In-situ TEM observation of Electrical Wind Force Assisted Amorphization in $Ge_2Sb_2Te_5$ Phase Change Nanowires

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Phase-change memory utilizes the electric field-induced reversible structural change in chalcogenide materials to switch between crystalline (low resistance) and amorphous (high resistance) phases to store information in a rapid and non-volatile manner. In spite of extensive investigations of the phase-change and electronic switching, the underlying mechanisms involved in the relationship between structural and electrical properties in phase change materials is quite complex and remains poorly understood. Despite some success in theoretical approaches to explain the atomic motions involved at the atomic-scale, visualization of electrically-driven structural transition has been experimentally challenging. Moreover, the direct correlation of structural phases to their electrical states and real-time observation of the switching process remains largely unexplored. This limitation is mainly because the active phase-change material in thin-film PCM devices are embedded within multiple layers, which prohibits direct probing of structural transformations on a working device with high spatial resolution while under electrical biasing. Detailed understanding of electrically-driven switching process in phase change materials is essential to achieve their successful integration into memory devices.

We have performed real-time monitoring of electric-field switching behavior of phase change $Ge_2Sb_2Te_5$ nanowires (NW) by transmission electron microscopy (TEM). For TEM observation, we fabricated lateral-type GST NW devices on top of electron transparent Si_3N_4 membranes assembled on a specially designed TEM holder to apply electrical pulses to the NW device. Combining with the real-time imaging system, *in situ* TEM allowed us to operate the PCM device in the TEM column, at the same time while observing the structural and chemical changes between amorphous and crystalline states. During the programming process, we observed dynamic image contrast changes upon approaching the phase-change voltage, even before the initiation of actual electric-switching from crystalline-to-amorphous state. During crystalline-to-amorphous phase transition, a high-density of entangled dislocations were observed to form and pile up in the vicinity of the phase change region. Typically, we observed dynamic motion of dislocations, which form towards the positive electrode direction and move towards the negative electrode, along the direction of movement of holes (charge carriers). This transient behavior of the electrical-switching indicates the critical effect of electric-pressure on phase change phenomena. After the amorphization process, the boundary of the amorphous mark evolved asymmetrically depending on the bias polarity, which shows that the electric-pressure assists the crystalline-to-amorphous phase transition. Using simple analysis, we show that the hole-wind force accounts for the electric-field dependent motion of dislocations that leads to a build-up of large stress in the phase change region. The observation of large electric-pressure induced by carrier momentum transfer leading to crystalline to amorphous transition gives new insights into the unusual fast switching behavior of $Ge_2Sb_2Te_5$ materials.