Doping-dependent Terahertz Conductivity and Phase Transition in $NdNi_{1-x}Cu_xO_3$ Thin Films

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***Abstract*—$NdNi_{1-x}Cu_xO_3$ thin films are studied for structural and electronic properties. Merely 2% Cu-doping induces metallic state in otherwise insulating $NdNiO_3$ film at low temperatures. The terahertz conductivity shows Drude behavior and the conductivity is tuned by Cu-doping in these films.**

I. INTRODUCTION

THE nickelates with $RNiO_3$-type (R = Rare earth ion) chemical stoichiometry show interesting phase-diagram with respect to R ion size variation [1]. Amongst these, only few systems ($NdNiO_3$, $PrNiO_3$ and $LaNiO_3$) show simultaneous electronic and magnetic transitions at low temperatures. The electronic properties and hence metallic state of these nickelates can be engineered by lattice-mismatch-induced strain in thin films [2]. In addition, electrostatic- and chemical doping-induced carrier injection show drastic modifications in the electrical conductivity of these thin films. Recently non-Fermi liquid behavior is observed to be induced due to compressive strain in $NdNiO_3$ film [3]. Additionally, quantum criticality of metal-insulator transition has been obtained at certain level of compressive strain. Thus the metallic state of this system is far from understood yet.

We have deposited $NdNi_{1-x}Cu_xO_3$ ($0 \le x \le 0.10$) thin films with compressive strain on single-crystal substrate of $LaAlO_3$ (001). Here we show that Cu-doping is effective in inducing metallic state in $NdNiO_3$ films at very low temperatures, which was otherwise an insulating state without doping. The present results are also compared with those of earlier reported Mn-doped $NdNiO_3$ films, where metallic state was totally suppressed due to Mn-doping at Ni-site [4].

II. RESULTS

Our earlier results show that Mn-doping suppresses metallic behavior at high temperatures (>200 K) whereas it increases density of states and thereby promotes hoping of charge carriers in the low temperature regime. Mn ions acquired tetravalent state at trivalent Ni site and hence cause changes in the electronic band-structure [4].

Here we report our studies on $NdNi_{1-x}CuO_3$ thin films (~35 nm) made by pulsed laser deposition method. The purity of the films was confirmed by X-ray diffraction and Reciprocal Space Mapping. Only 2% Cu-doping completely suppressed the insulating state and shows metallic behavior throughout temperature range (5 K – 300 K) as shown by electrical resistivity measurements (not included here). Temperature dependent terahertz time-domain spectroscopy was employed to understand the induced metallic behavior of Cu-doped films below and above 200 K (T_N in undoped $NdNiO_3$ film).

Fig. 1 shows the terahertz conductivity of $NdNi_{1-x}Cu_xO_3$ films with varying frequency and temperatures. As depicted in the figure, the terahertz conductivity shows Drude behavior in Cu-doped $NdNiO_3$ films. The conductivity is found to tune with the level of doping in the films. The x=0.02 film shows a drastic increase in the terahertz conductivity in temperature regions below 200 K. In the same temperature region, the undoped $NdNiO_3$ film remains insulating.

III. SUMMARY

Only 2% Cu-doping at Ni-site, the $NdNi_{1-x}Cu_xO_3$ system shows a phase transition from insulating to metallic state. Further increase in Cu-doping increases the resistivity although the system remains metallic from 5 K-300 K in contrast to undoped $NdNiO_3$ films. The terahertz conductivity is tuned by Cu-doping in the films.

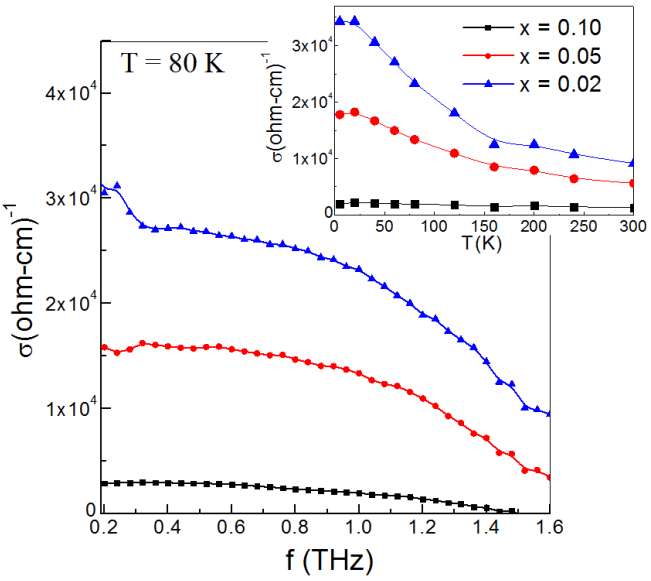

Fig. 2. Frequency dependent terahertz conductivity of $NdNi_{1-x}Cu_xO_3$ thin films. The inset figure shows the temperature dependent behavior of terahertz conductivity at 1 THz. The x=0.02 film shows a sharp rise in conductivity below 200 K.

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