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希薄磁性半導体(Zn,Cr)Te 中の Cr 不純物準位の STM 観察

STM observation of Cr impurity states in diluted magnetic semiconductor (Zn,Cr)Te

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Cr-doped ZnTe ((Zn,Cr)Te) has been regarded as one of the promising diluted magnetic semiconductors (DMSs) for future spintronic application, because of its intrinsic room-temperature ferromagnetism when Cr composition is about 20 % [1]. As a possible mechanism of this ferromagnetic interaction between neighboring Cr atoms, the double-exchange interaction has been proposed theoretically [2]. However experimental study to verify the theoretical proposal has not been enough. In order to investigate information of such short-range interaction, we performed scanning tunneling microscopy / spectroscopy (STM / STS) measurement for (Zn,Cr)Te.

A (Zn,Cr)Te film (250 nm) was grown by molecular beam epitaxy on a p-ZnTe substrate with a buffer undoped ZnTe layer (10 nm) at 300 ℃. The Cr composition was estimated to be about 5 %. In order to obtain clean cross-sectional surface for STM observation, we cleaved the multilayer sample in high vacuum chamber (~10^{-5} Pa) and installed it to UHV STM chamber without any exposure to air. All STM / STS measurements were performed at 77 K or 8 K.

As shown in Fig.1, we observed single Cr atoms as atomic-scale protrusions at a sample bias voltage (V_s) of -2.0 V. Furthermore, as shown in Fig.2, we observed Cr atoms with neighboring Cr atoms (III, IV) in addition to Cr atoms imaged as single atoms (I, II). In order to investigate electronic states of these Cr atoms, we measured STS on them. As shown in Fig.3, the d*I*/d*V*-*V* curves were completely different depending on presence or absence of Cr at a measured position; in a small V_s region, d*I*/d*V* on a Cr atom was much larger than that on a position without Cr. This result suggests that a doped Cr atom formed an impurity state at a deep level within the band-gap of the host ZnTe, as proposed by the earlier first principles theoretical study [2]. Moreover, the STS results also indicate that impurity states of Cr atoms with neighboring Cr were completely different from those of single Cr atoms. The d*I*/d*V*-*V* curves measured on single Cr protrusions (I, II) had a peak at V_s = -1.4 V. It reflects a impurity state of single Cr atom. On the other hand, the curves measured on Cr atoms with neighboring Cr (III, IV) gradually rose from small negative bias voltage. This result suggests that the impurity state was broadened by coupling with neighboring Cr atoms. This broadening could be well explained by the ferromagnetic double exchange interaction, as the theoretical study has proposed[2]. Consequently, the result of our study indicates that we are able to discriminate the Cr impurity states in relation to magnetic interaction. We expect that further detailed analysis using atomic-resolution STM/STS, which investigate the impurity states at various spatial arrangements with neighboring Cr atoms, would contribute toward clarifying the mechanism of ferromagnetism in this material. At the presentation, in order to discuss the impurity states in more detail, we will present a theoretical results calculated by DFT.

[1] H. Saito et al. Phys. Rev. lett. 90, 207202 (2003)
[2] K. Sato et al., Semicond. Sci. Technol. 17, 367 (2002).

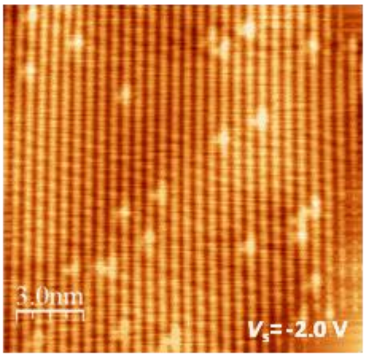

Fig.1 STM topographic image of single Cr atoms in the (Zn,Cr)Te layer. (set point : V = -3.5 V, I = 20 pA).

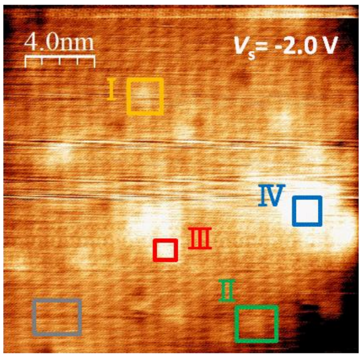

Fig.2 STM topographic image of (Zn,Cr)Te region used for STS measurements (Fig.3). (20×20 nm^2, V = -2.0 V, I = 20 pA)

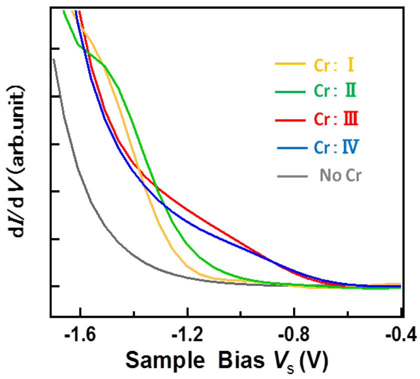

Fig.3 d*I*/d*V*-*V* curves measured on respective regions as indicated in fig.2. (set point : V = -5.0 V, I = 20 pA)