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Study of the memory mechanism of AlO_x-ReRAM

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Outline

Resistive random access memory (ReRAM) is a promising candidate for the next generation memory. The following items were clarified for ReRAM using anodic porous alumina (AlO_x), and we propose the following memory mechanism.

1) AlO_x-ReRAM operates in both ways, as bipolar-type, and as unipolar-type. 【Fig.2】
2) EELS measurements confirmed that high-density oxygen vacancies (Vos) exist in the AlOx vertical cell boundary. 【Fig.5】
3) Thermally stimulated current (TSC) in the OFF state revealed that narrow states exist at approximately 0.6 eV below the conduction band. 【Fig.6】
4) Resistance change by temperature in the OFF and ON states shows the insulating and metallic behavior, respectively. 【Fig.7】
5) Electronic band gap of AlO_x obtained by the measurements agrees well with that of amorphous alumina based on a first-principle calculation. 【Fig.8】
6) The first-principle calculation indicates that narrow sub-band emerges in the band gap and that the energy level depends on the electrically charged state of the oxygen vacancy (V_o). These charged states are stabilized by the structure relaxation of Al ions around the V_o. 【Fig.3】
7) Memory mechanism:

Once enough localized electrons from the lower electrode are accumulated in the isolated V_os, overlapped wave functions of the injected electrons could form a narrow sub-band among the band gap and trigger the insulator to conductor transition. In a word, reversible change of increasing / decreasing of electric charge in the V_os causes formation / disappearance of narrow sub-band developed to the conductor / insulator transition, respectively. 【Fig.4】

Self-forming of Mesoscopic structure

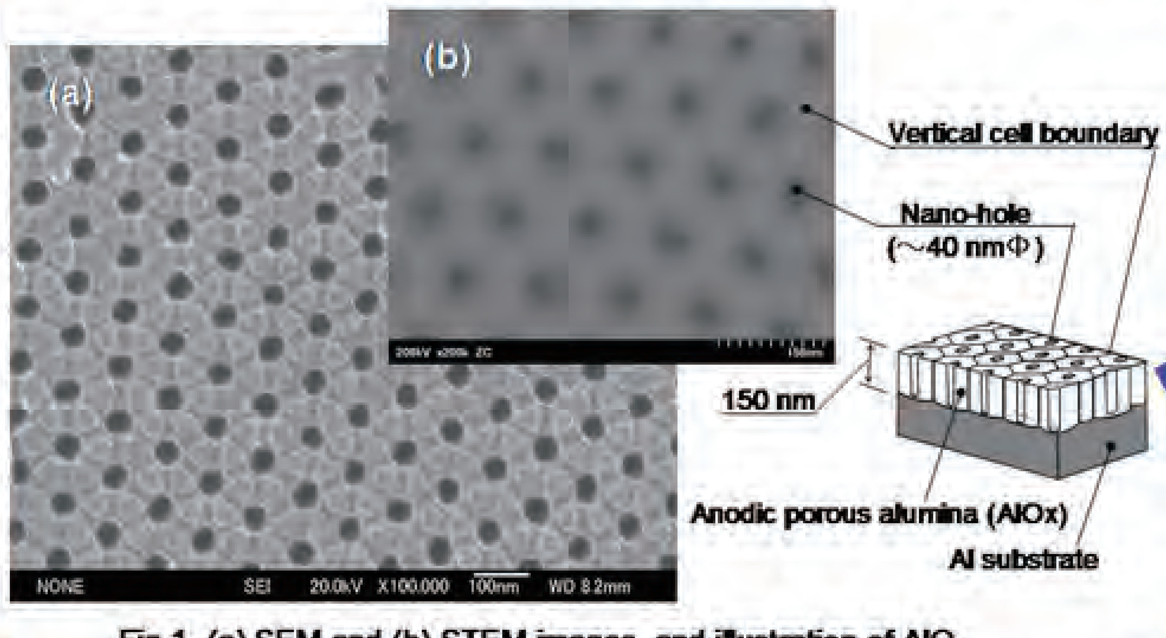


Fig.1 (a) SEM and (b) STEM images, and illustration of AlO_x

Improvement of I-V property

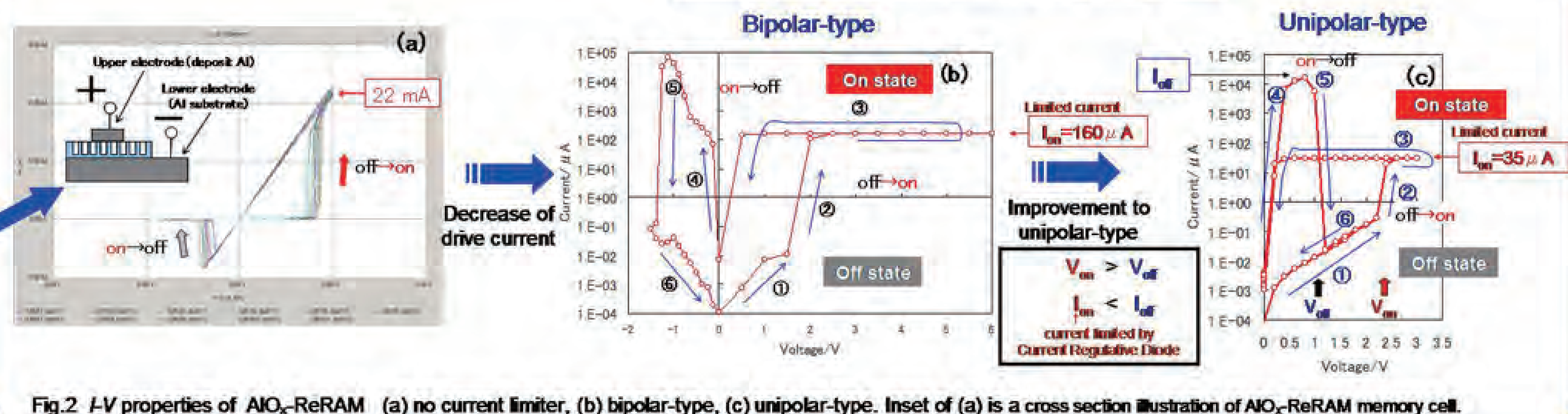
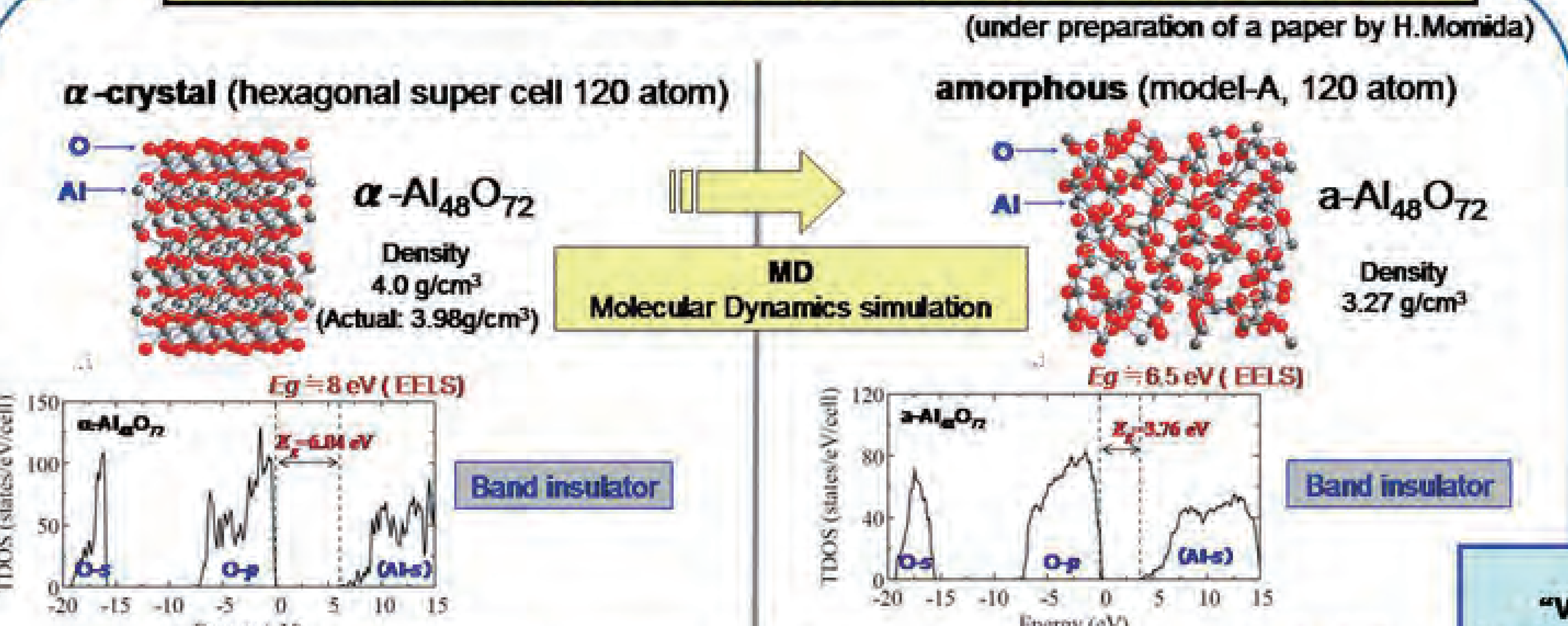


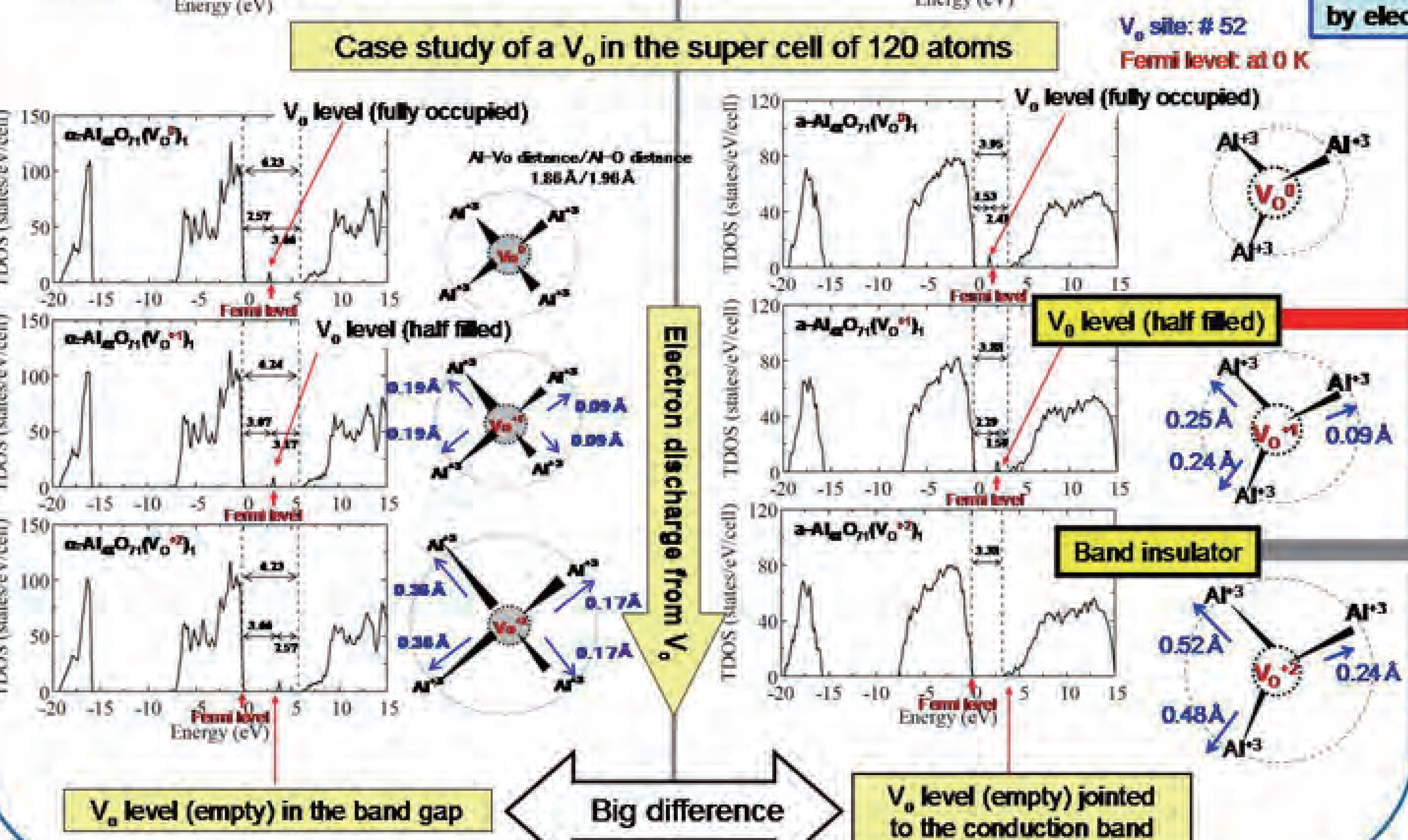
Fig.2 I-V properties of AlO_x-ReRAM (a) no current limiter, (b) bipolar-type, (c) unipolar-type. Inset of (a) is a cross section illustration of AlO_x-ReRAM memory cell.

Computer simulation by the first-principle calculation and MD

Electronic structure changes due to V_o charge state (α - crystal and amorphous alumina)

(under preparation of a paper by H.Momida)





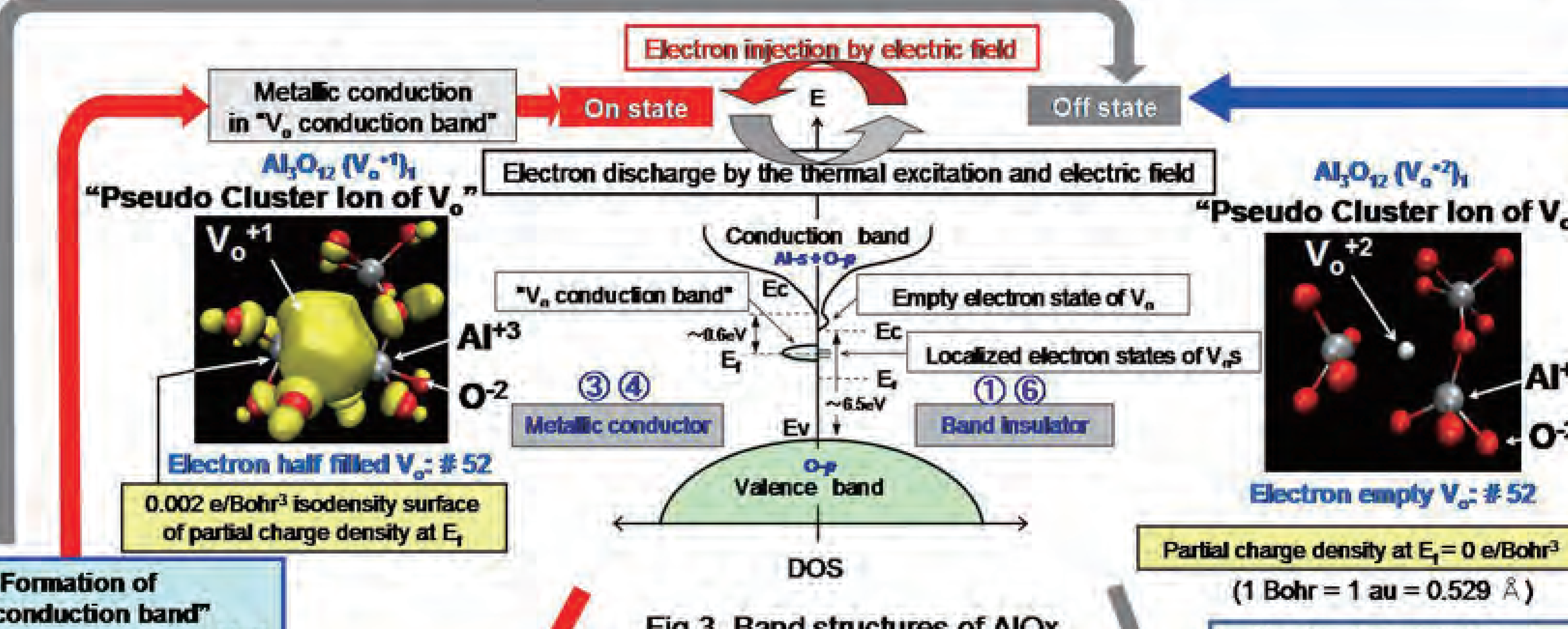


Fig.3 Band structures of AlOx

Number of Fig. 3 and Fig. 4 corresponds to the number of Fig. 2(C) (①~⑥) respectively.

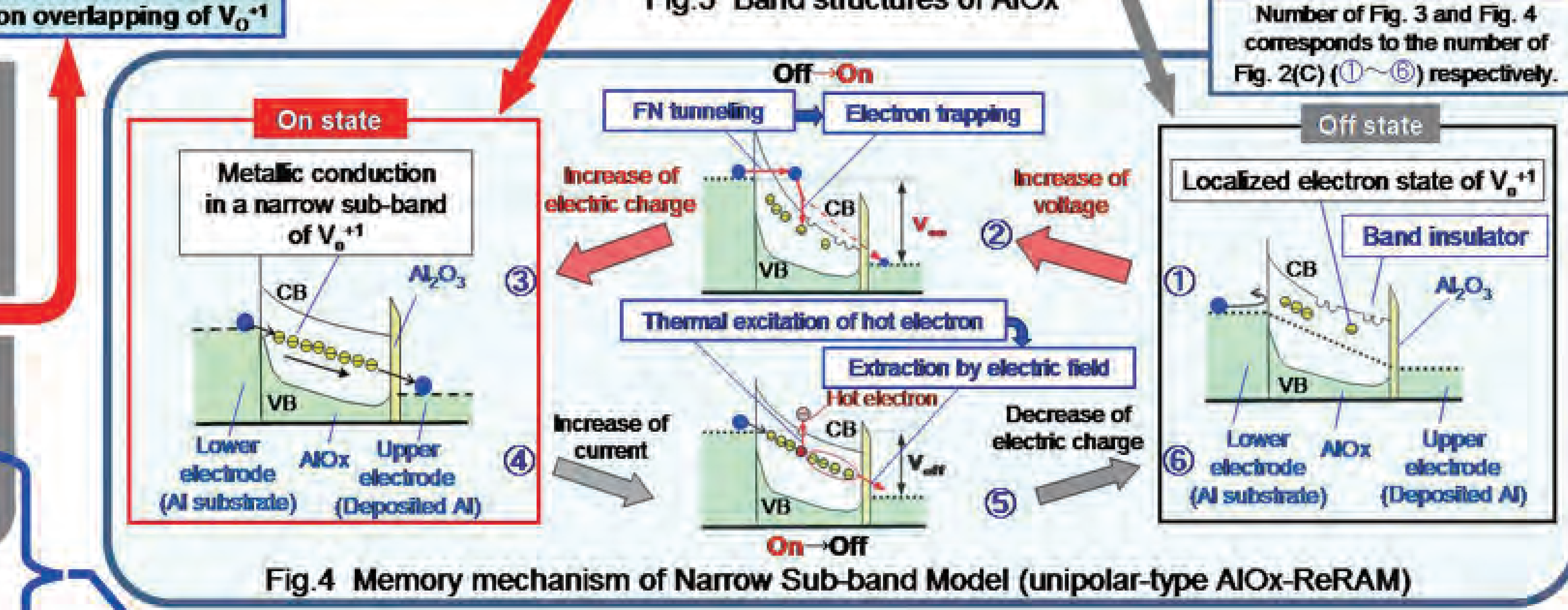


Fig.4 Memory mechanism of Narrow Sub-band Model (unipolar-type AlOx-ReRAM)

Structure relaxation of Al ions around the V_o

Bistable Electric structure

"Pseudo Cluster Ion of V_o"

Summary

The existence of high-density V_o in AlO_x was clarified by TEM-EELS. The first-principle calculation indicates that V_o^{+2} is changed into V_o^{+1} by electron injection, and then overlapping of the electron wave function of the V_o^{+1} forms a narrow sub-band "V_o conduction band" among the band gap, and the change of the electronic structure is stabilized by the structure relaxation of the Al ions around the V_o. The origin of the conductor-insulator transition of AlO_x-ReRAM is thought to be the V_o conduction band formation / disappearance that occurs because of only electron injection / discharge through the lower / upper electrode, respectively.

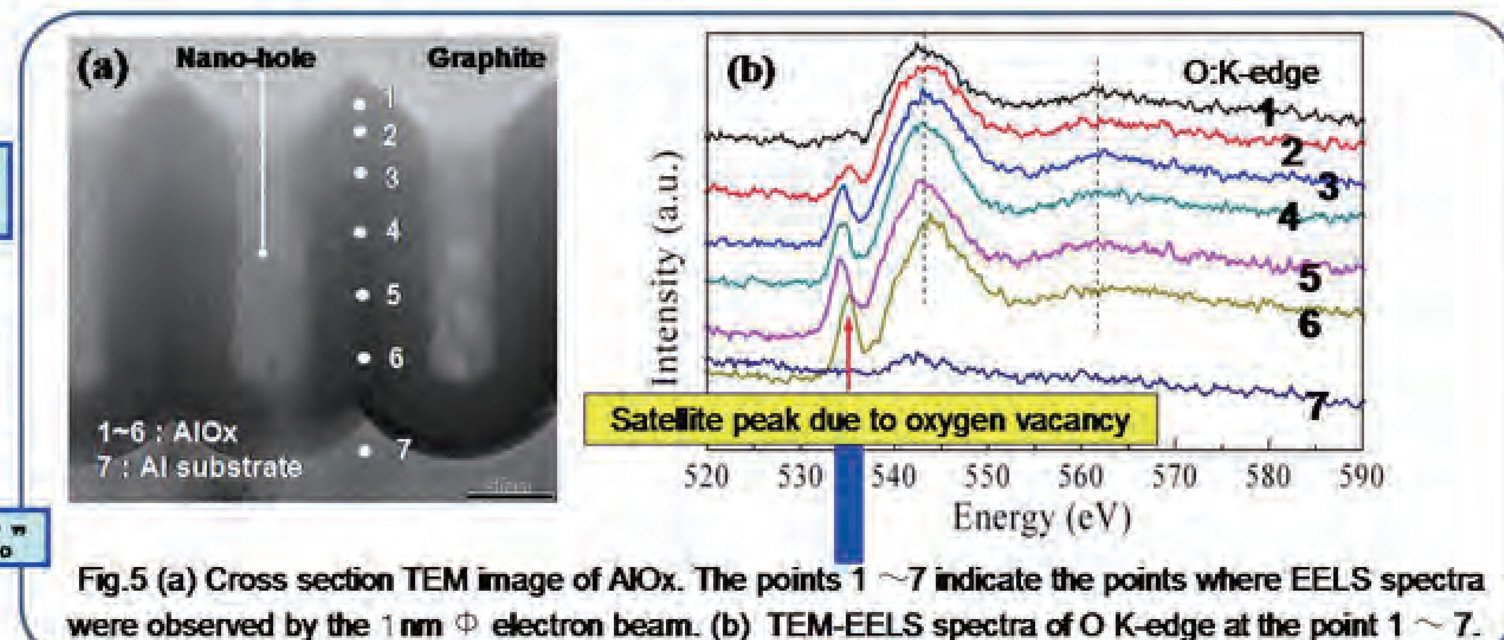


Fig.5 (a) Cross section TEM image of AlOx. The points 1 ~7 indicate the points where EELS spectra were observed by the 1 nm Φ electron beam. (b) TEM-EELS spectra of O K-edge at the point 1 ~ 7.

Existence of V_os was clarified.

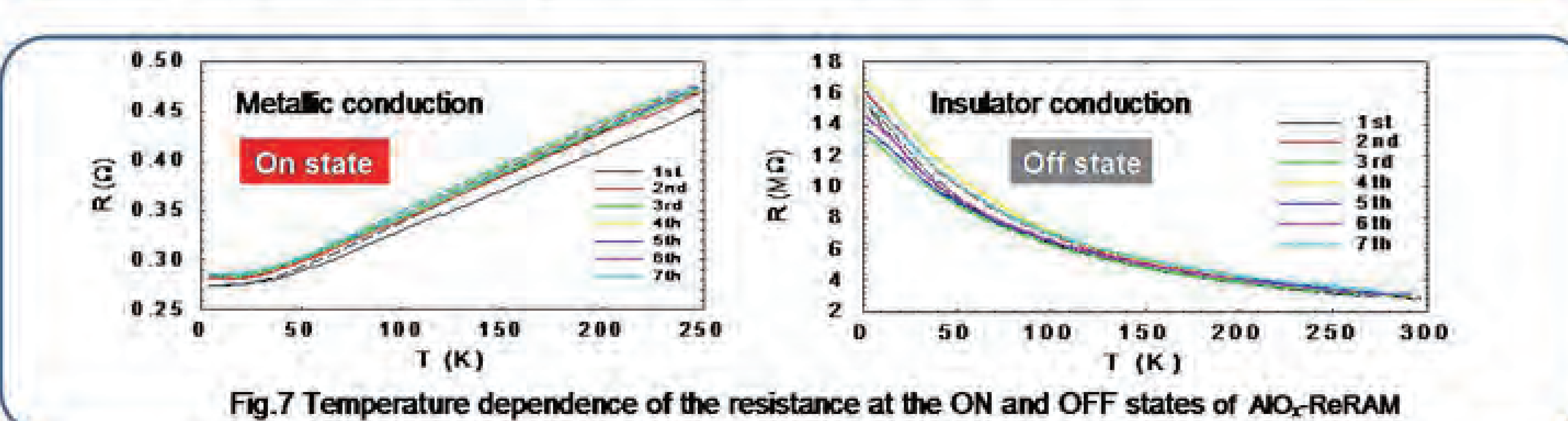


Fig.7 Temperature dependence of the resistance at the ON and OFF states of AlO_x-ReRAM

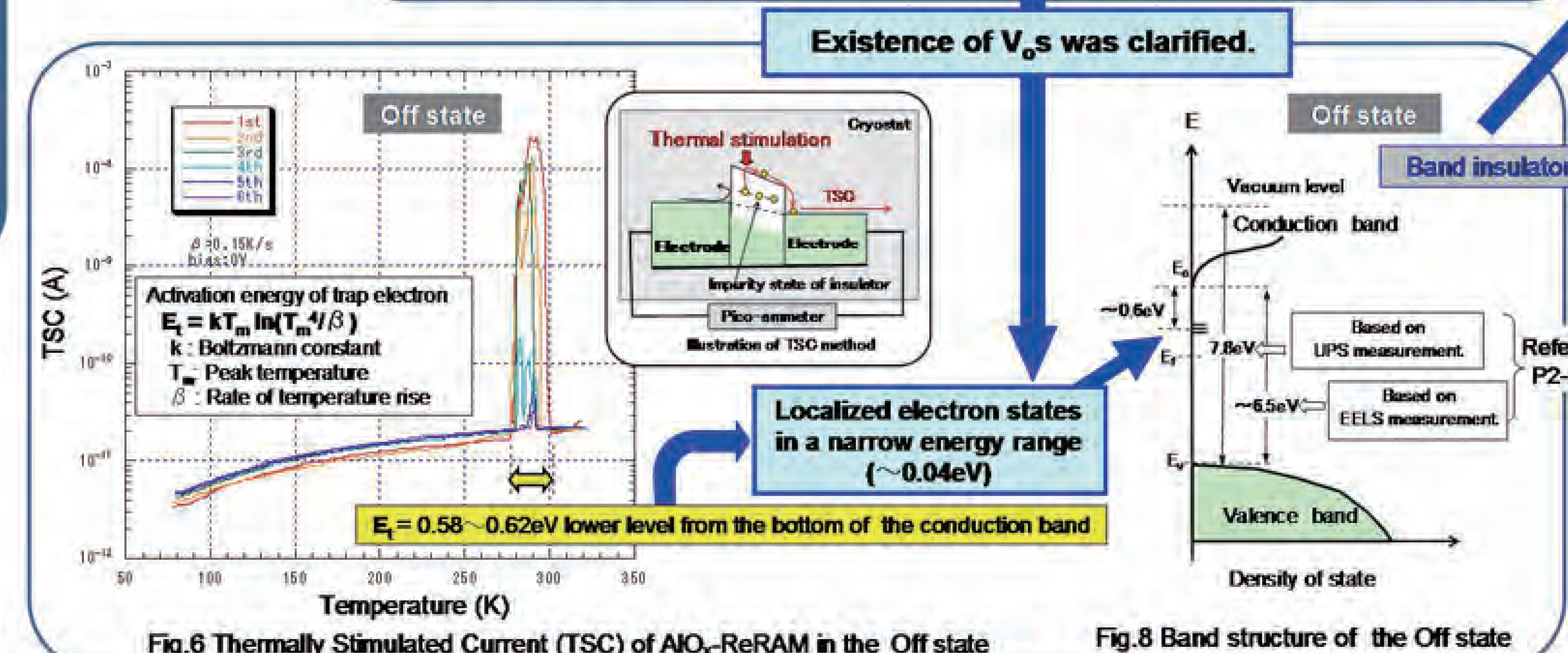


Fig.6 Thermally Stimulated Current (TSC) of AlO_x-ReRAM in the Off state

Fig.8 Band structure of the Off state

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