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# The impact of inserted Ta ultra-thin layer on the resistive switching voltage in Ir/Ti/Ta/$HfO_2$/TiN/Ti/$SiO_2$/Si devices

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## Abstract

**We fabricated resistive switching (RS) devices which possess Ir/Ti/Ta/$HfO_2$/TiN/Ti/$SiO_2$/Si structure with different Ti and Ta thicknesses by using a magnetron sputtering method. The lowering of operating voltage was observed when the combination of the thickness of Ti and Ta layer was Ti (45 nm)/Ta (5 nm). Based on the dependence of operating voltage on combination of top electrode thicknesses, we discuss the role of Ta layer and the impact on the RS effects and advance some suggestion to control the operating voltage of RS effects.**

## 1. Introduction

Resistive switching (RS) effects of functional oxides have been intensively investigated in past decade because it can be utilized for high-density nonvolatile memory, i.e., resistance random access memory (ReRAM)[1, 2]. ReRAM is one of the promising candidates for the next generation nonvolatile memory owing its simple structure, low switching current, high scalability and good compatibility with CMOS technologies.

The RS effect has been observed in many kinds of capacitor-like structures containing various transition metal oxides (TMOs) sandwiched between two metal electrodes. Among TMOs, binary oxides, such as $HfO_x$[3-5], $TiO_x$[6,7], CoO[8], NiO and $TaO_x$, have received considerable attention because RS devices consisting of those materials have a simple production process.

Recently, ReRAMs based on RS effects of binary oxides have been commercialized. However, the difficult challenges still remain in controlling the chemical reaction at the metal/oxide and metal/metal interfaces and the parasitic capacitance of ReRAM devices. The result of first principle calculation on metal/$HfO_2$/metal structure RS device which has been reported in these days suggests that both the electronic coupling between metal electrode and $HfO_2$ and the amount of oxygen vacancies in $HfO_2$ have strong implications for the RS effects [9].

Based on these calculations, we attempted to develop a new method to reduce the oxide layer more effectively without changing the combination of metal electrode and oxide layer. To achieve this purpose, we fabricated Ir/Ti/Ta/$HfO_2$/TiN/Ti/$SiO_2$/Si structures with different Ta thickness by magnetron sputtering method and investigated the relation between the thickness of Ta layer and RS behavior. Additionally, we investigated the effect of post deposition annealing (PDA) since it is known that PDA improves reliable RS operation [10].

## 2. Experiments

Using a magnetron sputtering (CFS-4EF, Shibaura Mechatronics Corporation) method, the 5 nm-thick Ti and 50 nm-thick TiN electrode layer were deposited on a thermally grown $SiO_2$ layer on a p-type Si(100) substrate. Subsequently, $HfO_2$ thin films were deposited on the TiN/Ti/$SiO_2$/Si substrates by the magnetron sputtering method using $HfO_2$ target at 0.5 Pa Ar + $O_2$ mixture ambient (Ar : $O_2$ = 19 : 1) without substrate heating. The thickness of $HfO_2$ layer is 5 nm. Then, Ta, Ti, Ir circular top electrodes (TE) with the diameter of 50 μm were deposited on $HfO_2$ layer in sequence without substrate heating. After TE deposition, some samples were annealed (PDA) under the following conditions, at 400 °C for 30 minutes in a chamber under 1.0 Pa Ar ambient (99.9995 %). Figure 1 shows the cross sectional schematics of the RS device and the measurement circuit. *I–V* characteristics were measured by using a two-point probe method to determine the forming voltage $V_F$, the forming current $I_F$ and the RS ratio ($R_H/R_L$) , where $R_H$ and $R_L$ are resistance values of a high-resistance state (HRS) and a low-resistance state (LRS), respectively.

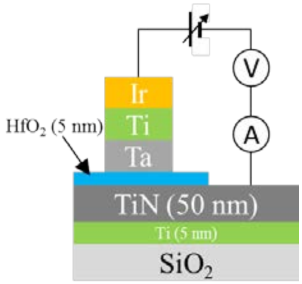


Fig. 1. Cross sectional schematics of the sample and the measurement circuit for electrical characterization.

## 3. Results and discussions

Figure 2 shows the relation between forming voltage and the forming current of the device with different Ti and Ta thicknesses, Ta (50 nm), Ti (30 nm)/Ta (20 nm) and Ti (45 nm)/ Ta (5 nm), respectively, with or without PDA. The name and the combination of the thickness of each metal layer are shown in Table 1. From here, we use the name of the sample to describe each sample. As seen in Fig. 2(a), the forming voltages of the device-A hardly decrease at all after annealing procedure. However, the forming current of the device-A increases by a double-digit after annealing procedure. Similarly, the forming voltage of the device-B is unaffected by annealing but the forming current increases by a double-digit. On the other hand, the forming voltages of the device-C decrease from 2.6 V to 1.7 V.

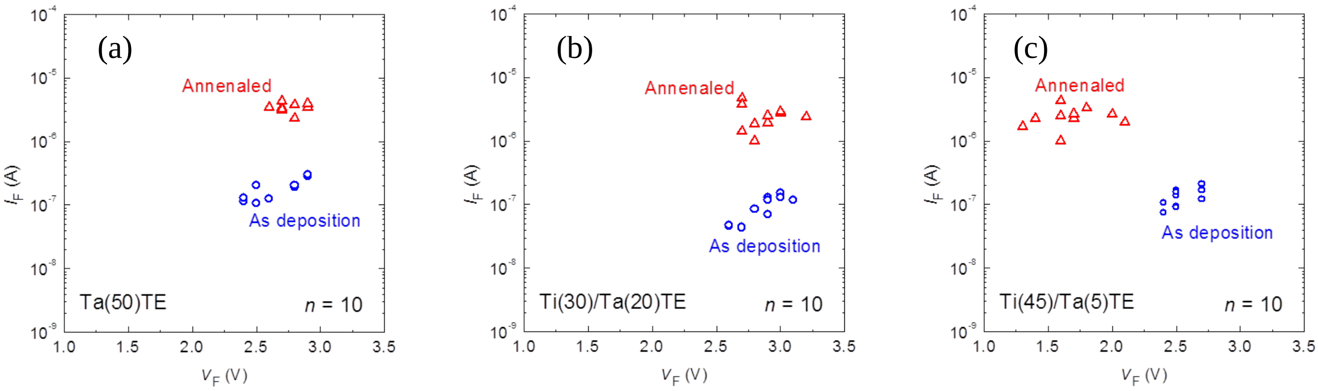


Fig. 2. The relation between forming voltage and the forming current with and without annealing of (a) device A, (b) device B and (c) device C. The red triangles show the relation of the annealed devices and the blue circles show the relation of as deposited (without annealing) devices. "*n* = 10" indicate the number of measured samples.

Table I  Structure and the name of the sample

| Name | thickness of Ir layer (nm) | thickness of Ti layer (nm) | thickness of Ta layer (nm) |
|---|---|---|---|
| device A | 50 | 0 | 50 |
| device B | 50 | 30 | 20 |
| device C | 50 | 45 | 5 |

These results indicate that the oxygen atom inside the $HfO_2$ layer migrate from $HfO_2$ layer to Ti electrode layer by passing thin Ta layer owing to the thermal annealing.

Figure 3 (a) and (b) show the *I* – *V* characteristics of device C before and after annealing procedures. As seen in Fig. 3(a), the ON/OFF ratio of the device-C before annealing is rather small. In contrast, the device C after annealing showed the large RS effect. Besides, the current at low resistance state of the device-C after annealing are ten times smaller than those of device C before annealing. Both set voltage and reset voltage of the device-C after annealing are smaller than 1 V and the value of the operating current is about 1 mA to 10 mA. It is known that the operating current depends on the size of the area of RS device [11]. Therefore, it is expected that the operating current of the device can be decreased by decreasing the size of the devices.

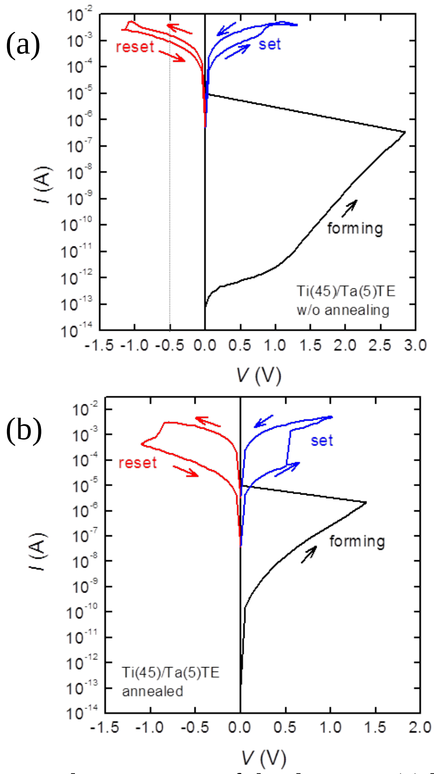


Fig. 3. *I-V* characteristics of the device-C (a) before annealing and (b) after annealing.

## 4. Conclusions

The forming current of RS device which possess $Ir/Ti/Ta/HfO_2/TiN/Ti/SiO_2/Si$ structure increases by double digits by annealing the device at 400 °C after metal electrode deposition. The forming voltage of the device-C after annealing is smaller than the forming voltage of device-A and B after annealing. This result corresponds to the result of first principle calculation shown in [9]. These results indicate that the RS behavior can be improved by controlling the structure in the vicinity of the interface of oxygen and metal electrode. We believe that this method is applicable to lower and control the forming voltage and operating current of ReRAM.

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