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Abrupt metal insulator transition of TiO_2 and $Al_xTi_{1-x}O_y$ thin films

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1. Introduction

The transition from insulator to metal has been observed in strong correlated materials[1, 2]. An abrupt change of resistance for metal insulator transition (MIT) material can be induced by temperature, pressure and electrical field [1-3]. An abrupt current jump can be used as a high speed switching device for an important application of MIT [3].

In order to apply the MIT material to switching device or thermal sensor, reproducible and stable MIT materials are required. We explore TiO_2 and $Al_xTi_{1-x}O_y$ (ATO) films as a MIT materials. ATO films can overcome the disadvantages of TiO_2 resulting in combined high permittivity, low leakage current and high thermal stability[4]. We observed current jump for applying electrical field in TiO_2 and ATO films grown by plasma enhanced atomic layer deposition (PEALD). The jump ratio and stability depend on the deposition conditions such as deposition temperature and the amount of feeding the amount of Ti atoms.

2. Results and discussions

TiO_2 and ATO films were deposited by PEALD at 200 and 250 ℃. Trimethylaluminum and titanium isopropoxide were used as Al and Ti precursor, respectively. In the ATO deposition, one cycle of Al_2O_3 and N cycle of TiO_2 constitute one cycle of ATO where N is 2 and 3, which is designated by (1,N). The plasma pulse time was 1.0 s and 2.5s. In order to measure current voltage characteristics, Mo/oxide/indium tin oxide (ITO) and Al/oxide/ITO device structures were fabricated.

Current-voltage (I-V) characteristics of devices were measured by a precision semiconductor parameter analyzer (HP 4156B). The elemental composition of the film was determined by Auger electron spectroscopy (AES).

TiO_2 films with 62 nm were deposited at 250 ℃ with the plasma time of 2.5 s without post annealing. The Mo/TiO_2/ITO/Glass structures were fabricated to measure the I-V characteristics of TiO_2 films. In order to prevent any possible damage due to excess current, a compliance current was set to 50 mA. The positive bias was applied At first, current increases steadily until a voltage of 4.2 V where a sudden increase of current was observed. This is called as forming process[5]. Then, a second biasing, an abrupt conductivity jump occurs at about 1.7 V where the current increases by twenty times. Figure 1 shows the I-V characteristics of TiO_2 films. The forming voltage and the transition voltage are designated as V_f and V_t, respectively in Fig. 1.

In a repeated trial, an abrupt jump was also observed. However, a discontinuous jump in current was finally disappeared after a several tens trials.

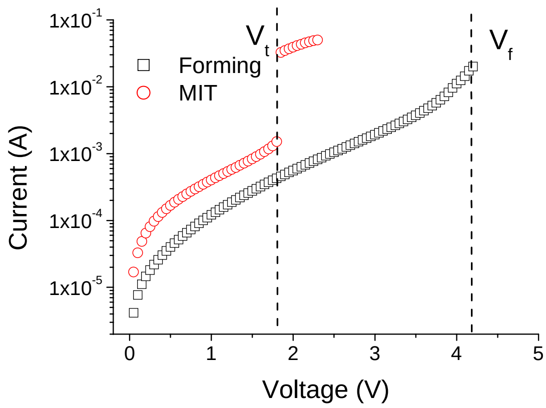

Fig. 1. Current voltage (I-V) curves in a log scale of TiO_2 with 62 nm grown at 250 ℃. Mo/TiO_2/ITO/Glass structures were fabricated.

In order to acquire stable operation of a discontinuous jump in current, ATO films were deposited. At a growth temperature of 200 ℃, ATO (1,2) at a plasma time of 1.0s was grown by PEALD. In order to measure I-V characteristics, the Mo/ATO (1,2)/ITO/Glass structure was fabricated. The Ti content was 20.6 at%. At a minus bias voltage, the forming voltage was 17 V and the transition voltage was in a range of 2.6 to 3.3 V.

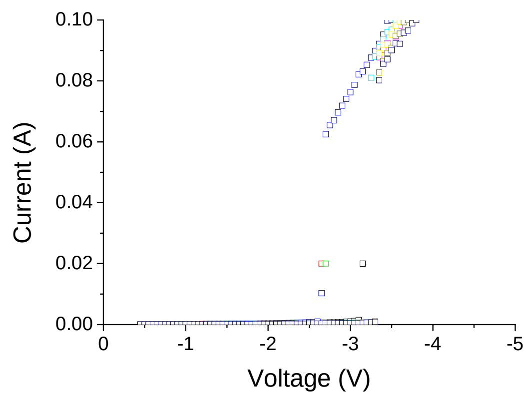

Fig. 2. Current voltage (I-V) curves in a linear scale of ATO (1,2) with 65 nm grown at 200 ℃. The data was obtained in the repeated biasing. Mo/ATO/ITO/Glass structures were fabricated.

Table I. MIT data observed in ATO films grown at 200 and 250 ℃. The forming voltage (V_f), MIT transition voltage and jump ratios are listed. The markers of * and × mean unstable MIT and no MIT operations, respectively.

Films	Electrode	Dep. Temp. (℃)	Ti content (at %)	Minus voltage			Plus voltage		
				$\|V_f\|$ (V)	$\|V_t\|$ (V)	Jump ratio	V_f (V)	V_t (V)	Jump ratio
ATO (1,3)	**Mo/ITO**	200		20	2.6~2.8	30~45	19	1.5~1.8	8
ATO (1,2)	**Mo/ITO**	200	20.6	17	2.6~3.3	100	17	2.0	20
	Al/ITO	200	20.6	13	3.1~3.8	6~50 *	12	1.6~2.4	×
ATO (1,3)	**Mo/ITO**	250	21.6	19	3.6~4.1	105~125	19.5	2.4	3~15
	Al/ITO	250	21.6	16	2.8~3.6	2~3 *	17	1.8~2.0	2.5~3.5
ATO (1,2)	**Mo/ITO**	250	18.3	22.0	3.8	85	32.5	2.3~2.8	6~45
	Al/ITO	250	18.3	18.8	2.7~2.9	9~14*	20.5	2.1~2.9	4~20*

The transition jump ratio in conductivity was about 100 and a stable operation was accomplished in a repeated biasing. Figure 2 shows a I-V curve in a linear scale in the Mo/ATO(1,2)/ITO structure. At the higher bias voltage after the current jump, a linear relation between current and voltage is observed. It is a typical ohm's law, which is the characteristics of conduction in metal thus metal state was obtained after the current jump.

Table I shows the main data related with MIT for ATO samples deposited at various conditions. A larger jump ratio was obtained in Mo/ATO/ITO structure than in Al/ATO/ITO structure and asymmetrical I-V behaviors were observed on both bias directions. Since I-V characteristics strongly depend on the electrode material and position, electrode dominates the MIT phenomenon. The forming voltage is proportional to growth temperature, electrode as well as the Ti content. While, the transition voltages are relatively invariant with above conditions.

In order to investigate the durability of MIT operation, the Mo/ATO/ITO device was connected serially to resistor and ac pulse generator. The 1 kHz ac signal (4.5 V dc) was applied. When 4.5 V are applied in a device and a resistor, 2.8 V and 1.7 V were measured in the MIT device and the resistor, respectively. The current flows through the MIT device at 4.5 V dc bias. After 30 minutes later, the MIT operation is maintained and this result is depicted in Fig. 3. Hence, this result shows a stable operation of MIT and the MIT device may be applicable to the switching device or other devices.

3. Summary

We observed the MIT phenomenon in TiO_2 and $Al_xTi_{1-x}O_y$ (ATO) films. In particular, ATO films exhibited a stable operation of MIT. It was observed that the current jump ratio was about 100 in ATO films, which may be applicable to the switching MIT devices.

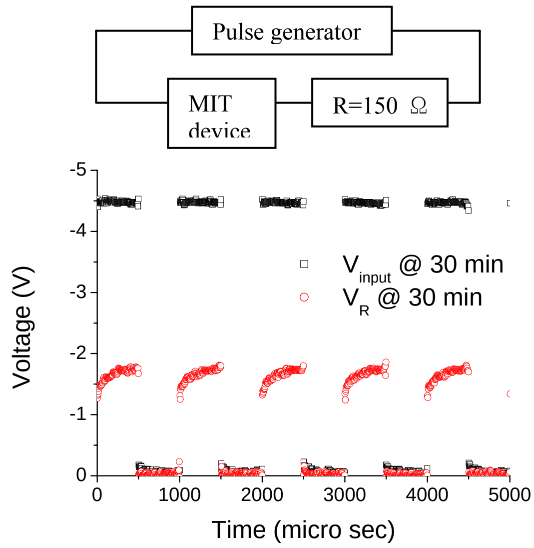

Fig. 3. The MIT device (Mo/ATO (1,3)/ITO) is connected to the resistor (150 Ω) and the pulse generator (1 kHz). The voltage of total (Vinput) and of resistor (VR) were measured after 30 minutes.

Acknowledgements

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