GeSbTe (GST) is one of the most attractive materials used for the Phase-change Random Access Memory (PRAM) because of the high $I_{\text{on}}/I_{\text{off}}$ ratio and rapid phase-transition between amorphous and crystalline states. The phase stability of GST layer, however, should be strengthened in order to assure ten year’s reliability of devices. That is, cyclic read/write operations can lead to atomic migration and phase separation resulting in the failure of devices. In order to enhance the resistance to thermal and electrical stresses, doping of light elements is conventionally adapted to GST. In this study, a carbon-doped GST (C-GST) was prepared and evaluated the migration behavior of GST layer by using sequential experiments of in-situ TEM and atom probe tomography (APT).

The stack of TiSiN(heater, 10nm)/C-GST (undoped or carbon-doped, 30~100 nm)/TiN(top electrode, 30nm) was deposited on the Si substrate by using PVD. At first, the phase-changing behavior of the FIB-prepared device sample was investigated. By using in-situ TEM probing, the gap with two orders of magnitude was achieved between High Resistance State (HRS) and Low Resistance State (LRS). Then, the same specimen was loaded to an APT, in order to investigate the exact movement of elements corresponding to the electrical fatigue. Femtosecond-pulsed UV laser (100kHz, 343nm) was utilized for the assistance of the field-evaporation of the sample.

The resistance of undoped-GST was rapidly dropped by cyclic I-V measurement and finally stuck to the low resistance state as shown in figure 4. At the same time, the local contrast of undoped-GST layer was continuously changed. According to AP analysis, this contrast change was due to the phase separation of GST into GeSb-rich phase and Te-rich phase. On the contrary, no significant migration was observed at the C-GST sample. However, atom probe tomographic image obtained after I-V measurement reveals that GeTe cluster was formed in the C-GST layer. Since the GeTe materials is also phase-changing material with acceptable performance, the GeTe clustering can be allowed from the device performance point of view.
Fig. 1: TEM image of needle-like GST stack. Cyclic I-V curve could be simultaneously measured in a TEM.

Fig. 2: Data retention measurements of GST stack. Resistance of undoped GST is gradually decreased and stuck at LRS. C-GST keeps the high resistance up to $10^3$ cycles.

Fig. 3: APT Elemental map of C-GST before cyclic I-V measurement. Orange dots represent GeTe. No significant clustering was observed.

Fig. 4: APT Elemental map of C-GST after cyclic I-V measurement. GeTe clusters were randomly distributed in the C-GST layer.