Examination of MoS_2 films and MoS_2-based memristors with HRTEM & EDX

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Neuromorphic computing has emerged as a potential solution to the problem of reaching Moore's law limit. This new computer architecture is based on circuits that use resistive-switching (RS) devices called memristors. Molybdenum disulfide (MoS_2), a two-dimensional layered material (2DM) with van der Waals (vdW) bonding, has recently demonstrated ultimate down-scaling to monolayer thickness[1] and good device performance[2]. MoS_2 is proven to be a promising candidate for such devices, since MoS_2-based memristors showed the potential to emulate learning and memory behaviors[3] by using threshold switching and acting as an artifical neuron[4].

For this reason, transmission electron microscopy (TEM) techniques were utilized in order to examine two differently grown MoS_2-based sets of samples. First, a systematic study of the growth of MoS_2 films using chemical vapor deposition (CVD) under different conditions was investigated. Second, the characterization of a CMOS-integrated nanoscale MoS_2 memristors was examined[5].

The CVD-grown MoS_2 investigation showed that higher growth temperatures lead to the formation of a SiO_x layer on top of the MoS_2 layers on SiO_2/Si substrate. High-resolution TEM (HRTEM) imaging verified the vdW layer orientation of CVD-grown MoS_2. The fabrication of lateral-plane MoS_2 was found to be consistent. In contrast, the vertical-plane MoS_2 exhibited partially random orientations of its lattice planes, which could be attributed to the incomplete formation of the initial Mo thickness for the thermally converted metal film to achieve the vertical orientation. Finally, under a certain temperature threshold the MoS_2 film is found to only partially form.

Then, HRTEM, scanning transmission electron microscopy (STEM) and energy dispersive X-ray spectroscopy (EDXS) measurements were performed to nanoscale MoS_2 memristors on silicon CMOS microchips. The study of vertical Au/Ag/MoS_2/Pd memristors at pristine and low resistance states (LRS) showed that the RS of the devices is based on the electrochemical metallization (ECM) mechanism. Specifically, the formation and rupture of metallic conductive filaments is occurring when an electric field is applied, forcing the Ag ions to migrate from the active electrode to the inert counter electrode through the MoS_2 layers.

Our results enabled valuable insight into the MoS_2 film growth and could also be used in promoting the quality of future CMOS-compatible 2DM-based memristive technologies. We would like to acknowledge Prof. Andrei Vescan, Dr. Holger Kalish and Prof. Michael Heuken for providing samples. This work was funded by the Federal Ministry of Education and Research (BMBF, Germany) in the project NEUROTEC (Project No. 16ME0399, 16ME0398K, and 16ME0400).

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