

Role of Nucleation and Growth Phenomena in Metallization of Micro- and Nanostructures

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Electrodeposition is widely used for metallization of various microstructures in microelectronics and microsystem technology¹. Electrochemical metallization has become recently of significant importance also for the coupling of micro- and nanotechnology. The development of effective techniques for metallization, however, requires a better understanding of the role of involved nucleation and growth phenomena in the micro- and nanometer scale.

In this contribution, the specific aspects of nucleation and growth in metallization of micro- and nanostructures will be considered and discussed on the basis of experimental results obtained in selected systems. Important for metallization by electrodeposition are the aspect ratio h/d (depth/width) of the structures and the electronic properties of involved materials. In the case of negative conductor/dielectric structures with small aspect ratio ($h/d < 1$) the mechanism of metallization is determined by the rate J [$\text{cm}^{-2} \text{s}^{-1}$] of primary nucleation, the lateral growth rate V_l [cm s^{-1}] of supernuclei, and the structure width d [cm]. At $(Jd^3/V_l) \ll 1$ the metallization occurs by a *mononuclear mechanism*, i.e. by the appearance and growth of single crystalline supernucleus^{2,3}. The so-called *multinuclear mechanism* involving formation and growth of many supernuclei operates at $(Jd^3/V_l) \gg 1$. The surface state of the foreign substrate is crucial for metallization. The maximum number of supernuclei (crystallites) N_{max} forming the metal film depends on the density of active nucleation sites N_0 [cm^{-2}] and the deposition conditions. The influence of the substrate surface state on initial nucleation kinetics was investigated in various systems using current transient measurements and microscopic observations.

A characteristic feature of electrochemical nucleation is the existence of a threshold of the cathodic overpotential called “critical overpotential” η_{crit} below which J is practically zero and above which it rises steeply^{2,3}. Based on this critical overpotential concept, effective double pulse polarisation routines for metallization under conditions of instantaneous nucleation and growth can be developed (Fig. 1). An example for metallization of a negative n-Si/SiO₂ microstructure with an aspect ratio of 1/10 using a such polarization routine is shown in Fig. 2. The resulting profile of the deposited Ag film indicates an increased local current density at the edges of the microstructure. A minimization of this non uniformity can be achieved by reducing the structure size, optimizing the deposition conditions and using levelling agents. Levelling additives are successfully applied also in the so-called “superfilling” (perfect filling) of completely conducting negative microstructures with higher aspect ratio ($h/d > 1$)⁴. In such structures the metallization process starts uniformly at all points of the microstructure by primary nucleation. However, the appearance of concentration gradients of depositing species during the advanced deposition stages usually leads to a preferential deposition at the top of the microstructure, which results in an imperfect filling. The superfilling technique⁴ developed by IBM is based on an approach previously applied successfully to levelling in

conventional electroplating. In this case the inhibitors acting as levelling agents usually enhance also the secondary nucleation (on top of growing crystallites) which leads to the formation of deposits with a fine grained equiaxed structure.

Problems arising in metallization of structures with very small dimensions in submicrometer and nanometer ranges will be discussed. Possibilities for activation of such structures or localization of metal deposition process by local probe techniques will be also considered.

REFERENCES

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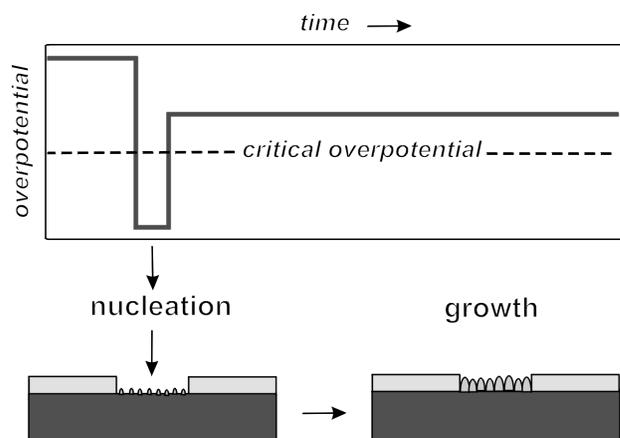


Fig. 1: Schematic representation of a double pulse polarization routine for metallization.

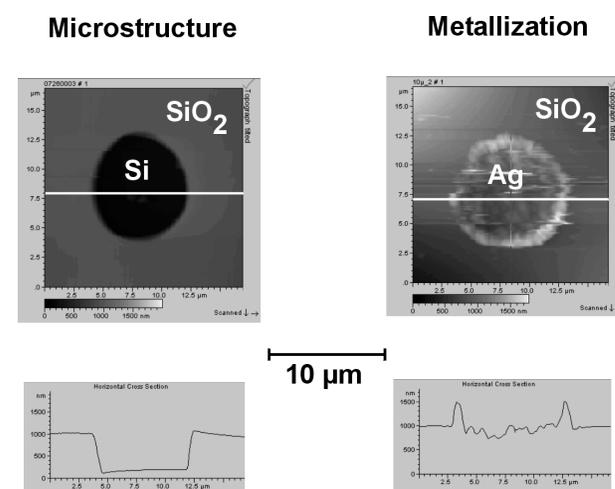


Fig. 2: AFM images of a n-Si/SiO₂-microstructure prior and after metallization by Ag electrodeposition.