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Coexistence of charge trapping and silver filaments in AgInSbTe memristor

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ABSTRACT

We investigate memristive behaviors of Ag/$Ag_5In_5Sb_{60}Te_{30}$/Ag devices. Both of the intrinsic space charge limited conduction and extrinsic electrochemical metallization effect are confirmed to be responsible for the memristive switching. With the cooperation of the two mechanisms, the resistance can be tuned more gradually and precisely by controlling the polarity, the amplitude, the width, and the number of applied voltage pulses, which can be applied to emulating the synaptic long-term potentiation and long-term depression by different types of spikes.

Key words: chalcogenide, memristor, charge trapping, silver filaments, gradual resistance tuning

AgInSbTe (AIST) is a chalcogenide compound which has been widely used in the phase change disk and electronic phase change memory for the high contrast between its crystalline state and amorphous state. In amorphous state, AIST material has a long-range disorder structure with individual cavities[1], which may be an inducement to the effect of trap-controlled space charge limited conduction (SCLC)[2,3]. Furthermore, considering that electrochemical metallization effect (ECM) is very common in Ag-containing chalcogenides[4,5] and the long-range disorder structure and individual cavities facilitate a fast diffusion of Ag cations, the AIST may act as a fast ionic conductor[6]. Both of the two effects can lead to memristive switching in amorphous state without phase change process, which has been confirmed in AgInSbTe material[7].

The device structure was as follows: substrate/Ag (200 nm) /$Ag_5In_5Sb_{60}Te_{30}$ (25nm) /Ag (200nm). The films were deposited by DC magnetron sputtering and the active areas of 100 × 100 μm^2 were defined by a photolithography process. During the measurement, bottom electrode was grounded and positive bias means the current flows from the top electrode to the bottom electrode.

We investigated memristive I-V hysteresis loops (Fig. 1). Curve fitting method demonstrated that the I-V characteristics corresponded to the SCLC theory fundamentally besides several leaps of resistance. The abrupt increase and decrease of resistance were owed to the ECM effect. Meanwhile, the ECM effect brought out more intermediate resistance states and the resistance can be tuned more precisely by controlling the polarity, the amplitude, the width, and the number of applied voltage pulses (Fig. 2). When applying successions of pulses with constant amplitude or width to the devices, resistance rose or descended after each pulse. Higher or wider positive (or negative) pulses resulted in faster resistance decline (or rise) and lower (or higher) ultimate resistance state. The results indicate that the resistance can be tuned gradually and the increasing of the amplitudes and widths enlarged the resistance variation. The memristive behaviors are reproducible and the gradual resistance tuning characteristics in different cells are similar (Fig. 3).

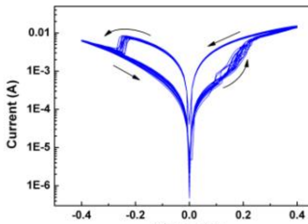

Fig. 1. The I-V curves of Ag/AIST/Ag devices.

For future neuromorphic computing, memristors with gradual resistance tuning characteristics are utilized as electronic synapses. The analog resistive properties driven by electrical pulses are similar to the plastic synaptic weight modification due to neural spikes. Biological synaptic functions responsible for memory and learning in brain, such as long-term potentiation, spike-timing dependent plasticity, could be implemented in such memristors by well-designed spike schemes[2,8]. Moreover, the devices provide feasible options for other analog applications.

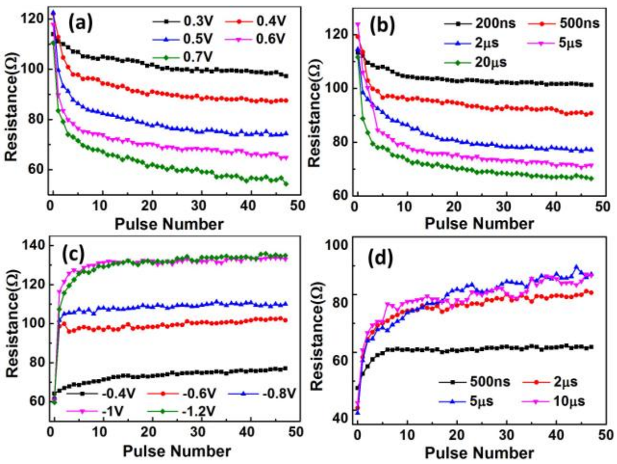

Fig. 2. (a) The gradual resistance tuning under a succession of positive pulses with 5 µs width and different amplitudes, (b) positive pulses with 0.5 V amplitude and different width, (c) negative pulses with 5 µs width and different amplitudes, (d) negative pulses with -1 V amplitude and different width.

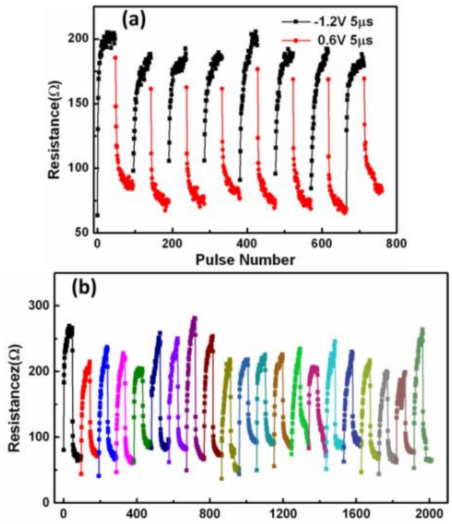

Fig. 3. (a) Repeatability of gradual resistance tuning behavior in Ag/AIST/Ag devices. (b) The gradual resistance tuning behaviors in different cells. Each of the cycles shows the tuning of a cell.

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Biographies

Zhang Jinjian was born in 1987 in China. He received the bachelor degree from Huazhong University of Science and Technology, China in 2010. He has been a Ph.D. student in Huazhong University of Science and Technology since 2010 and his research is concerned with the memristive behaviors in chalcogenide semiconductors and their applications.