Supplementary Material: Infrared Nano-Imaging of Electronic Phase across the Metal-Insulator Transition of $NdNiO_3$ Films

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Cryogenic near-field optical microscope

The homemade AFM assembly (including the parabolic mirror focusing the incident laser light) is mounted on the cooling stage of cryostat (CryoVac). The base temperature of the AFM assembly is 85 K with a liquid nitrogen bath. All measurements were conducted in an ultra-high vacuum ($< 10^{-9}$ mbar) environment to prevent the surface contamination (such as accumulation of dirt and impurity). We use a fiber-coupled interferometer (attocube, LDM1300) to monitor the oscillation of tip. The probes we use are commercially available from Nanoworld (Arrow™ NCPt). The drift of tip oscillation amplitude is about 5% in an hour at 85 K. A DC bias could be applied on the Z-axis piezo-stacks of the tip step motor to continuously adjust the tip position in the range of 100 nm. When the tip position is out of the adjustment range of the DC bias, the step motors are used to recover the amplitude. The challenges for imaging include changes in piezoelectric response of the sample scanner and thermal drift of the sample stage relative to the tip at variable temperatures. We use the standard testing sample TGQ1 (NT-MDT) for the calibration of the imaging distortion at variable temperatures. The position of the sample can be manually adjusted at different temperature. A raw scanning range is often larger than the area of the subsequent statistical measure. By tracking the pixels of the impurities, we can tailor and correct the raw images to acquire signal from the same area at different temperatures.

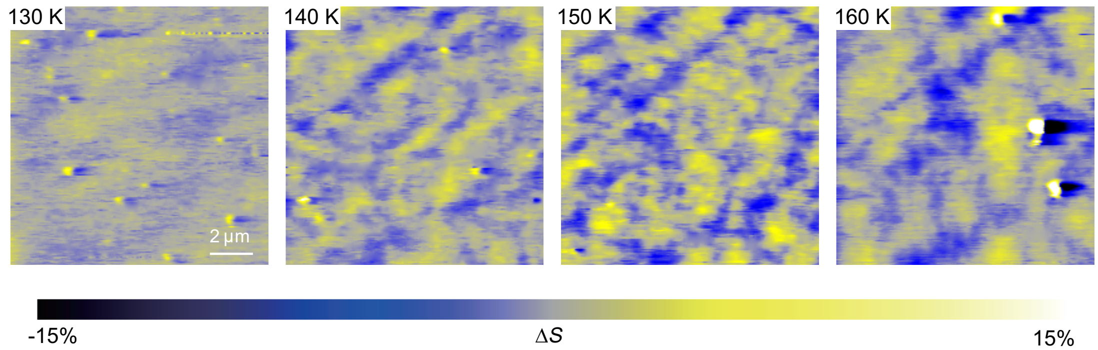

Fig. S1. More images of relative nano-IR signal (ΔS) on warming of $NdNiO_3$ films with 15 nm thickness.

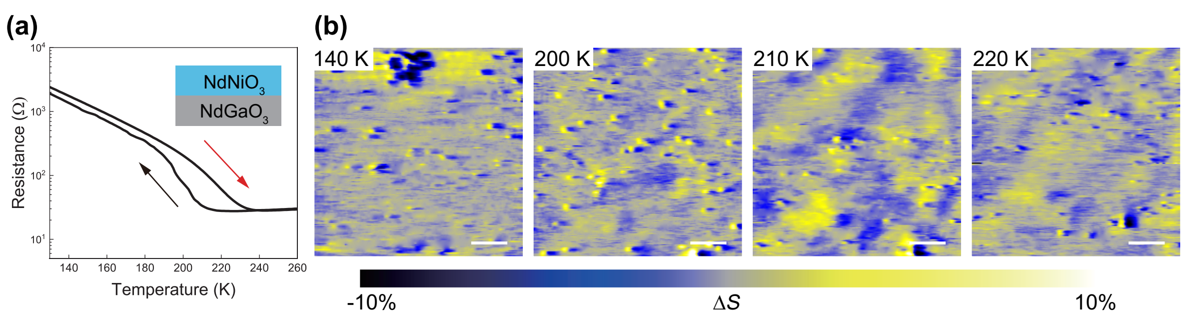

Fig. S2. $NdNiO_3$ films with 15 nm thickness on (100)-oriented $NdGaO_3$ substrate. The in-plane lattice mismatch is +1.8%. (a) Resistance versus temperature from the transport measurement. Arrows indicate the direction of transitions on warming (red) and cooling (black). (b) Images of relative nano-IR signal (ΔS) on warming in the $NdNiO_3$ films with 15 nm thickness. The stripe-like modulation is formed during the phase transition near 210 K.

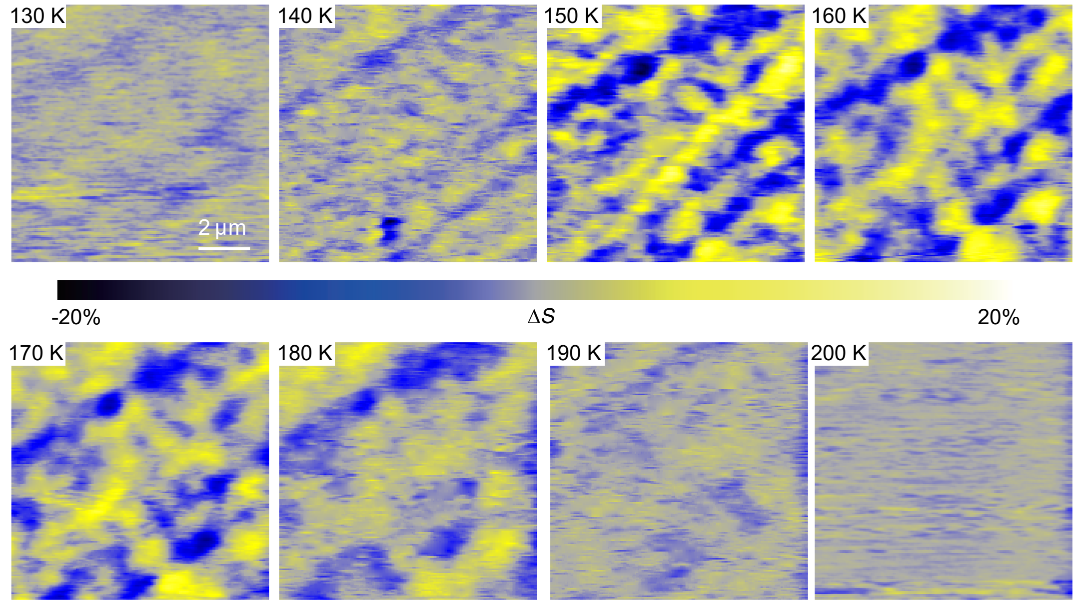

Fig. S3. Images of relative third harmonic nano-IR signal during the warming transition in $NdNiO_3$ films with 15 nm thickness. As a comparision with relative second harmonic nano-IR signal in the same field of view shown in Fig. 3(a).

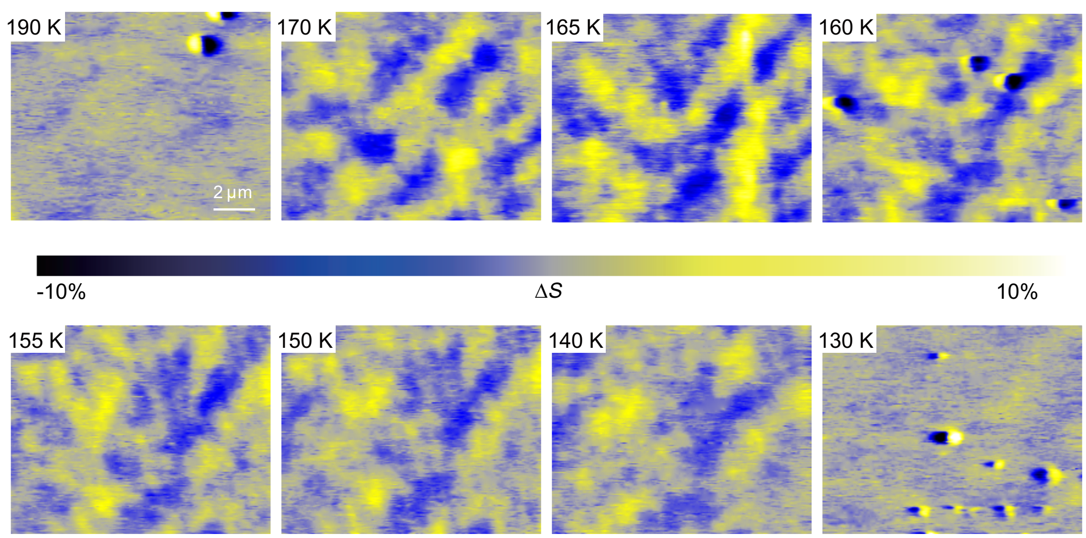

Fig. S4. Images of relative nano-IR signal (ΔS) on cooling in $NdNiO_3$ films with 7 nm thickness.