Electron beam fabrication of masks in amorphous metal-chalcogenide bilayers

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Abstract. Electron beam induced surface modifications have been employed in modifying chalcogenide/silver bilayers formed with As$_2$Se$_3$, GeSe$_2$, Sb$_2$S$_3$ etc. to produce submicrometre and nanometre dimensional patterns which may eventually have potential applications in single stage processing of nanometer x-ray and extreme ultraviolet (EUV) masks for silicon chip fabrication. The x-ray masks with differing structures have been fabricated over a range of electron beam accelerating voltages and electron beam intensities. The use of copper as well as carbon as the soft x-ray source has been investigated. Characteristics of the transferred image have also been studied. Silver patterns, formed in bilayers on silicon wafers, with potential applications in fabrication of EUV masks, have been studied by scanning Auger microscopy.

1. Introduction

The main objective of lithography in fabricating masks is to enable the production of printed patterns on exposure to light or ultraviolet radiation that are a faithful reproduction of the mask pattern. However, as the feature sizes shrink as a result of the pressure to increase the capacity of silicon chips, faithful printing becomes more difficult due to diffraction effects. A reduction of the wavelength of the radiation used in mask exposure is therefore required. Radiation in the extreme UV (EUV) or soft x-ray regions has to be used. Electron beam fabrication is also required to produce masks with reduced feature size. The electron beam induced properties of chalcogenides can be utilised to produce EUV and x-ray masks for future mask generation technology. The photodoping of amorphous chalcogenides (e.g. GeSe$_2$, As$_2$Se$_3$ etc.) with metals (e.g. Ag, Cu etc.) and the migration of metals in these materials under electron irradiation have potential applications in the production of x-ray [1, 2] and EUV masks. As a result of electrochemical modification nanometre and micrometre dimensional patterns can be produced in amorphous chalcogenide-metal bilayers supported on an x-ray transparent membrane or on a solid substrate for EUV mask applications where metal lines can form the patterned absorber layer in the reflective EUV masks. Since an electron beam is utilised to generate patterns on these bilayers the resolution of the patterns will depend on the size of the electron source. Parameters such as the film thickness, x-ray transmission, accelerating voltage and electron dose from the electron beam are important in mask fabrication.

Mylar and copper x-ray sources can be used to test x-ray mask exposures. Copper produces 1.2 nm x-rays (Cu $L_\alpha$) whereas Mylar produces a 3.67 nm x-rays (C K). However, the use of Cu $L_\alpha$ x-rays leads to a uniformity problem in the photore sist AZ PN114 after development. Because of backscattering from the substrate, the bottom of the resist gets an additional dose that is distributed over an area much larger than the beam with a characteristic length of several micrometers. This leads to an additional flattening of the beam profile which can have an adverse effect on pattern sidewalls and lead to long range distortions of patterns. The exposure of unaddressed areas is called the proximity effect which is a limiting factor for e-beam lithography especially for high resolution features.

The present study of x-ray masks has focused on developing a novel fabrication technique involving a single processing step using electron beam generated patterns in chalcogenide/silver bilayers. A test
pattern for both x-ray sources was generated to determine the optimum dose required to expose a negative chemically amplified resist AZ PN114. Proximity effects in the patterns have also been studied. The possibility of fabricating EUV masks in metal-amorphous chalcogenide bilayers has also been investigated.

2. Experimental

Amorphous chalcogenide/silver bilayers were deposited by thermal evaporation at a pressure of better than $2 \times 10^{-4}$ Torr onto silicon wafers and also onto silicon wafers that contained a thin film window composed of a silicon nitride membrane ($\text{Si}_3\text{N}_4$) of 100 nm thickness and 1 mm$^2$ area. The thickness of the amorphous chalcogenide films and the silver films ranged from 100 to 530 nm and 30 to 100 nm respectively.

Various test patterns of the order of micrometre width were generated by a modified JEOL JSM-T220 SEM, a JEOL 120C STEM and a Microlab 350 scanning Auger microscope. The T220 was externally controlled by means of ELPHY Quantum nanolithography software supplied by RAITH. Accelerating voltages between 5 kV and 30 kV were used in the SEM. The STEM was operated at 100 kV. Various exposure parameters such as beam current and electron dose were studied to optimise the production of high contrast x-ray masks. The structure and topography of the patterns drawn on the substrate were both studied using a Digital Instruments Dimension 3000 Atomic Force Microscope (AFM) in tapping mode. Energy dispersive X-ray microanalysis (EDX) and Auger electron spectroscopy measurements were carried out to characterise the composition of the mask patterns.

3. Results and Discussion

The accelerating voltage was found to be a crucial variable in the formation of the x-ray mask structures when exposed to a greater than optimum electron beam dose. In the T220 SEM, the use of a low accelerating voltage (5 and 10 kV) tended to produce a silver deficient trough-like patterned structure in the membrane supported bilayers whereas a protruding patterned structure was observed at higher accelerating voltages (e.g. 20, 25 and 30 kV). In the STEM, only trough-like patterns were observed in the membrane supported bilayers [2].

Cross-sectional line profiles along two grid directions in the T220 SEM generated masks were subsequently examined to assess the proximity effect due to electron scattering. A two dimensional AFM image shows adjacent perpendicular-lines that intersect each other as well as the adjacent cross sections (magnified) (figure 1). The width along a diagonal at the line intersections was found to be $(3.35 \pm 0.23)$ µm taken along a line at $45^\circ$ to the horizontal lines. An average height increase on the
line height at the intersections was found to be 6 nm, which was a 7% increase in height. Since a high dimensional stability is required in producing x-ray masks it is important to quantify any variations in material and instrumental parameters that could affect the mask patterns.

One aspect of mask fabrication is the sensitivity of the mask material to the type of x-ray source. When masks generated in the JEOL 120C STEM were exposed to C K x-rays, an improved photoresist uniformity and contrast in the transferred pattern was achieved by comparison with exposure to Cu Lα x-rays. Figure 2 shows the micrometre dimensions of the transferred pattern from a trough-structured mask which was composed of a series of lines and grids that were formed by an electron beam in the a-As$_2$Se$_3$/Ag bilayer.

Figure 2. Image formed in the AZ PN114 photoresist from transmission of carbon K x-rays through a-As$_2$Se$_3$/Ag mask patterned in the JEOL 120C STEM.

Figure 3. Section analysis from a mask pattern generated by the JEOL 120C STEM electron beam in an a-As$_2$Se$_3$/Ag bilayer and the associated projected image.

Section analysis of a typical x-ray mask, generated in the JEOL 120C STEM that was formed in a bilayer consisting of a 380 nm thick As$_2$Se$_3$ film and a 30 nm thick silver film, demonstrated that the depth of the trough structure in this type of mask pattern was about 200 nm (figure 3). From this it is clear that the electron beam has effectively milled out the bilayer through to the underlying Si$_3$N$_4$ membrane layer rather than causing the metal to migrate away from the electron beam scan line as has been observed in previous work [3]. The line width of the mask pattern measured at the same position in each line was (2.93 ± 0.13) µm. The projected transferred pattern shows a protruding line structure with about the same width as the transmitting features on the mask.
Figure 4 shows the formation of a silver structure from a GeSe₂/Ag bilayer film on a silicon substrate when an electron beam is rastered across the bilayer in a UHV Auger system. In this case no carbon contamination was detected in the Auger system as opposed to mask structures generated in the T220 SEM where some carbon has always been detected. Silver patterns formed in this way have potential applications as the patterned absorber layer in reflective EUV masks.

![Figure 4](image)

**Figure 4** (a) Square silver structure obtained by rastering the electron beam (b) Ag, Ge and Se Auger signals in this structure as a function of electron beam exposure time.

4. Conclusions

X-ray masks can be fabricated by scanning an electron beam across metal/chalcogenide bilayers on different substrates to form linear patterns that can be metal-free, metal rich or are produced by material evaporation. Due to the higher absorption of the C K X-rays in the photoresist material and the higher sensitivity of the resist to C K X-rays, improved contrast can be obtained in the images of the mask obtained with this x-radiation. Future experiments should involve the use of an electron source that is capable of generating nanometre scale patterns in the metal-amorphous chalcogenide mask material leading to nanoscale patterns in the photoresist. Contamination-free silver-rich patterns have been generated in UHV conditions and could have applications in EUV mask fabrication.

References

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