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Layer-number dependence of NCCDW-ICCDW phase transition in 1T-TaS_2

The electronic properties of two dimensional (2D) nanomaterials depend on how degree they are "two dimensional". TaS_2 is known a 2D material having charge density wave (CDW) phase transitions, where several groups have reported the change in the conductivity between commensurate- and nearly-commensurate- (NC) CDW phases around 150 K modulated by controlling dimensionality [1,2]. In our study, the change in electronic properties is investigated for the NCCDW-incommensurate (IC) CDW phase transition around 350 K.

The TaS_2 thin flakes were prepared by mechanical exfoliation of bulk crystals of 1T-TaS_2 grown by the chemical transport synthesis on a SiO_2 (285 nm) /Si substrate. A FET device for the conductivity measurement were fabricated by EB-lithography process. Raman spectroscopy was performed with an excitation wavelength of 532 nm on a temperature controllable stage.

The resistivity abruptly decreases on entering the ICCDW phase from the NCCDW phase as shown in Fig. 1. Most notably, the transition temperature depends on the sample thickness. The transition temperature increases as decreasing layer number of TaS_2. This is explained by the metastable nature of NCCDW states, which is a short-range order of CCDW state. As the dimensionality of TaS_2 becomes lower with decreasing in the number of layers, the temperature region of NCCDW states becomes wider due to more quantum fluctuation. Thus, the transition temperature between NCCDW-ICCDW increases as the number of layers decreases. In addition, temperature hysteresis between heating and cooling also shows thickness dependence. The hysteresis is known to be originated from height of activation barrier between different CDW states [3,4]. In our study, as the thickness becomes thin, the hysteresis becomes small. This behavior is considered to be arising from the dimensionality. As decreasing thickness, interactions between layers, such as coulombic interaction, decrease, which causes increase in flexibility of lattice and electrons. Consequently, the energy barrier corresponding to the temperature hysteresis between NCCDW-ICCDW phase transition would decrease as thickness decreases.

Raman spectra are also changed in accordance with NCCDW-ICCDW phase transition as shown in Fig. 2. As increasing temperature, the peaks at 75 cm^{-1} broaden and the small peaks at 105, 245, 307 and 382 cm^{-1} disappear. The temperature dependence of the position and half width of the peaks also indicate the transition temperature increases and the temperature hysteresis decreases as the layer number decreases.

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Figures

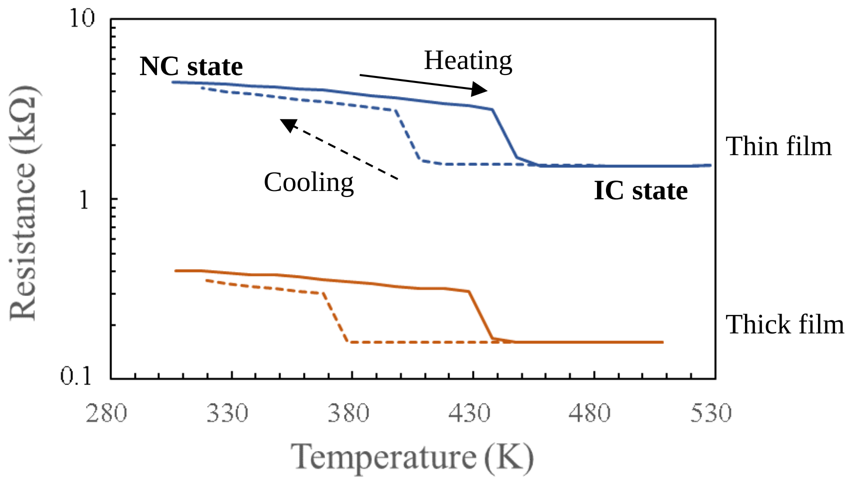

Figure 1: Temperature dependence of resistivity around NC-IC CDW phase transition for TaS_2 thin film (～19 layers) and thick film (～24 layers)

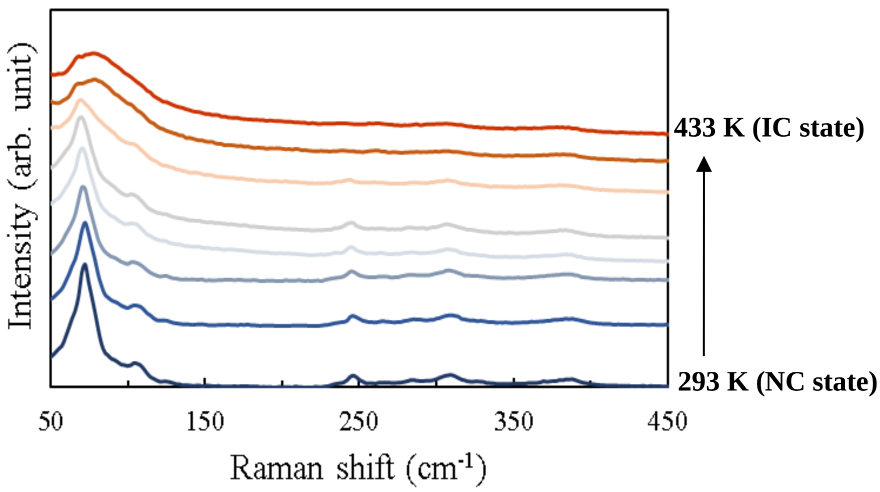

Figure 2: Temperature dependence of Raman spectra around NC-IC CDW phase transition for TaS_2 thick film