Finishing of EUV Photomask Substrates by CNC Precessed Bonnet Polisher

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ABSTRACT

The progressive transition from Excimer to EUV lithography is driving a need for flatter and smoother photomasks. It is proving difficult to meet this next generation specification with the conventional chemical mechanical polishing technology commonly used for finishing photomasks. This paper reports on the application of sub-aperture CNC precessed bonnet polishing technology to the corrective finishing of photomask substrates for EUV lithography. Full-factorial analysis was used to identify process parameters capable of delivering 0.5 nm rms surface roughness whilst achieving removal rates above 0.1 mm^3/min. Experimental results show that masks pre-polished to 300~600 nm P-V flatness by CMP can then be improved down to 50~100 nm P-V flatness using the automated technology described in this paper. A series of edge polishing experiments also hints at the possibility of increasing the quality area beyond the 5 mm defined in the official EUV photomask specification.

Keywords: Finishing, EUV Photomask, Precessed Bonnet Polishing, Corrective Polishing, Full Factorial, Ultra-Precision, Edge Polishing, Quality Area.

1. INTRODUCTION

The specification for Extreme Ultraviolet Lithography Mask Substrates states that Peak-to-Valley flatness error should range between 30 nm to 100 nm over the quality area (that is, up-to 5 mm away from the substrate edges). Such low flatness error is difficult to achieve on square shaped substrates with the conventional chemical/mechanical polishing (CMP) equipment typically used in industry. To solve this problem, an innovative sub-aperture CNC polishing process is presented (see Fig. 1), which answers the need for corrective finishing after conventionally polishing by CMP equipment.

Figure 1: EUV Photomask on 7-Axis CNC Bonnet Polisher

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This CNC process is based on soft bonnet tool precession, which has been reported at various stage of its development [1,2,3]. The operation can be summarized as follows: the position and orientation (precession angle) of a spinning, inflated, membrane-tool are actively controlled as it traverses the surface of a workpiece (see Fig. 2). The workpiece may have any general shape, including concave, flat, or convex, aspheric or free-form. Whilst a classical polishing tool is pressurized against the surface of the part, with no attempt to control actively the Z position of the tool in a local or global coordinate frame, in the technique we describe the Z position, precession, as well as the contact-force, are actively controlled with a CNC machine tool. This process may be used with any combination of cloth and abrasives, depending on the substrate material, in order to generate a sub-aperture spot that traverses the workpiece with controllable feed rates.

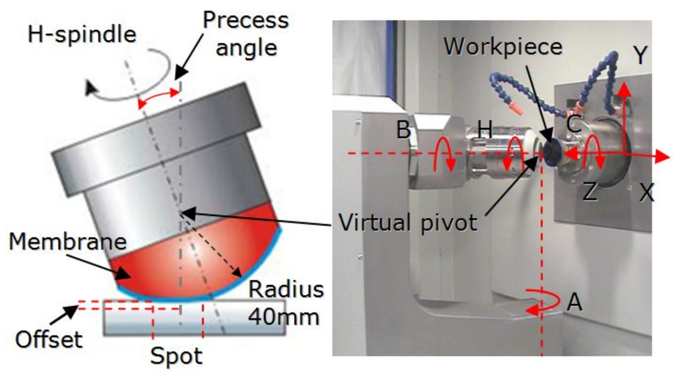


Figure 2: Principle of precessed polishing tool and 7-Axis CNC machine

The precessed bonnet polishing technique has now been applied to corrective finishing of EUV photomasks (after conventional polishing by CMP equipment). The experiments carried out so far have dealt with characterization of the achievable flatness error and surface roughness, as well as the potential for increasing the size of the quality area.

2. SURFACE TEXTURE

In order to determine the surface texture performance of the bonnet polishing process on fused silica, full-factorial characterization of 3 of the available CNC process parameters was carried out (using 2 different Cerium Oxide abrasive grits, i.e. 0.5 and 1.5 microns). The CNC parameters were: (1) bonnet air pressure, (2) bonnet precession angle, and (3) bonnet rotation speed. Using the smaller grit size (0.5um diameter particles size), a range of process conditions were found that could deliver surface roughness below 0.5nm rms (see Fig. 3 and 4).

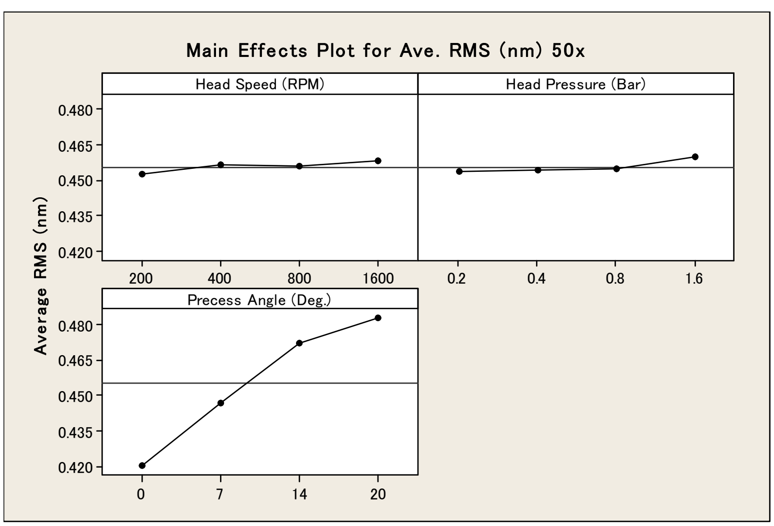


Figure 3: Surface roughness as function of individual parameters (using 0.5um CeO_2)

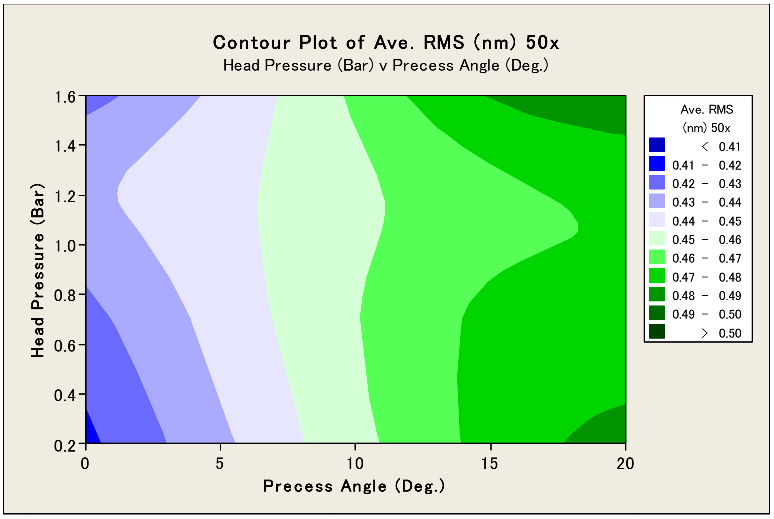


Figure 4: Combined influence of head speed and head pressure on surface texture (precess angle constant)

A small amount of waviness could be observed in some of the micro-roughness measurements (see Fig. 5 top). A series of pitch polishing tests was carried out, to try and eliminate this underlying waviness. These trials were successful, although extremely fine surface scratches could be seen at 100x magnification with a laser microscope (see Fig 5 middle).

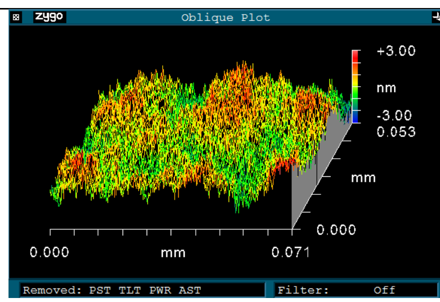
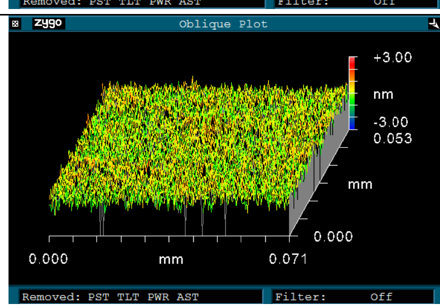
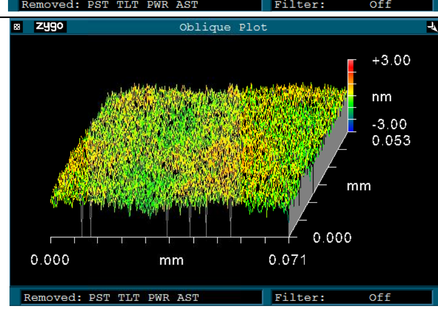
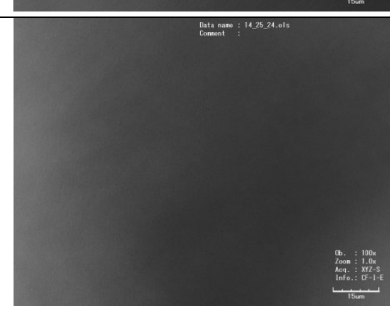
Condition	RMS (nm)	Interferometer	Microscope
After Bonnet Polishing	0.81		
After Pitch Polishing	0.48		
After Final Smoothing	0.48		

Figure 5: Surface texture at various stages of the pitch polishing trials

To remove these scratches, a final smoothing pass using conventional bonnet polishing at 0 deg precess angle (pole down) could be performed. The scratches disappeared without deterioration of the RMS value (see Fig. 5 bottom).

3. FORM CORRECTIOM

Corrective polishing experiments were carried out, using process parameters that would deliver surface roughness below 0.5 nm rms whilst still achieving relatively high removal rates (above 0.1 mm^3/min). Corrective polishing software was used to numerically optimize raster polishing tool paths on the sample. The software uses influence functions generated on a piece of same material and curvature to optimize the feed rate of the polishing spot across the workpiece.

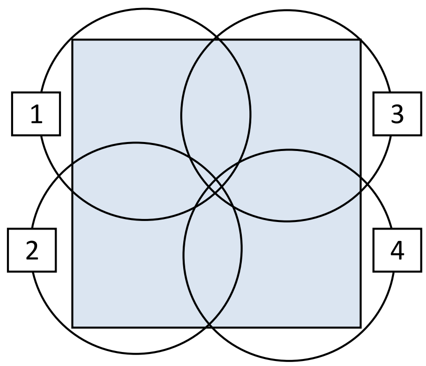


Figure 6: Quadrants measured for input into stitching software)

The photomask flatness was measured with a 4" Fizeau interferometer. The workpiece was measured in quadrants (see Fig 6), which were then assembled together using stitching software [4]. The stitched flatness error was then fed into the feed rate moderation software, for tool path output to a 7-axis CNC machine. Flatness improvement was demonstrated from 300~600 nm P-V down to less than 50 nm P-V (see fig. 7). Depending on the amount of flatness error after CMP, the polishing time ranged from 15 to 45 minutes.

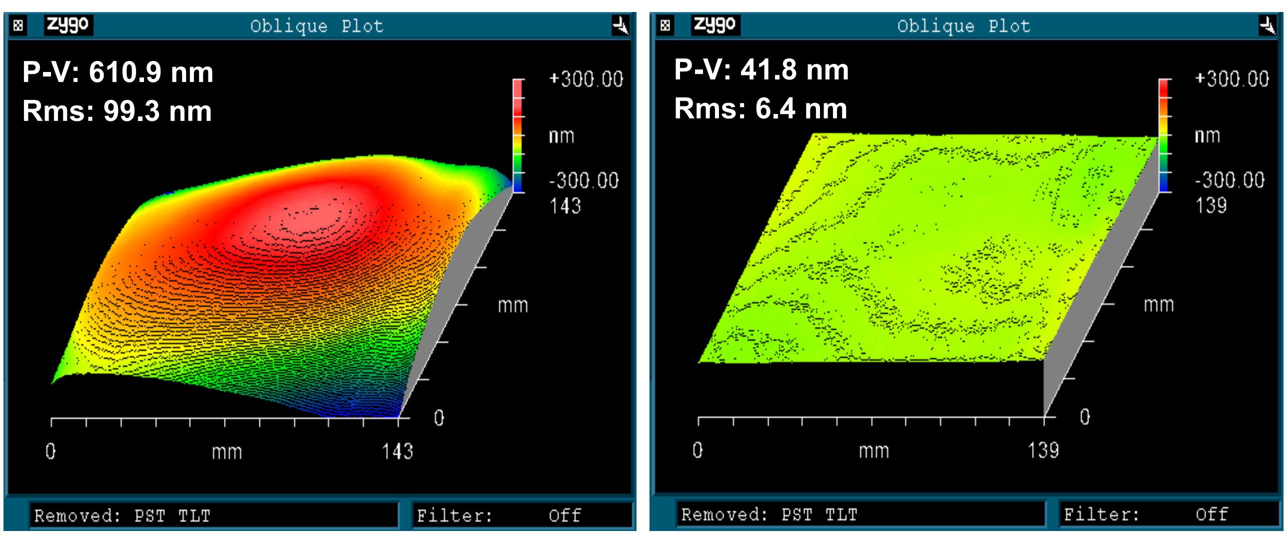


Figure 7: Flatness of Photomask before and after Corrective Polishing

4. EDGE CONTROL

Recently, a series of paper relating to the subject of edge control with precessed bonnet polishing was published [5,6]. Building on the knowledge accrued from the research reported in these papers, a series of experiments was carried out on photomasks using varying process conditions at the edge of the photomask substrate. The principle of these experiments is shown in Fig. 8: As the sub-aperture polishing spot approaches the edge of the sample, its diameter is reduced whilst the feed rate is decelerated.

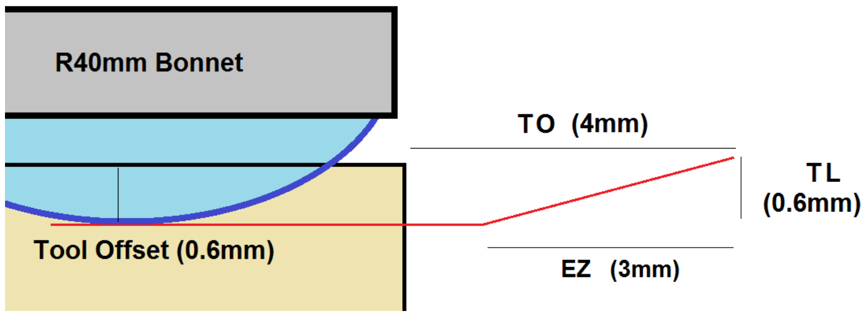


Figure 8: Edge control Parameters (TO: Tool Overhang, EZ: Edge Zone, TL: Tool Lift)

In order to observe the change in polishing effect near the edge, the workpiece surface was measured before and after polishing, such that the two measurements could be subtracted (see Fig. 9)

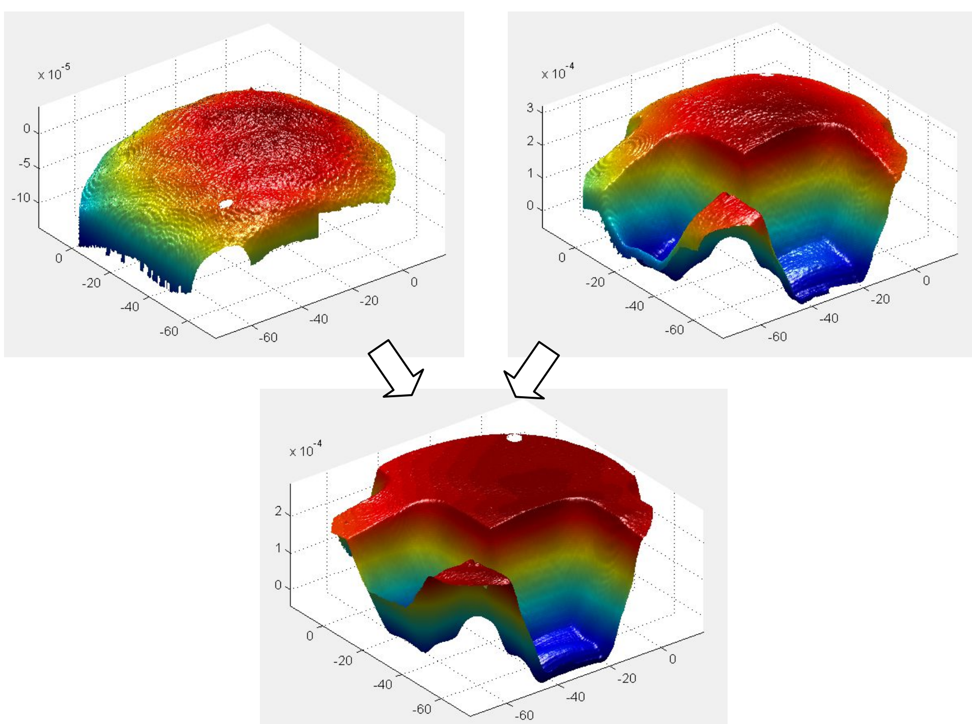


Figure 9: Edge polishing experiments (subtracting measurements before & after polishing)

The edge profile as a function of the tool overhang and edge zone values are shown in Fig. 10. The purple vertical lines correspond to a distance of 5mm and 3mm to the edge of the photomask. This series of experiments provides clues of an ability to increase the quality area of EUV photomasks beyond the 5 mm defined in the specification, by optimizing the parameters of the edge transitions. Optimization of these parameters will be further researched in the future.

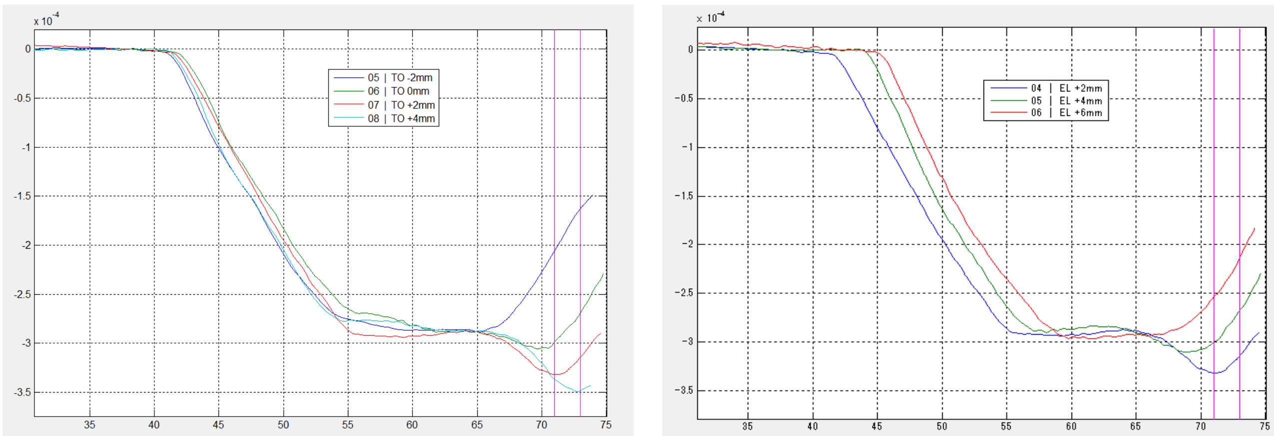


Figure 10: Edge Profile as function of Tool Overhang (left) and Edge Zone (right)

5. CONCLUSION

The specification for EUV photomasks is driving a need for improved polishing technology, capable of very low levels of flatness. In this paper, a CNC controlled sub-aperture finishing process called “precessed bonnet polishing” was presented, and applied as a post-finishing process after chemical/mechanical polishing. This process was shown to be capable of achieving flatness less than 50nm P-V whilst maintaining surface texture below 0.5nm rms. Depending on the amount of flatness error after CMP, such results can be achieved with polishing times ranging from 15 to 45 minutes.

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