Morphological Studies of Focused Ion Beam Induced Tungsten Deposition

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A widely used approach to interconnect prototype circuits and to rewire defective circuits is direct writing of metal lines at the backend of the process line by means of focused ion beam (FIB) induced deposition. In this work we investigate the focused ion beam induced chemical vapor deposition process of tungsten focusing on nucleation at the early stages of the formation process, the formation of a contiguous interface, and finally the linear growth. The study involves in situ characterization of the evolving layer surface employing FIB-secondary electron microscope (FIB-SEM) imaging. For the experimental studies of the focused ion beam induced tungsten deposition, a Micrion FIB-2500 system is used operating with a gallium liquid metal ion source. The Ga^+ ions are extracted from a small local region of a gallium droplet and then collimated and focused to an ion beam by an electrostatic lens arrangement. A total acceleration voltage of 50 kV is applied between the ion source and the sample.

If the deposition process is carried out in a previously determined rectangular area *A,* the average current density *j* is defined as *j=I/A*, where *I* is the ion beam current and *A* is the scan area.[1] Ion beam induced deposition occurs, if appropriate gases adsorb on the substrate surfaces and decompose during ion beam exposure, thereby forming nonvolatile residues. In order to enable deposition, tungsten hexacarbonyl ($W(CO)_6$) is injected into the reaction chamber by a narrow capillary tube. The deposition strategy consists of a sequence of scans over the target area, issuing pixel size, pixel distance, dwell time, cycle time, and refresh time. In order to determine the evolution of the tungsten deposition process, the process was build up by single deposition steps, each followed by an imaging scan to enable in situ observations of the developing nanoscale structures. Fig. 1 represents a typical image revealing the evolution of tungsten layer formation in its initial phase, when tungsten grows on a SiO_2 surface. At the onset of the deposition, the time resolved analysis shows nucleation at sites which are stochastically but homogeneously distributed all over the exposed area. After formation of the nuclei, a continuous growth of these nuclei was observed under irradiative exposure. From a certain state on, the discs do not grow anymore but tend to collapse to form larger connected structures (Fig. 1). It is remarkable that the formations grown in the earlier deposition steps are essentially preserved during the consecutively following deposition steps. With exception of the ongoing merging process causing the individual boundaries between the "islands" to vanish the principal shapes of the structures are not destroyed by the ion beam. After the exposure to an accumulated ion dose of about $0.25\ nC/\mu m^2$ (1.56×10^{17} ions/cm^2), the merging process of former separated regions result in a contiguous and merely plane metal surface.

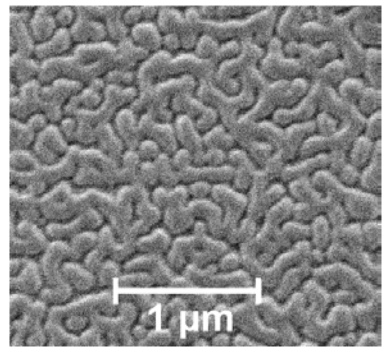

Fig. 1: FIB-SEM image of an ion beam induced CVD tungsten deposit on thermal silicon dioxide.

After a contiguous tungsten layer has formed during the initial growth on the SiO_2 surface, the further deposition process is characterized by homological growth of tungsten on a tungsten surface and the thickness of deposited metal correlates linear with the total ion dose. In a further step the impact of the average current density *j* on the deposition yield was determined using tungsten films deposited on a tungsten surface. In order to give a concise interpretation of the experimental findings a simple analytic model describing the deposition process is used. [2] In Fig. 2. the atomic deposition yield Y_A determined by experiments is plotted versus the average ion current density. The negative yield values correspond to conditions where the sputter effect of the ions exceeds the ion induced deposition. Y_S is the sputter yield, Φ the precursor gas flux and σn_0 the asymptotic yield at $j=0$.

The solid line in Fig. 2 represents a fit of the model to the data.

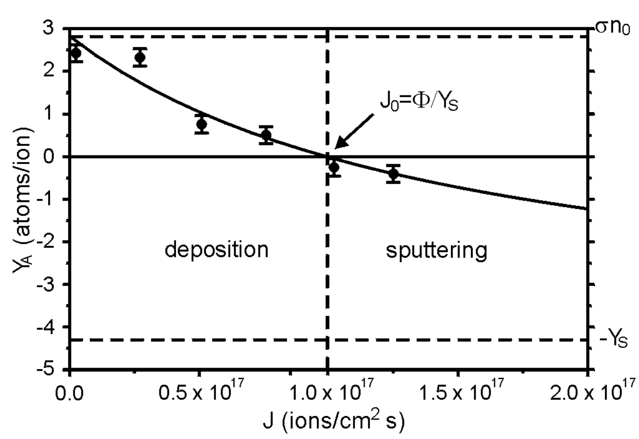

Fig. 2: Atomic deposition yield of tungsten hexacarbonyl under ion exposure as a function of the average ion current density. The solid line represents a fit due to the analytic model.

The critical ion current density J_0, where ion sputtering exceeds deposition was identified by the model. Because the model shows good agreement with the measurement it should be suitable for further survey concerning FIB process development.

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[1] P. G. Blauner, J. S. Ro, Y. Butt, J. Melngailis, J. Vac. Sci. Technol. **B 7** (4), (1989), p.609-617.
[2] F. G. Ruedenauer, W. Steiger, D. Schrottmayer, J. Vac. Sci. Technol. **B 6** (5)**,** (1988), p.1542-1547.