Terahertz conductivity across the insulator-metal transition of epitaxial Praseodymium Nickel Oxide thin films

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***Abstract*—Here we report the low energy (0.8 - 7 meV) charge dynamics probed by Terahertz time domain transmission spectroscopy on 40 nm thick $PrNiO_3$ (PNO) thin films deposited on the $(LaAlO_3)_{0.3}(Sr_2TaAlO_6)_{0.7}$ (LSAT) (110) substrate grown by pulsed laser deposition method. We have experimentally investigated both complex dielectric constant and optical conductivity spectra with respect to temperature ranging from 5 K to 300 K. Terahertz optical conductivity for PNO thin films shows two *I-M* transitions at 130 K (similar to that of the bulk PNO) and a re-entrant *I-M* transition around 25 K. The behavior of reentrant *I-M* transition at 25 K may be due to the presence of Pr_2NiO_4 minor impurity phase.**

I. Introduction

PEROVSKITE Nickelates $RNiO_3$(R= rare-earth ion) belong to correlated class of transition metal oxide systems. These materials exhibit insulator-metal (*I-M*) transition which can be engineered using strain, hydrostatic pressure, chemical doping, etc. Among these, the $PrNiO_3$ (PNO) exhibits simultaneous *I-M* transition and Neél ordering exactly at ~ 130 K. The understanding of the low energy charge dynamics of $RNiO_3$ compounds is still lacking. Recently, it was shown that the charge ordered state can be stabilized in the tensile strained epitaxial PNO thin films [1]. To obtain deeper understanding on the electronic state and the low energy dynamics of PNO, the Terahertz (THz), the - time domain spectroscopy (TDS) measurements were carried out in order across the I-M transition in a large temperature range of 5 K – 320 K.

II. Results

THz-TDS measurements were carried out in transmission mode on epitaxially grown PNO thin film deposited on $(LaAlO_3)_{0.3}(Sr_2TaAlO_6)_{0.7}$ [LSAT] (110) substrate by pulsed laser deposition technique. The low energy charge dynamics in the energy range of 0.8 - 7 meV were calculating the complex refractive index. The the complex dielectric constant and optical conductivity were extracted for the PNO films by solving the Fresnel's equations [2]. We observe a Drude like behavior for the PNO film across the *I-M* transition as shown in the figure 1. Hence the conductivity spectra were fitted to the Drude law for metals which can be written as follows:

$$\sigma(\omega) = \frac{1}{4\pi} \frac{\Gamma_d \omega_P^2}{\Gamma_d^{\,2} + \omega^2}$$

We obtained convincing fits and deduced values of the parameters after fitting for scattering rate (Γ_d) as 13.3 meV, 15.1 meV and 21.4 meV and plasma frequency (ω_p) as 399.5 meV, 405.2 meV and 444.4 meV for temperatures 5 K, 200 K and 300 K, respectively. From these parameters we find that in the insulating state the values of Γ_d is nearly half compared to that above the *I-M* transition indicating a robust insulating state for PNO film having lesser scattering of the Drude carriers. However, it is interesting to note the temperature dependence of the THz conductivity for the PNO films depicts two *I-M* transitions at 130 K (reminiscent as of the bulk PNO) and a re-entrant *I-M* transition around 25 K (inset figure 1). This re-entrant *I-M* transition phenomenon is rather surprising and cannot be attributed to tensile strained PNO thin films as they exhibit robust insulating state due to charge ordering phenomenon. From the XRD data, we noted that a secondary phase o Pr_2NiO_4 (004) coexist with the primary phase of $PrNiO_3$. Hence, the unusual I-M transition at 25 K may arise due to presence of Pr_2NiO_4 (004) minor phase (corresponding impurity peak in the XRD plot shown in the inset of the figure 1(b))[3]. This type of anomalous behavior in transport properties due to presence of minor additional phases has been previously reported for resistivity measurements performed on PNO thin films deposited on Si substrate, by A Kumar *et al* [4].

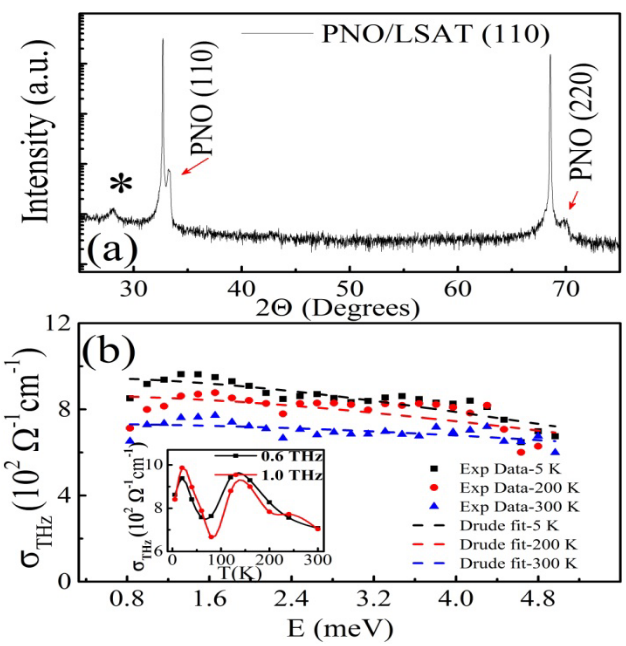

FIG. 1. (Color online) (a) shows the XRD pattern of the PNO thin film grown on LSAT (110) substrate, * indicates the Pr_2NiO_4 (004) minor impurity phase peak in the XRD plot. Fig. 1 (b) shows Drude fits of Terahertz optical conductivity spectrum (σ_{THz}-E) of PNO/LSAT (110) thin film at various temperatures. Inset of fig. 1(b) shows the temperature variation of Terahertz optical conductivity.

III. Summary

To sum up, we have studied the low energy dynamics of $PrNiO_3$ thin film using THz transmission spectroscopy. The

THz conductivity exhibits intriguing *I-M* transitions in the epitaxial $PrNiO_3$ thin-films, similar to that of exhibited by the DC conductivity data.

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