Performance of Cu/TaOx/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 (ALD) and electron beam physical vapor evaporation tantalum oxide deposited by atomic layer deposition case of EBPVD devices, it was found that V_{set} for ALD TaOx films 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 TaOx. ALD TaOx devices outperform those with EBPVD TaOx in DC sweeping and in pulse measurements. The resistive Cu/TaOx/Pt devices have been fabricated in a crossbar array on a thermally oxidized Si wafer. Metall electrodes were deposited by e-beam evaporation and patterned by lift-off technology. Both types of devices have the same TaOx 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") TaOx 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. TaOx has a higher dielectric constant, about 38, than TaOx, around 16, further implying lower level of defects in TaOx than in TaOx.

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 TaOx 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 TaOx thickness while V_{set} and V_{reset} voltages were independent of the TaOx 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 TaOx are much tighter than the distributions of EBPVD TaOx. The variability of R_{on} is likely related to greater variability of defect densities in EBPVD TaOx. The narrow distribution of R_{on} in ALD devices is to significantly lower defect levels and higher density in TaOx than in EBPVD TaOx. It is also observed that ALD devices with Vo switch more reliably than with Cu CF. For ALD devices R_{on} of Vo 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 85°C 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 stoichiometric TaOx films with a low concentration of defects and high density. Such Cu/TaOx/Pt devices exhibit more reliable switching than EBPVD Cu/TaOx/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 Vo nanofilaments.

References
[3] M. Verma, Y. Kang, T. Potnis, M. Orlowski, “Comparison of Cu/TaOx/Pt devices with PVD TaOx of different thickness”, to be published