Comparison of Resistive Switching between Tantalum Oxides Deposited by Atomic Layer Deposition and E-beam Physical Vapor Evaporation

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Performance of $Cu/Ta_xO_y/Pt$ devices is compared between tantalum oxide deposited by atomic layer deposition (ALD) and electron beam physical vapor evaporation (EBPVD). Formation, set and reset of Cu and oxygen vacancy (V_O) conductive filaments (CF) [1] are evaluated for both dielectrics and related to the respective material properties. XPS data shows that ALD forms a stoichoimetric Ta_2O_5, while EBPVD results in oxygen deficient TaO_x films. Forming voltages of Cu and V_o CFs for ALD Ta_2O_5 devices are considerably higher than for EBPVD TaOx devices and its $V_{form,}$ V_{set}, V_{reset} and R_{on} distributions are much tighter than the corresponding distributions for EBPVD TaO_x. ALD Ta_2O_5 devices outperform those with EBPVD TaO_x in DC sweeping and in pulse measurements. The resistive $Cu/Ta_xO_y/Pt$ devices have been fabricated in a crossbar array on a thermally oxidized Si wafer. Metal electrodes were deposited by e-beam evaporation and patterned by lift-off technology. Both types of devices have the same Ta_xO_y thickness of 16nm. In our measurements, Pt electrode is grounded and the bias is applied to the Cu electrode.

The improved device performance of ALD devices is attributed to more conformal, uniform, and denser ("pin-hole free") Ta_2O_5 thin films formed by ALD than by EBPVD. Defects are known to be essential for resistive memory devices. However, a high level of defects in the dielectric reduces the device reliability [2]. The dielectric constants of both tantalum oxide films are measured by Keithley C-V test. Ta_2O_5 has a higher dielectric constant, about 38, than TaO_x, around 16, further implying lower level of defects in Ta_2O_5 than in TaO_x.

For the characterization of oxygen vacancy V_o CFs a negative voltage is swept from 0 to -8V for the forming and from 0 to -4V for the set operation. At a certain V_{form}, a forming operation is observed when the cell changes from high resistive state (HRS) to a low resistive state (LRS). Since under negative voltage the migration of Cu^+ ions is suppressed, the LRS is attributed to the formation of a V_o CF in agreement with [1]. For Cu CF set operation, a positive voltage is swept from 0 to 5V for forming and from 0 to 3V. A compliance current (I_{cc}) of 100 μA is used for the set operation to avoid damage to the device. A compliance current of 0.1A is used in the reset operation for both V_o and Cu CFs with a bias voltage sweeping from 0 V to -2 V.

An ALD based device has typically V_o and Cu CF forming voltages of about -6.5V and 3.5V, respectively, much higher than those of EBPVD devices, which are around -4V and 2V, respectively. After the initial forming, the set voltages for both ALD and EBPVD devices are found to be around -2.5V for Vo CFs and 1.5V for Cu CFs. This is in agreement to PVD samples with different TaO_x thicknesses of 8nm, 16nm, and 32nm [3]. In the case of EBPVD devices, it was found that V_{form} for both Cu and Vo CFs increased considerably with the TaO_x thickness while V_{set} and V_{reset} voltages were independent of the TaO_x thickness. V_{set}, V_{reset} distributions and R_{on} distributions of Cu and Vo CFs are shown in Fig.1 and Fig.2, respectively. It can be seen that set and reset voltages for V_o CF for ALD and for EBPVD are similar, but the absolute values are more scattered for EBPVD devices, resulting in an overlap of the set and reset ranges. In Fig.2 it is seen that R_{on} distributions for ALD Ta_2O_5 are much tighter than the distributions of EBPVD TaO_x. The variability of R_{on} is likely related to greater variability of defect densities in EBPVD TaO_x. The narrow distribution of R_{on} in ALD devices is to significantly lower defect levels and higher density in Ta_2O_5 than in EBPVD TaO_x. It is also observed that ALD devices with Vo switch more reliably than with Cu CF. For ALD devices R_{on} of V_o CFs generally vary from a hundred ohms to less than 1KΩ, while the R_{on} of Cu CFs range from a few hundred ohms to 50KΩ. This wide variation of R_{on}(Cu-CF) entails wide V_{reset} distribution which may interfere with V_{set} for Cu CFs. It has been observed that Cu CFs with large R_{on} display considerable instability leading in some cases to self-dissolution and volatile switching behavior [4]. The retention tests on both devices performed at 85C° show uniform (stable) R_{on} and R_{off} distribution with retention time up to 10^5 s.

In conclusion, ALD deposition allows for highly conformal and uniform dense stoichoimetric Ta_2O_5 films with a low concentration of defects and high density. Such $Cu/Ta_2O_5/Pt$ devices exhibit more reliable switching than EBPVD $Cu/TaO_x/Pt$ devices with much tighter distribution of the switching parameters. Moreover, the comparison between ALD and EBPVD devices gives insight into the mechanisms leading to forming, set and reset processes of the Cu and V_o nanofilaments.

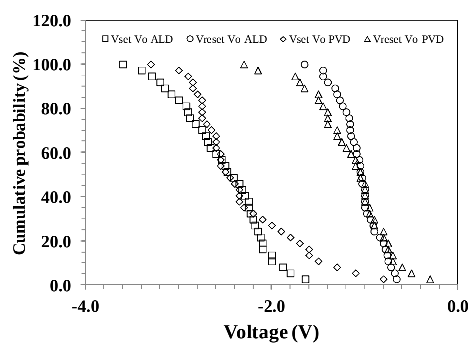

Fig.1 V_{set}(Vo ALD), V_{set}(Vo PVD), V_{reset}(Cu ALD), V_{reset}(Cu PVD) distributions of $Cu/Ta_xO_y/Pt$ devices.

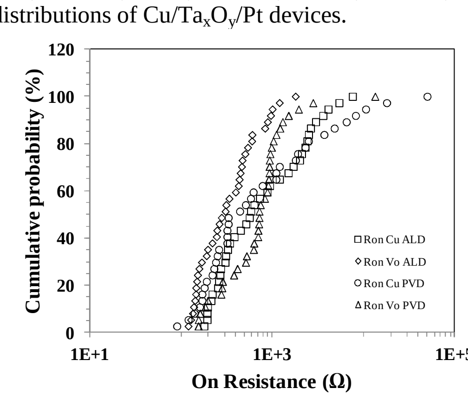

Fig.2 R_{on}(Cu ALD), R_{on}(Cu PVD), R_{on}(V_O ALD), R_{on}(V_O PVD) distributions of $Cu/Ta_xO_y/Pt$ devices.

References

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