Nanoscale Patterning of UHV Clean Si(001)

R. Linklater and J. Nogami
Dept. of Materials Science and Engineering, University of Toronto, Toronto, ON, Canada

Introduction

This work is focused on establishing a repeatable experimental procedure for patterned deposition of metal onto a semiconductor substrate in UHV. This is achieved through the use of a self-aligning nanostencil, or shadow mask with nanoscale apertures, brought to within a small distance of the substrate. Thermally evaporated metal reproduces nanostencil features on the substrate.

Shadow effects of the nanostencil edge were examined with STM and results show interesting diffusion behaviour of deposited metal on the semiconductor surface.

Investigation of the deposited metal features was carried out by SEM and STM.

Deposition Model

Deposition model based on a line of sight geometry. Although this neglects any surface diffusion of the deposited metal, a model of this type has been shown to be a reasonable approximation in published literature1. Feature resolution is limited by the $d/L$ ratio. We use contact alignment of the nanostencil to the substrate to achieve a small $d$. The length $L$ is fixed in the experimental chamber.

The edge of the nanostencil creates a metal gradient with three distinct regions: 1) a metal film, 2) a penumbra and 3) an umbra. The penumbra width is also controlled by the $d/L$ ratio. By measuring the penumbra width $w_p$ we can estimate the nanostencil to substrate separation.

In our system the source to nanostencil separation is $L = 225$ mm, the source size $w_s = 70-100$ nm and the smallest apertures are typically $w_s = 10-15$ nm. Thus the mask to substrate separation should be $d = 10-15 \mu m$, to limit the feature spreading to $50$ nm.

Gold Gradient Imaged with STM

Composite image of the gold gradient formed by edge of the nanostencil. 10 STM images, each 100 x 100 nm.

Three shadow regions:

1. FULL GOLD FILM, constant gold thickness, not covered by nanostencil
2. PENUMBRA, area partially covered by nanostencil edge, displays decreasing gold coverage from full thickness to a 1ML band
3. UMBRA, area completely covered by nanostencil, Au diffuses into umbra and forms small islands of 1ML height

RMS roughness is proportional to the metal thickness above 1ML2 and is measured in this region the gold mounds display a plateau morphology up to the onset of the penumbra as seen in the composite image. This morphology is visible in the composite image. This morphology agrees with literature4.

Height of gold monolayer islands is 150 pm (empty area far from the shadow boundary). Gold mounds maintain this plateau shape up to the onset of the penumbra region, as would be expected for a single atomic layer film5.

Comparing the coverage profile with the roughness profile shows that coverage of ~0.5ML occurs near maximal roughness in umbra region, as would be expected for a single atomic layer film5.

Conclusions

Sub-micron patterning experiment. Pressure ~ 10^-1 Torr. Thus the Si(001) was not UHV clean and a native oxide was present. 1.6nm of Silver deposited. Ag clustering, not uniform dot as expected on clean Si(001). Ag Dot size: 560 x 660 nm compared to Nanostencil Holes: 450 x 560 nm. Spreading of ~ 100 nm gives $d = 15 \mu m$.

References


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