbTiO_3$, $Pb(ZrTi)O_3$ and $BaTiO_3$; second, it can be easily synthesized at much lower temperatures than other metal oxides such as $Sr_{1-x}Ca_xRuO_3$ and $SrRuO_3$; third, with multilayers containing LNO, the diffusion of ions into YBCO during fabrication may be smaller than with multilayers of other materials containing divalent ions such as $Sr^{2+}$ or $Ca^{2+}$; finally, LNO has only two metal ions in it and its composition is thus easier to reproduce during deposition than other materials with more ions.

Significant understanding of LNO has been attained through numerous experiments and theoretical analyses [1–10]. Using pulsed laser depositions (PLD), several research groups [11–16] have successfully grown LNO and/or superconducting films on $SrTiO_3$ (STO) and $LaAlO_3$ (LAO) substrates. However, when applications at high frequencies (microwave, millimeter wave, and far-infrared wavebands) are concerned, MgO is a better substrate than STO or LAO because of the fact that its dielectric constant is smaller and its loss lower. Our research has thus been focused on how to fabricate LNO thin film on (100) MgO substrate. As it is difficult for

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LNO to grow epitaxially on (100) MgO substrate due to large lattice mismatch, we introduce STO as a buffer layer. Besides, high quality superconducting YBCO thin film can be successfully fabricated in situ on top of the above structure. In this paper all the details of the work will be reported and discussed.

## 2. Experimental details

All the films are fabricated in situ using PLD (KrF Excimer Laser COMPex 205 working at 248 nm) with an intensity of 3 J/cm$^2$ and a repetition rate of 8 Hz. The depositing gas is highly pure oxygen ($\geq$99.999 95%).

Parallel to each other, the substrate and the target are about 4.5 cm away. The target is rotating during the ablation process in order to reduce nonuniform erosion. All the materials used to fabricate the targets are of high purity (99.99% or more). During fabrication, STO, LNO, and YBCO are deposited in sequence, of course under different conditions. To make the descriptions concise, we list in Table 1 all the optimal conditions we have found. Used in the experiments for characterizing various items are X-ray diffraction with Cu Kα radiation for crystallinity (XRD, Rigaku D/Max RA X-ray diffractometer with a rotating anode), atomic force microscopy in contacting mode for surface morphology and roughness of the films (AFM, MultiMode Nanoscope III, which is a scanning probe microscope operated in contacting, non-contacting or tapping modes), and XP-2 Surface Profiler for the thickness of each layer after it is fabricated. And standard four probe measurements with silver contacts are carried out to study the electrical and superconducting properties of the multilayer structures in a liquid nitrogen system (in the 78–300 K range).

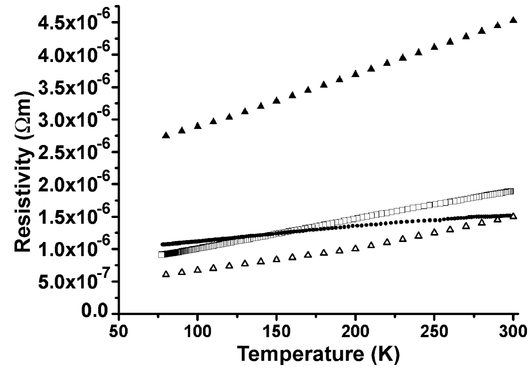


Fig. 1. Resistance vs. temperature curves (dots) of the LNO film grown on STO buffered (100) MgO Substrate. Values taken from other groups' experiments (triangles and squares) are also shown.

## 3. Results and discussions

Fig. 1 gives the experimental resistance–temperature ($R-T$) curve of the LNO film (solid dots). For comparison, data from previous authors are also included where solid triangles are for a sample fabricated at the substrate temperature of 610 °C [13], hollow triangles for a sample fabricated at 700 °C [13], and hollow squares for a sample fabricated at 650 °C [16]. Although the slope of our curve is slightly different from others, it exhibits a good metallic behavior from $1.52\times10^{-6}$ Ω m at 300 K to $1.07\times10^{-6}$ Ω m at 78 K. Note that no special annealing for LNO has been done in the whole process. This means LNO is less sensitive

Table 1.
Conditions for depositing various layers

| Step | Purpose | Substrate and its temperature °C | Depostion rate (nm/min) | Thickness of the deposited film (nm) | Gas pressure (Pa) |
|---|---|---|---|---|---|
| 1 | Deposition of STO onto MgO | MgO ($3\times10\times0.5$ mm$^3$), 700 | 6 | 30 | 15 |
| 2 | Deposition of LNO onto STO/MgO | STO/MgO, 650 | 8 | 40 | 20 |
| 3 | Deposition of YBCO onto LNO/STO/MgO | LNO/STO/MgO, 770 The finished YBCO/LNO/STO/MgO are kept at 540 °C in 1 atm of oxygen for 20 min so that correct stoichiometry can be obtained in YBCO | 10 | 100 | 30 |
| | A bare sample of LNO/STO/MgO is exposed to the same heat treatment as though YBCO was deposited so that it can be used as a reference for comparison | LNO/STO/MgO, 770 The sample is kept at 540 °C in 1 atm of oxygen for 20 min | | | 30 |