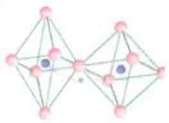
昆明理工大学

（Kunming University of Science and Technology）

光电子新材料研究所



（Institute of Advanced Materials for Photoelectronic）

2005～2007论文集

（第三集）

KMUST•IAMPE

昆明.中国

Kunming. China

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序

二十一世纪将是材料与冶金科学大显身手的世纪，光电子功能材料作为各种光电转换器件的基础，将广泛应用于信息工业、能源产业、航空航天、军事等国民经济的各个领域。

我校的光电子新材料研究所在张鹏翔教授的带领下，正是以光电子、纳米功能材料研究作为自己的方向。在原子层热电压材料及器件的研究中，形成了一支研发能力较强的科研队伍，取得了国际领先的研究成果，发表了一些高质量的学术论文，为该领域的研究和发展作出了贡献。在这样的背景下，有必要总结和推广其经验，以便同其他兄弟单位、院校进行学术成果交流、开阔视野、相互提高。为此昆明理工大学光电子新材料研究所决定将 2005～2007 年在国内外公开发表的学术论文编辑成册。

在此，我非常支持和期待本论文集的编辑出版成功，并衷心的祝愿贵所在今后的研究中取得更大的进步和更多优秀成果。

戴永年

2007年12月

❖❖ 2004 年（补充部分）❖❖

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2005年4月 CHINESE JOURNAL OF LIGHT SCATTERING Apr. 2005

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Strain Effects on Physical Properties of $La_{1-x}Sr_xMnO_3$ Thin Films

应变对 $La_{1-x}Sr_xMnO_3$ 薄膜的物理性质的影响

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Both tensile strain and compressive strain effects on the properties of $La_{1-x}Sr_xMnO_3$ ($x=0.1$) films were investigated. The films on $SrTiO_3$(100) display 'unusual' tensile strain[1], which supports a ferromagnetic metallic behavior when film thickness is larger than 10nm. The films on $NdGaO_3$(100) presenting compressive strain, on the other hand, demonstrate strongly enhanced insulating behavior.

In order to obtain unambiguous results, all film samples were prepared using the same deposition conditions. Several groups of film with thickness from 10nm to 200nm for both tensile and compressive strain were fabricated and used to perform the related measurements. Furthermore, to be sure that the resultant behaviors are mainly owing to epitaxial strain, careful analysis is done based on the comparative study of defect models[2], different deposition conditions, other reported results[3], as well as our experimental results. Because low deposition temperature (in our experiments, 790℃) tends to cause island growth, which always results in the occurrence of the second phase (physical phase), high deposition temperature is employed (850℃) to get single-phase samples. For the films on $NdGaO_3$ substrate, magnetic measurements were not carried out due to the fact that $NdGaO_3$ is a magnetic material, which easily blurs out the intrinsic magnetic behavior of film (due to its much smaller quantity). We noted that the films on $NdGaO_3$ behaves unlike bulk materials do up to 200nm[1], which means the strain is not fully released, while the behaviors of films on $SrTiO_3$ quickly converge to those of bulk materials when film thickness is larger than 10nm even the mismatch between substrate and film material (absolute value) for the latter is smaller than that of the former. X-ray diffraction is performed to determine the extent of epitaxy of films (Fig.1), the films on $NdGaO_3$ illustrate$^{[110]}$ orientation (because $NdGaO_3$ is a distorted perovskite) and the films on $SrTiO_3$, are of$^{[001]}$ orientation. Physical properties are collected in Fig.2. The resistivity on the insulating side can be fitted well using adiabatic small polaron model, in which resistivity can be expressed as: $\rho \propto T\exp(E_p/2K_BT)$[4]. It is clear that for films under tensile strain (on $SrTiO_3$), insulator-metal transition is observed (Fig.2 (b)), the binding energy of small polaron EP becomes large with increasing thickness, while for films under compressive strain (on

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$NdGaO_3$), the insulator－metal transition is not observed, EP becomes small with increasing thickness.

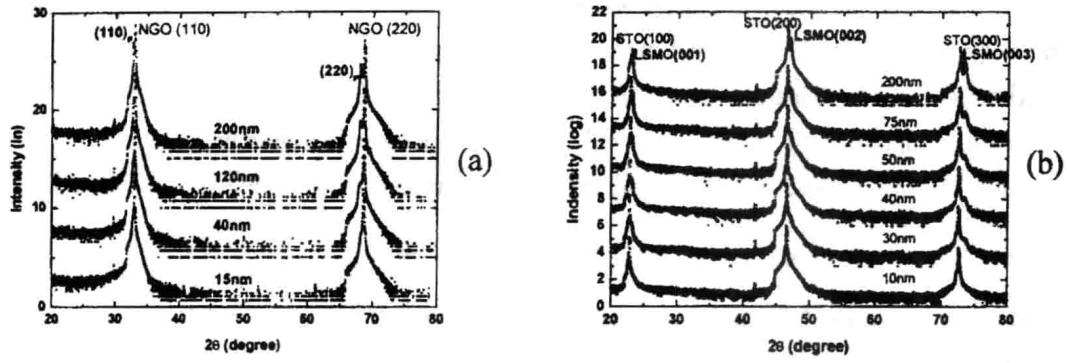

Fig. 1 X－ray diffraction patterns for the films on $NdGaO_3$(100) and $SrTiO_3$(100) substrates.

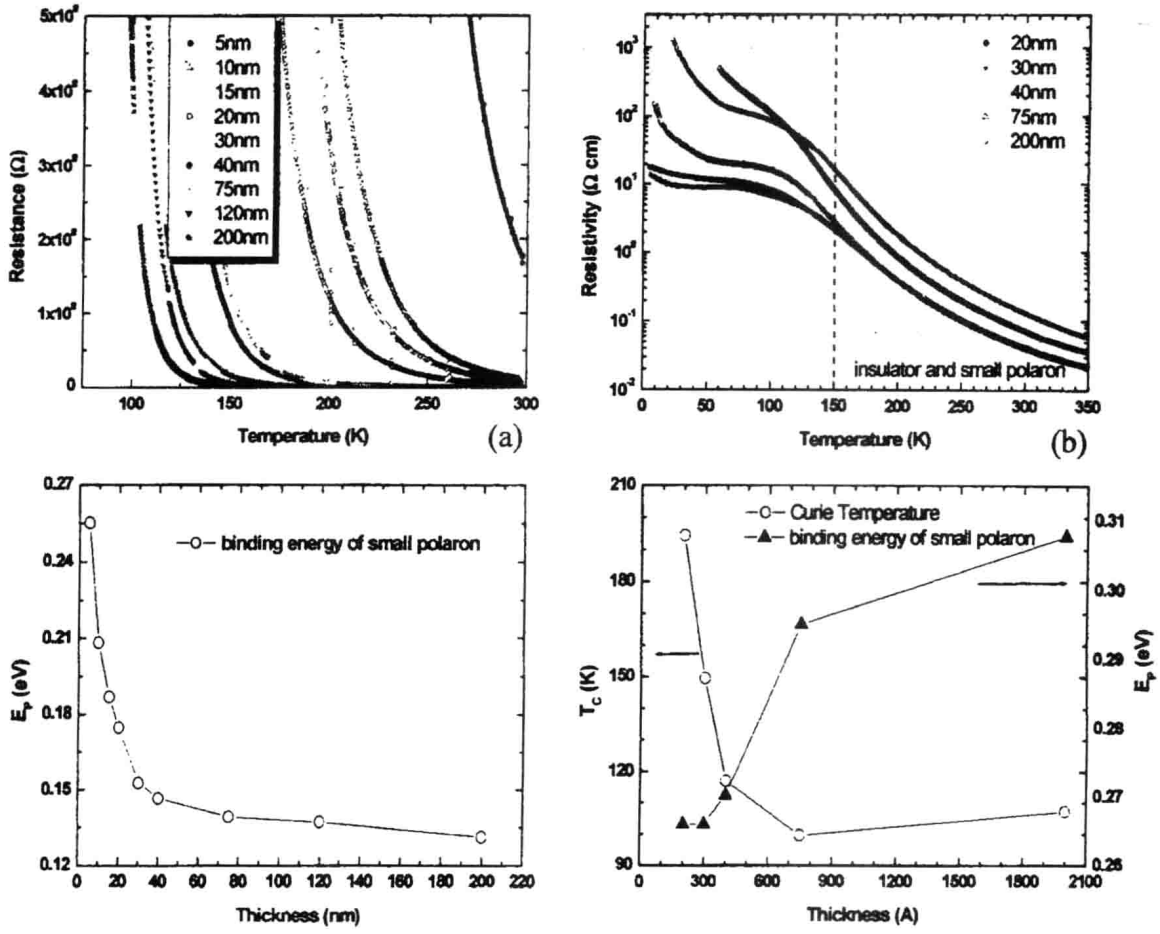

Fig. 2 (a) resistivity vs. temperature, and binding energy of small polaron (E_p as a function of film thickness) of films on $NdGaO_3$; (b) resistivity vs. temperature, E_p and ferromagnetic transition temperature (T_C, as a function of film thickness) of films on $SrTiO_3$.

A model based on strain effects on Mn－O bond length and Mn－O－Mn bond angle, therefore, on double exchange, superexchange, as well as on stability of orbital ordering, is proposed to interpret the

experimental results: when lattice mismatch is small, change in Mn－O－Mn bond angle is dominant and determines physical properties of films; when mismatch is large, alteration in Mn－O bond length is the main effect of strain and determines properties of films, however it plays an opposite role compared with bond angle; if modifications in bond angle and bond length can be comparable, the films will display complicated behaviors, for instance, in the case of films on $LaSrGaO_4$(001) (not shown here).

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Properties of $La_{1-x}Sr_xMnO_3$ Ultra-Thin Films on $SrTiO_3(100)$*

$SrTiO_3(100)$上 $La_{1-x}Sr_xMnO_3$ 超薄膜的特性

ZHANG H.[1,2,3], ZHANG P.X.[1,2,3], ZHANG G.Y.[1,3],
YU L.[2,3], G.Cristiani[2], H.U.Habermeier[2,3]

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In this paper, we briefly report the property difference of $La_{1-x}Sr_xMnO_3(x=0.1)$ ultra-thin films ($^{[001]}$ orientation) at different thickness grown on $SrTiO_3(100)$ substrate. It is found that the magnetic interaction is greatly enhanced when film thickness is between 5nm-10nm.

The film samples were prepared using standard pulsed laser deposition (PLD) technique. Transport property and magnetic property were measured and atomic force microscope (AFM) was employed to determine the growth mode of films. The orientation of ultra-thin film was exptrapolated through analyzing X-ray diffraction data of thicker films. There is no any other phase (physical or chemical phase) detected in the films grown at high (850℃) deposition temperature (FHDT). Furthermore, FHDT always show step-flow growth, while the films at low (790℃) deposition temperature (FLDT) are dominant by island growth, simultaneously with the second phase (physical phase) showing up when film thickness is larger than 10nm. Both ferromagnetic transition temperature (TC) and insulator-metal transition temperature (TP) of ultra-thin FHDT is substantially higher than those of ultra-thin FLDT, while the properties of very thick films gradually converge to those of bulk material, which implies that stoichiometric films are achieved. In order to obtain reliable results, several sets of ultra-thin films samples were prepared using the same deposition conditions. The difference between the physical properties of FLDT and FHDT can be attributed to their different strain state. A distinct critical thickness (~5nm) for ultra-thin FHDT was found, which divided the ultra-thin FHDT into two regimes according to their quite different physical properties. The physical properties are independent of growth modes when film thickness is less than 5nm (Fig.1). A complete physical phase-diagram of FHDT is constructed (Fig.2). Apart from strain effect, some unknown effects should be involved in, which compete and are comparable with strain effect, when thickness is between 5nm and 10nm. There is an abrupt increase the magnetic properties in 5nm-10nm region of FHDT, where both TC and TP of these films demonstrate higher value than other films. The magnetic enhancement in ultra-thin films makes it very interesting for application. On the other hand, the abrupt increase of insulating property with decreasing thickness (below 5nm), which strongly suggests the existence of physics unknown to us. The behaviors of thicker films (>10nm) can be understood within the frame of strain effect. However, the magnetization increas

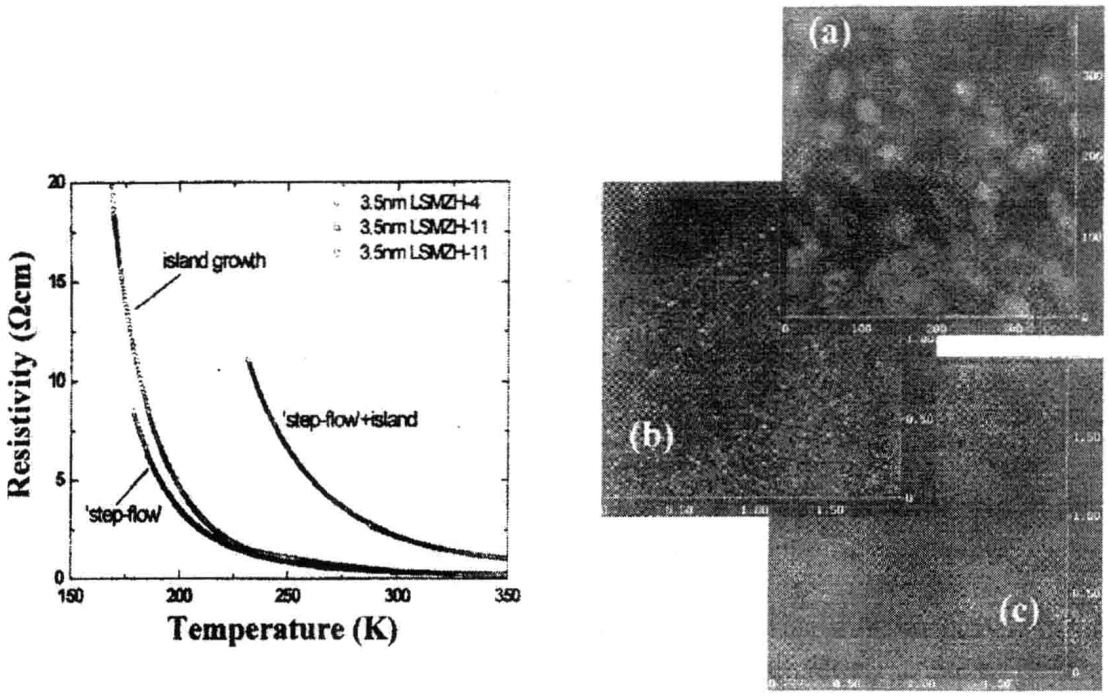

Fig. 1 Left: temperature dependence of resistivity of 3.5 nm thickness films (FHDT); Right: growth modes, which are corresponding to the samples for resistivity measurements on lift side. The height of step is typical one unit cell (0.3 nm - 0.5 nm) [(a): island growth; (b) island + 'step - flow' growth; (c) step - flow growth].

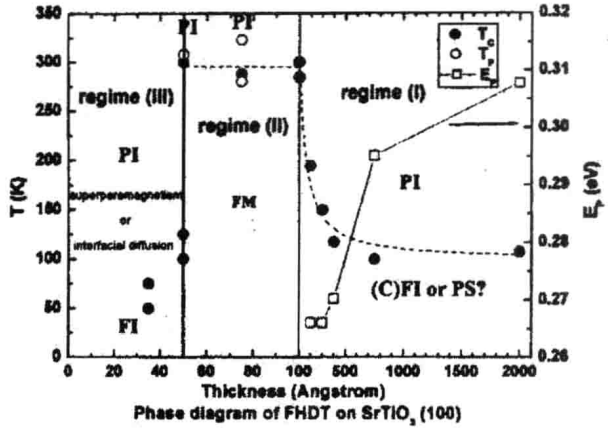

Fig. 2 Physical phase diagram of FHDT. E_p: binding energy of small polaron; PI: paramagnetic insulator; FI: ferromagnetic insulator; FM: ferromagnetic metal.

es with decreasing thickness and arrives to a saturated value in the thickness range of 5nm to 10nm. This magnetic enhancement strongly indicates that the ground state of thicker films or bulk material might be canted (anti) ferromagnetic insulator[1] or a state of so - called phase separation[2]. Moreover, we also noted that even for ultra - thin films (5nm < thickness < 10nm), TP is always larger than TC. Sometimes, the temperature difference between TP and TC can be as high as ~40K. To understand the full phase diagram, further studies are needed.

In conclusion, the comparative study of FHDT and FLDT, firstly, allows one to find out the opti-