GISAXS and GIXRD study of the early stage of Cu growth on Si(001)-H

(GILLES B.)

It is well known that epitaxial growth of metals on Si(001) surfaces remains a tricky problem due to silicide formation and the large misfit between the structures. As a matter of fact, polycrystalline growth is obtained very often. As an exception, Cu/Si(001) have been used over the past two decades as templates for the growth of Cu/Ni multilayers designed for their Perpendicular Magnetic Anistropy (PMA) [1]. Hydrogenation of the Si(001) surface is a prerequisite and is usually obtained by dipping the substrate into a HF bath. Although it is generally assumed that hydrogenation inhibits copper diffusion into silicon, a thin silicide interfacial layer has been observed. The η-Cu_3Si phase has been suggested, though no extensive study has ever been reported on the early stage of growth.

In collaboration with the CEA-SP2M, the CNRS-LTPCM laboratory is involved in a research program on the growth of ferromagnetic metallic layers on patterned Si substrates, taking advantage of the high technological recent developments on Si e-beam lithography. We have recently obtained very promising results by using a template technique for the growth of Pt (001) or Fe (001) buffer layers which are well suited for the growth of multilayers or ordered binary alloys exhibiting PMA. This template technique takes advantage of the spontaneous formation of Cu silicide at the early stage of growth of Cu. This very thin layer is used as a seed layer for the ultimate growth of the Pt buffer layer. The structural quality of the Pt layer highly depends on the silicide thickness and structure. We expect to gain much information on the silicide growth process from this proposed experiment, especially by combining GISAXS and GIXRD. We propose to investigate the whole growth process of Cu over a large range of thicknesses as a model for understanding the epitaxy of other materials using the Cu silicide template. The expected results will be of great importance for a Phd work in progress.

In agreement with the literature, our first experimental results show that a quasi-continuous copper silicide film is formed at the very early stage of the growth at room temperature [2]. Figure 1 is a typical RHEED pattern obtained after 1 nm Cu deposition. An intermediate rod structure may be observed between Si and Cu rods which is clearly related to the silicide structure. Unfortunately, identification of the actual crystallographic phase is not straightforward because RHEED has a low resolution and too few spots are observed. We expect to get this structural information from GIXRD diffraction patterns. Auger Spectroscopy analysis has confirmed silicide formation, showing a characteristic 92 eV Si splitted peak (figure 2). Over a wide thickness range, STM images (see figure 3) reveal the same characteristic features: an arrangement of mounds with a well defined correlation distance. The mean distance L between the islands may be deduced from the height autocorrelation function and it varies as a power function of the Cu thickness t, i.e. $L(t) \sim t^{0.5}$ (figure 4). This peculiar growth mode does not correspond to the usual self affine mode proposed by most kinetic models. We need much insight into the actual growth morphology, including the correlation between the height-height average distance and the lateral size of the crystallographic grains.

More precisely, we expect:

1) with GISAXS : the evolution of the mean distance between the mounds and their average size. A quantitative study may also provide information on their shape and arrangment.

2) With GIXRD : the silicide crystallographic phase information . Is the η-Cu_3Si phase the phase which actually is formed ? What about the silicide thickness ? What is precisely the grain disorientation and its evolution during growth ? What is the lattice strain and the effect of the silicide in the lattice accommodation between Copper and Si ?
3) With high-angle reflectivity between Bragg peaks, we hope to be able to determine at the first early stage of the silicide formation the diffusion mechanism. It is expected from the literature that Cu atoms diffuse into the Si lattice within a few atomic distances and form small buried mounds .

Fig. 1 : RHEED pattern from 1nm Cu/Si(001)

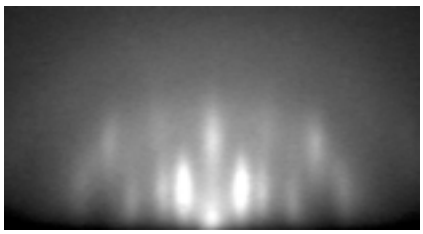


Fig. 2 : Auger spectrum for 1 nm Cu deposited film on Si(001)-H.

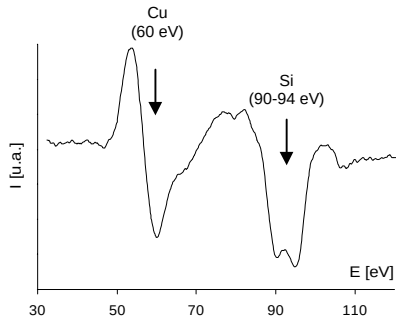


Fig. 3 : STM 30×30 nm image on a 0.25 nm Cu film (with 2 nm height full scale).

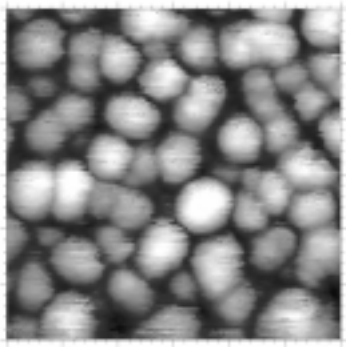
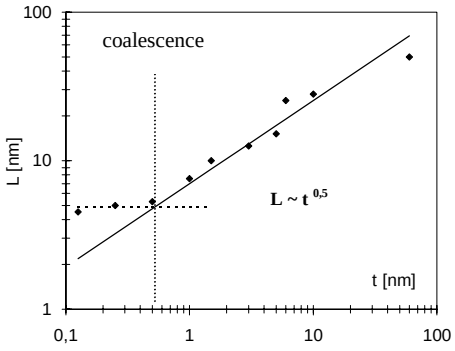


Fig. 4 : Radial Correlation length versus Cu deposited thickness.



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[2] Z.H. Zhang, S. Hasegawa, S. Ino, Surf. Sci. 415 (1998) 363-375.