



# Tunable metal-insulator transition of $V_2O_3$ thin films strained by controlled inclusion of crystallographic defect

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## ABSTRACT

Current understanding of the metal-insulator transition (MIT) of  $V_2O_3$  based on the electronic band structures states that the electrical properties of  $V_2O_3$  are extremely sensitive to the crystallographic structures. In the present report, we present the systematic tuning of the MIT characteristics through the control of crystallographic structure of the polycrystalline  $V_2O_3$  thin film. Both crystallographic textures and the residual strains due to the presence of controlled amount of stacking faults in the films could be adjusted with the proper control of deposition conditions and the corresponding changes in the electrical properties have been tracked to establish the tunability of MIT temperature as well as the transition rates. Observed change was understood with the consideration of electronic band structures, through which the effect of atomic distances to the electron band gap was demonstrated. Additionally, it was found that the lattice strain of a strongly textured  $V_2O_3$  influences both room temperature resistivity and MIT temperature.

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## 1. Introduction

The phenomena of metal-insulator transition (MIT) exhibited by the family of vanadium oxide compounds with various transition temperatures, have been actively explored for many years and continuously been a topic of intense research interests [1–3]. Wide variation in the properties of vanadium oxide might be attributed to the four possible oxidation states of vanadium,  $V^{5+}$ ,  $V^{4+}$ ,  $V^{3+}$ , and  $V^{2+}$ . [4] Although there are four distinct valences in vanadium, most of vanadium oxide compounds are actually considered to include mixed up of above mentioned states [5–7]. For this reason, exact origin of MIT has not been completely revealed yet with full considerations of all relevant physical and chemical parameters as well as their inter-relationships. Of the many vanadium oxide compounds [8], vanadium sesquioxide,  $V_2O_3$ , is known as one of the exemplary compounds and has been spotlighted as a material that exhibits simultaneous transitions of structural, electrical, optical and magnetic properties [9–14]. Specifically,  $V_2O_3$  is well-known to exhibit a structural transformation from hexagonal corundum structure at room temperature to monoclinic structure at around 150 K accompanied with up to 6 orders of change in the electrical resistivity. A particularly interesting application of this MIT

in  $V_2O_3$  is the high temperature superconducting coil with smart insulating layer in which  $V_2O_3$  layer is employed to work as the temperature-sensitive switch to bypass the local quenching of the superconducting wire due to the possible defects in superconductor [15,16]. Hence, the optimal tuning of MIT behavior is necessary depending on the required conditions of device operations. As the MIT of  $V_2O_3$  is expected to be highly sensitive to minute changes or deformations in the crystallographic symmetry and atomic dimensions, there have been many attempts to induce the changes in MIT temperature by applying microstructural deformation in many different routes such as the adjustment of hydrostatic pressure, the doping of impurity atoms (Cr, Ti, etc.), or application of interface strain between the substrates and films [17–24]. Hydrostatic pressure dependence of MIT has been studied with bulk  $V_2O_3$  system to change the unit cell volume [23,24]. Introduction of Ti or V vacancies is known to serve as compressive pressure to the lattice to reduce the crystalline dimensions (interatomic distances), and the MIT temperature was found to decrease with pressure until the insulating phase is eventually suppressed [21,22]. On the contrary, lattice expansions by Cr doping or by the epitaxial lattice matchings at the interfaces of films could increase the MIT temperature [18,20]. The effect of relaxed interface strain with increased film thickness has also been explored [17–19]. Recently, additional spectroscopy analysis revealed further details on the electronic band structures with regard to MIT properties of  $V_2O_3$  [25–27]. They reported that band structure and MIT temperature of  $V_2O_3$  could be

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