Thermoelectric and Non-linear Electronic Transport, Filament Formation and Gradual Set in Phase Change Memory Cells

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In our temperature (80 K < T < 350 K) and electric-field dependent (0 ~ 40 MV/m) current-voltage (I-V) measurements[1],[2] on reset $Ge_2Sb_2Te_5$ (GST) line-cells[3], we observed ***(i)*** resistance drift continues at cryogenic temperatures with drift coefficients linearly decreasing with 1/kT, ***(ii)*** distinct low-field hyperbolic sine and high-field exponential behaviors, ***(iii)*** acceleration and stoppage of drift with high voltage (> 20 MV/m) stresses, with I < 50 nA for T < 250 K, ***(iv)*** high-field differential resistances extrapolate to a single point for all T, ***(vi)*** devices respond to photo-excitation (T < 250K) only in the low-field regime.

Our results strongly suggest ***(i)*** resistance drift has an electronic origin and is due to gradual formation of a potential well in amorphous (a-) GST with the release of the trapped holes to the crystalline (c-) GST or the contact in time, ***(ii)*** high electric-field substantially distorts the energy-band profile and accelerates drainage of the stored holes, ***(iii)*** low-field behavior is due to percolative hopping transport, ***(iv)*** high-field behavior is due to high-level injection of electrons into a-GST through the tunnel-junctions at the interfaces and ***(v)*** electronic transport in a-GST is predominantly n-type, which has very significant thermoelectric consequences.

We have included the thermoelectric contributions of the carriers by correlating the temperature dependent activation energies[4] (E_a) we calculate to the Peltier coefficients in our electro-thermal dynamic-materials simulation platform. We have also locally varied E_a to capture the variations in a-GST[5]. The simulation results reveal ***(i)*** formation of narrow (~2 nm) filaments that get into thermal runaway, ***(ii)*** very substantial thermoelectric effects that drastically change the thermal profiles depending on the voltage polarity, ***(iii)*** evolution of the filaments from random percolation paths to a single molten filament aligned with the electric field, ***(iv)*** with the correct polarity, highest temperature appears at the apex of the amorphous dome in the mushroom cells, which allows controlled partial crystallization.

References

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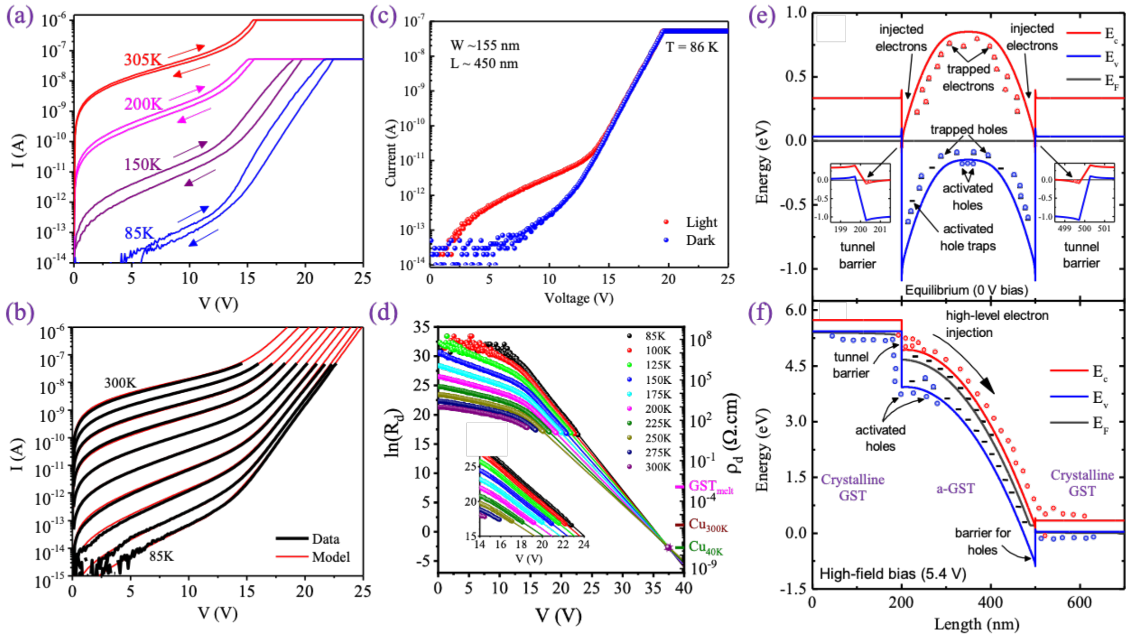

Fig.1. (a) I-V sweeps used to stabilize the cells immediately after reset for 4 different devices at indicated temperatures. $I_{compliance}$ = 50 nA (T < 250 K), 1 µA (T=305 K) [144], cell thickness = 20 nm. (b) Experimental I-V characteristics (black) of an a-GST line-cell after stabilization with high-field stress[145] at 85 K, and the model (red). (c) High-voltage sweeps (0 to 25 V) measured under light and dark at 86 K after the cell was stabilized with several high-voltage sweeps. (d) Differential resistance (R_d) versus voltage for different T. All high-field fits converge to a single point. Inset zooms into the fit range. (e) Energy band-diagram of c-GST/a-GST/c-GST at equilibrium, (f) under strong external electric-field, based on published parameters. Positive charging of the amorphous region leads to gradual increase in the potential barrier for electrons. High-field bias leads to drainage of the activated holes contained in the amorphous region, while simultaneously giving rise to high-level injection of electrons. n-type conduction is expected in the device.

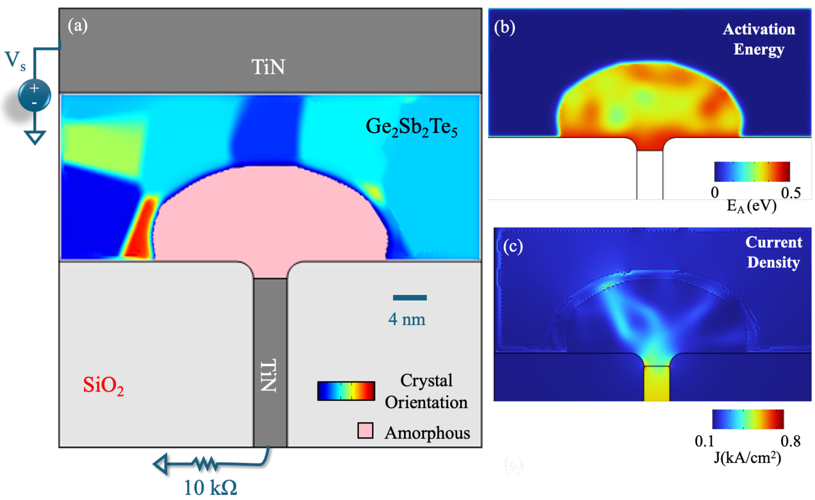

Fig.2. (a) A mushroom cell simulated using our electrothermal simulation platform with dynamic materials where the phase of the material changes depending on local temperature. Electrical conductivity of a-GST is a function of local temperature dependent activation energy and electric field, thermal conductivity is a function of phase of the material, electrical conductivity and temperature, and Seebeck coefficient is a function of temperature. Ambient temperature of 300 K is applied at the boundaries of an SiO_2 frame around the cell (not shown). Access device or the load resistor is simulated using SPICE models. (b) Activation energy map showing the random distribution within a-GST at 300K. (c) Current density at the beginning of a set operation showing filaments following percolation paths.

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