VO_2에서 구조상전이를 동반하지 않는 급작스런 금속-절연체 상전이현상 연구

Abrupt metal-insulator transition without a structural phase transition in VO_2

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Since Mott first predicted an abrupt first-order metal-insulator transition (MIT) without a structural phase transition driven by a strongly correlated electronic Coulomb energy[1], the MIT has not been found in experiments[2]. In particular, observations of first-order MITs for a Mott insulator have been achieved by temperature and pressure, and are always accompanied with a structural phase transition from the monoclinic structure of an insulator to the tetragonal structure of a metal. In this research, we report an abrupt first-order MIT that does not undergo a structural phase transition. The MIT is observed by micro-Raman scattering experiments using an Ar laser (514.5nm) with application of a DC electric field to a two-terminal device fabricated on a Mott insulator VO_2 film. The Raman-shift frequency and the bandwidth of the most predominant Raman-active A_g mode, excited by the electric field, did not change through the abrupt MIT, while, they, excited by temperature, pronouncedly softened and damped, respectively. It is suggested that an MIT without structural phase transition in strongly correlated materials occurs abruptly by an excitation such as an electric field due to a decrease of the on-site critical Coulomb interaction; this is the Mott transition. Furthermore, the abrupt MIT induced by electric field provides very important clues for solving ongoing debates on metallic characteristics near the MIT[2] and for future device applications.

Figure 1a shows the temperature dependence of resistance of VO_2 film I. An abrupt MIT and hysteresis are shown near $T_c \approx$ 340 K(68^0 C). This is consistent with previous measurements13,14. It was proposed that this abrupt MIT arises from the structural phase transition from monoclinic below T_c to tetragonal above T_c. Hall measurements reveal that the number of hole carriers increases with increasing temperature by $T_c \approx$ 340 K, and that electron and hole carriers coexist near T_c (inset of Fig. 1a). Figure 1b shows a current density J vs. voltage V curve measured by two-terminal device I fabricated on VO_2 film II. An abrupt current jump at 21.5 V and Ohmic behavior (metal characteristic) above 21.5V, are exhibited. The current density after the current jump is about J ~ 6 x 10^5 A/cm^2 measured in a circuit with 1 KΩ, which corresponds to a value obtained in a dirty metal. These are typical characteristics of a first-order MIT. Figure 2a shows the compliance-current dependence of Raman spectra observed at the current jump of a MIT voltage V_{MIT} = 10 ~ 11 V by VO_2 based two-terminal device II. With increasing of the compliance current, A_g and B_g modes in the spectra vanish without any change in their peak positions and bandwidths, which indicates that the features of the monoclinic phase do not change. From I = 16 to 30 mA, the peaks of Raman active mode of VO_2 are not found. The ratio of background levels of Raman spectra near $1000cm^{-1}$ for the metal phase at I = 16 mA to the insulator phase at I = 0 mA is about 1.23, which is quite close to the value of 1.20 obtained from the temperature dependence by considering the Boltzmann correction between 299 K and 341 K. This indicates that the measured phase has already become metal. Moreover, the ratio at I = 100 mA (Fig. 2b) is as high as 3.11, which is due to the increase of the number of conduction carriers excited by the electric field. We will also compare the abrupt MIT excited by temperature with that by an electric field, revealed by the micro-Raman spectra, in detail to show that the abrupt MIT is basically independent of the structural phase transition.

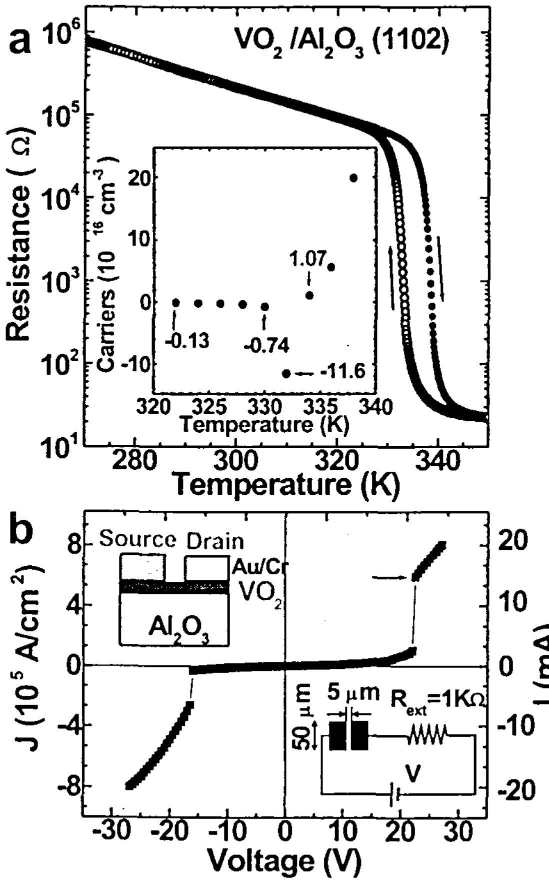

Fig. 1 a, Temperature dependence of the resistance of VO2 film I. b, Current-density J vs. voltage V curve measured by VO2 based two-terminal device I.

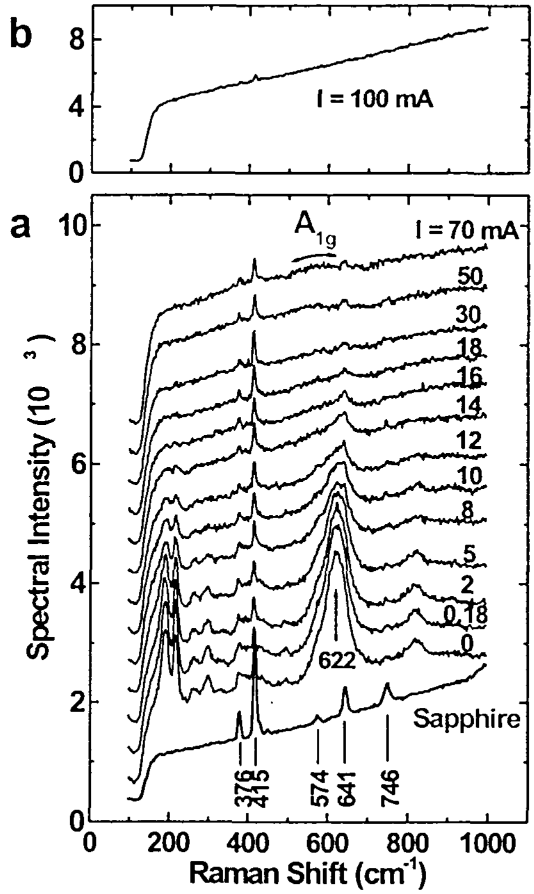

Fig. 2 Compliance-current dependence of Raman spectra measured by VO2 based two-terminal device II.

1. N. F. Mott, *Metal-Insulator Transition* (Taylor and Frances, 1990).
2. M. Imada, A. Fujimori and Y. Tokura, Rev. Mod. Phys. **70**, 1039-1263 (1998).