Thin copper films prepared by CVD from (HFA)Cu 1.5-COD

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Aluminum and Al alloys are currently the most widely used materials for integrated circuit interconnections. However, permanent increasing of the integration level and of the on-chip packing density in very-large scale integration has revealed a number of shortcomings of aluminum metallization. Copper is a potential successor to aluminum since copper electrical conductivity is approximately 1.6 times that of aluminum, and the thermal conductivity is approximately 2 times higher, resulting in improved electrical performance, reduced Joule heating and better heat transport. Moreover, because of the higher melting point of copper as compared with aluminum diffusion-driven processes, such as electromigration failure, should be less problematic.

Metal Organic Chemical Vapor Deposition (MOCVD) is one of the most advanced techniques to fabricate multilevel metallization in integrated circuits. The purpose of this work is to investigate surface morphology, structure and mechanical properties of thin Cu films obtained by MOCVD from hexafluoroacetylacetonato (1.5-cyclooctadiene) copper (I) in different deposition conditions.

Samples studied were Cu films 0.2-0.4 μm thick deposited onto SiO_2/Si substrates. Investigations were performed with scanning tunneling microscope (STM), transmission electron microscope (TEM) and nanoindenter.

All the Cu films studied are characterized by fine-grain surface topography (Fig. 1), where the grain sizes are governed by the parameters of the deposition process. STM-investigations demonstrate the following results. As the source temperature increases, the lateral sizes of the grains are the same but their average height is reduced. The increase of the substrate temperature results in the growth of the lateral sizes of grains and the decrease of the height. Simultaneous rise in the deposition duration and in the substrate temperature leads to the considerable increase of both the lateral sizes and the height of the grains in the Cu films.

In order to compare the surface topography of the films measured by STM with their internal microstructure and to reveal how they are related with each other we carried out TEM-investigations of the samples. It is found that the Cu films are polycrystalline with equiaxed grains. Average size of grains grows with increase in film thickness (see Table I) that is similar to STM-measurements.

Investigation of mechanical properties of the Cu films performed with nanoindenter allowed us to reveal correlation between the microstructure of the films studied and their microhardness. According to Hall-Petch equation, the hardness of bulk materials should decrease with increasing the grain size. Our experiments clearly demonstrate complete accordance of the microhardness of the films studied to the Hall-Petch equation. A film with a minimum grain size and a higher surface roughness possesses a maximum microhardness. At the same time, all the samples studied independently from the grain size have the same values of elastic modulus. It testifies to reproducibility of the chemistry of the Cu films obtained under different deposition conditions.

Quantitative description of the surface topography of the films is carried using the root-mean-square roughness and the fractal dimension. Increasing of the lateral sizes of grains is accompanied by decreasing the fractal dimension of the film surfaces. However the last characteristic is not essentially affected by changing the grain height. On the contrary, the root-mean-square roughness does not reflect the growth of the lateral grain sizes but correlates with changing their height. Thus the joint use of the characteristics is shown to allow precise numerical characterization of the surface topography of thin copper films.

Table I. Thickness *b*, grain size *d*, microhardness *H* and elastic modulus *E* of Cu films

Samples	*b*, μm	*d*, nm	*H*, GPa	*E*, GPa
1	0.2	100	2.66±0.2	134±3
2	0.4	400	2.14±0.1	134±3

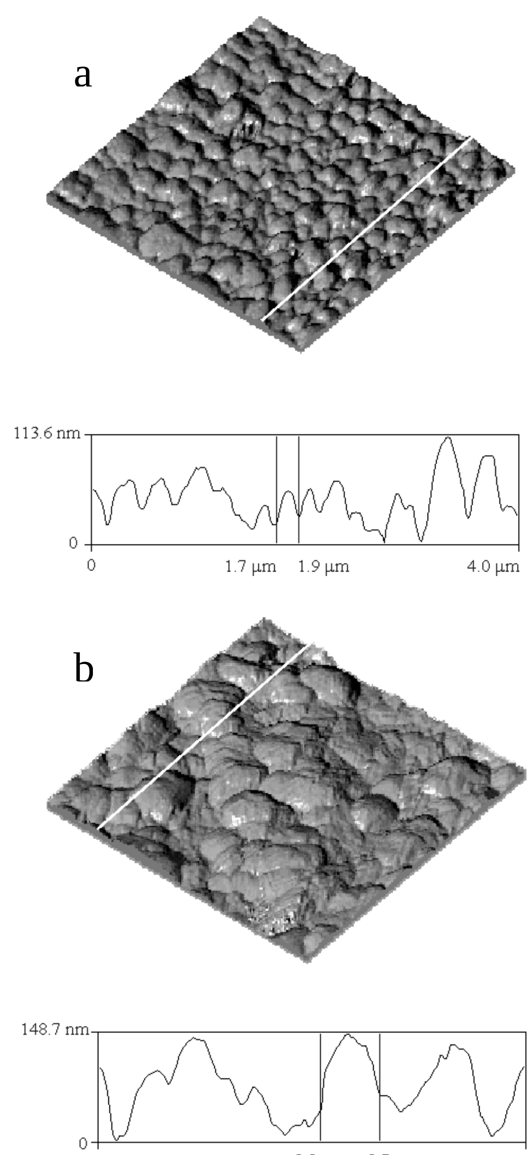

Fig. 1. STM-images and profiles of Cu films 0.2 (a) and 0.4 (b) μm thick deposited on SiO_2/Si substrates (samples 1 and 2 in Table I, rtespectively).