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Introduction

Any potential lithography must demonstrate an industrially-compatable reticle pattern repair process before the lithographic process can be seriously considered for production. Repair of clear defects on EUV reticles (i.e., regions on the mask which are reflective and should be non-reflective) requires the deposition of a thin layer of absorbing material. This process has been demonstrated in commercially available tools which were originally developed to repair proximity-print x-ray lithography masks. However, the repair of opaque defects (i.e., the recovery of reflectivity from regions on the reticle covered with an absorber) is more difficult. Opaque defect repair requires the removal of the absorber layer without damaging the underlying multilayer, a process which could degrade the mirror reflectivity. While opaque defect repair processes have been demonstrated in a research environment[1,2], these processes may not be commercially suitable. We are developing reticle repair processes that will be consistent with a commercially available repair tool. In this paper, we report on our first results.

Our reticle architecture is shown in figure 1; it is a substrate coated with a multilayer coating designed to reflect EUV radiation (the multilayer coated substrate is defined as the EUV "blank"). The multilayer is overcoated with a thin layer (~30 nm) of silicon to protect the multilayer during ion-beam repair processing. The thin silicon layer reduces the EUV reflectivity by ~3% and is required only on the EUV reticle (i.e., the EUV imaging optics do not require the silicon overcoat because they are not subjected to ion beam repair). A thin layer (~50 nm) of patterned metal provides the required contrast to pattern wafers. A number of different metals can be used for the absorber pattern, including Au, W, Ta, Ti, Pb, Ge, etc.

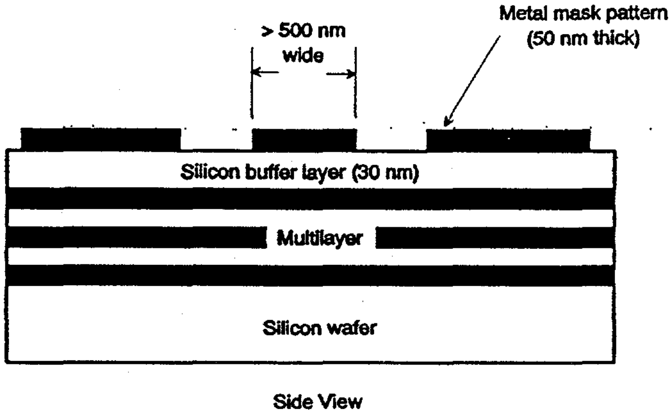

Figure 1. A cross sectional view of the EUV reflective reticle

Because the EUV imaging system demagnifies the image of the reticle onto the wafer, the aspect ratio of the patterned metal on the reticle is approximately 10:1; i.e., the metal is 10 times wider than it is tall for 100 nm features on the wafer.

Previously, we succeeded in removing a thin (5 nm Cr/ 50 nm Au) masking layer from the reticle blank without damaging the underlying multilayer(1). This was done with a 1 KeV, unfocussed Ar ion beam. While this demonstrated that it is possible to successfully remove the masking layer, the beam energy is too low to achieve submicron resolution in a focussed ion beam tool. The intent of this work is to develop a repair process that would use the Micrion Gas Field Ion Source (GFIS) repair tool to remove unwanted mask material without damaging the multilayer mirror. As designed, this tool will have the capability to focus 10 and 40 KeV ions of H, He, Ar and Ne.

Substrate Preparation

The reticle blanks used in this work were prepared with a 40 layer pair of molybdenum/silicon multilayers, overcoated with a silicon buffer layer, on silicon wafers. The multilayers were optimized to reflect ~13 nm radiation. The peak reflectivity of these mirrors was measured to be 57%, consistent with high quality multilayer mirrors with a 50 nm thick silicon overcoat (calculations indicate that these mirrors without the overcoat would reflect approximately 65%).

Calculations(3) indicated that the mean penetration depth of 10 KeV Ar and Ne is 12 (± 6) nm and 22 (± 10) nm respectively, while the mean penetration depth of 40 KeV Ar and Ne is 45 (± 17) nm and 64 (± 23) nm respectively. 30 or 50 nm of silicon was chosen as the overcoat thickness for the 10 KeV ions.

The reticle blanks were patterned with 10 metal pads (simulating the reticle masking material). Each pad was approximately 2 cm long and 7 mm wide, were patterned on the silicon overcoat using a liftoff process. For our first experiments, and to validate our

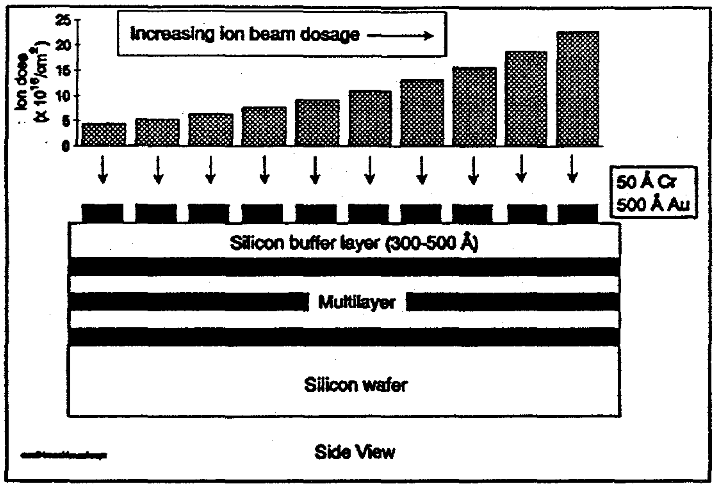

Figure 2. A cross sectional view of the mask reticle illustrating the ion beam dose per pad.

measurement protocol, 50 nm Au was used as the masking material (a 5 nm Cr adheasion layer, deposited directly onto the Si buffer layer, was used under the Au).

Opaque Defect Repair Experiments

The Micrion GFIS tool is under development and a prototype is scheduled for demonstration in September, 1995. To simulate the etching from this tool, we used an ion implanter. The implanter delivered 10 KeV Ne ions to the pads. Monte Carlo calculations(3) were made to estimate the dosage required to clear the metal pads, and this was compared to published results(4-5). The pads received a monotonically increasing dosage, figure 2, varying from approximately one-half to twice the estimated dosage required to fully sputter the masking material. During the ion beam etching, photoresist protected regions of the reticle for reference.

We used surface profilometry, x-ray reflectivity and x-ray fluorescence measurements to characterize the samples. Profilometry measurements indicated that the etch depth in the

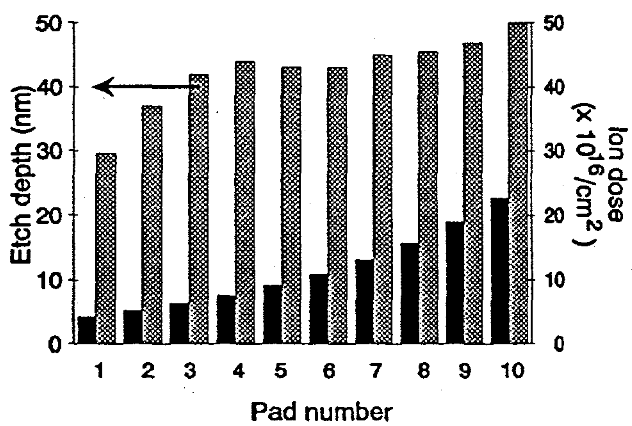

Figure 3. Measured etch depth (hatched bars, scale on left) vs. ion beam dose (solid bars, scale on right) for the reticle under evaluation. Profilometry measurements indicate that the etching stopped at approximately the Cr/Au interface.

metal pads was, at first, approximately linear with ion beam dose but additional ion beam etching did not remove substantially more material, figure 3. X-ray reflectivity measurements were made at the LBL Center for X-ray Optics and indicated that the reflectivity from the etched pads initally increased with increasing ion beam etching (i.e., reflectivity increased with the removal of the masking material) up to (approximately) half the expected value. Unfortunately, further ion beam etching did not substantially improve the reflectivity, figure 4. Further characterization included x-ray fluorescence measurements. From the fluorescence measurements, we were able to approximate the remaining Au/Cr layer thicknesses in all the pads. These measurements indicated that the Au layer thickness initially decreased with increasing ion beam etching; however, the final 5-10 nm of Au mixes with the 5 nm of Cr forming a layer which does not remove easily. This thin layer absorbs significant EUV radiation. Modeling indicates that the net EUV reflectivity from the individual pads agrees very well with the calculated reflectivity for a mirror with the appropriate metal overcoat.

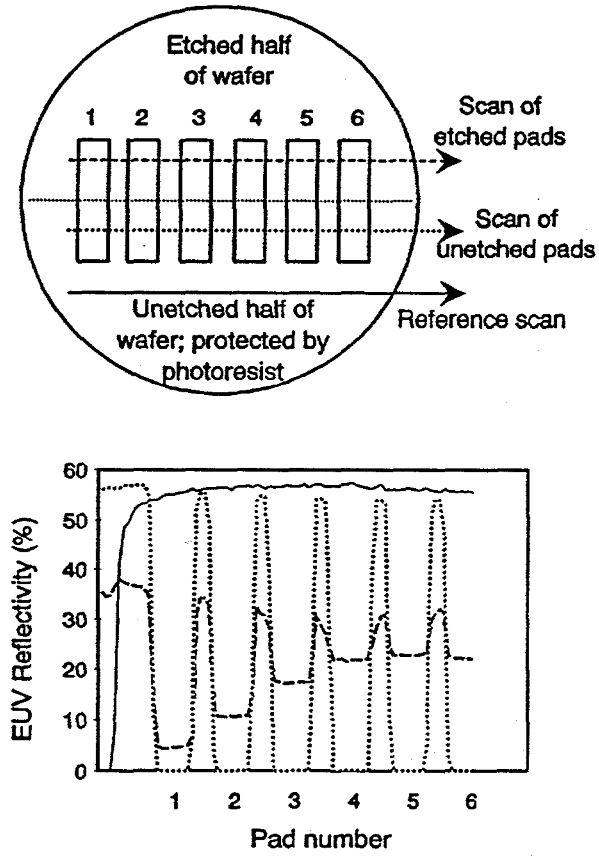

Figure 4. EUV reflectivity measurements of the reticle. The solid line in the top figure illustrates the location for the reference scan (in a region which was protected during ion beam etching) and in the bottom figure plots the EUV reflectivity as a function of position; The dotted lines illustrates the location of the scan and the EUV reflectivity for unetched reticle pads. The dashed lines illustrate the location and reflectivity of the pads which were etched with the Ne ions.

Conclusions

We have developed a protocol for testing defect repair strategies in EUVL reticle blanks. Consistent results were obtained from EUV reflectivity, x-ray fluorescence and profilometry measurements. Initial experiments with 10 KeV Ne ions indicates that a masking layer consisting of 5 nm Cr with 50 nm Au is a poor selection: during etching, the final 5-10 nm of Au mixes with the 5 nm of Cr to form a layer resistent to ion beam etching. It is possible that this can be minimized by using 10 KeV Ar ions, but a more suitable solution appears to use a different masking material.

Acknowledgements

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