Quartz etch process to improve etch depth linearity and uniformity using Mask Etcher IV

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ABSTRACT

Alternating Aperture Phase Shift masks (alt-APSM) are being increasingly used to meet present day lithography requirements by providing increased resolution. The quartz dry etch is a critical step in the manufacture of these photomasks. Etch depth linearity, phase uniformity and minimum etched surface roughness are critical factors .To achieve this, etched quartz structures need to have good selectivity to resist / chrome, vertical sidewalls and good etch depth uniformity over the mask area. Using the Mask Etcher IV at Unaxis USA, a series of experiments were performed to study and identify the trends in quartz etching for photomasks. Etch depth uniformity was measured using an n&k1700RT and etch depth linearity from feature sizes ~0.4 μm to ~1.4 μm was measured using an AFM. Cross sections of the ~0.6 μm structure were obtained using a SEM to check for profile and any evidence of micro trenching. After several set-up experiments, an optimized process to minimize etch depth linearity and improve etch depth uniformity was obtained and is presented here.

Keywords: Quartz Etch, etch uniformity

1. INTRODUCTION

Alternating Aperture Phase Shift Masks (AAPSM) provide enhanced resolution by phase shifting the transmitted light at feature boundaries. The quartz etch forms a critical part of the fabrication of AAPSM's since the quartz etch depth determines the phase difference at feature boundaries. The ITRS roadmap for the 65 nm node requires a phase uniformity of 180° ± 1° and a linearity of 2° range which translates to an etch depth uniformity of 2 nm. In addition, the etched features should be free of microtrenching and should have vertical sidewalls. In the absence of a suitable etch stop layer in quartz, the etch process should have an etch rate which is low enough to permit a level of process control necessary to achieve mean to target specifications.

At Unaxis, the Mask Etcher IV – Quartz module was designed to meet these stringent demands. Using a combination of hardware and process optimization, etch depth uniformity and etch depth linearity are initially characterized and then optimized.

2. APPROACH

2.1 Experimental Approach
The experimental approach was derived from previous work on earlier generation quartz etch tools. [1,2] The goals were to improve both the selectivity and etch linearity, while preserving the etch uniformity and profile. Initially a series of screening experiments was performed to understand the effects of process parameters (including process gas type) on etch profile and micro trenching, linearity, etch rate and selectivity. At this point etch rate uniformity was a secondary consideration.

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From these experiments, the radial and linear components of the etch depth uniformity were quantified and adjusted by modifications within the hardware. Whereas the linear component of the uniformity is entirely due to hardware asymmetry, the radial component is also influenced by process parameters. Because of this inevitable interaction, a second process iteration was performed using the modified hardware to generate an optimized process and hardware suite.

2.2 Test Patterns

Two different test patterns were used to characterize the quartz etch. The first pattern "Tampa SEM" was exposed by a laser writer onto 5000Å of OCG895i resist. The pattern has a line-space grating structure and SEM lines with varying feature sizes. The pattern covers a 132mm x 132 mm area on the surface of the photomask. This pattern is evenly loaded with 50 % exposed quartz load. A second pattern called "Tampa SEMLC" is a similar pattern apart from the load. It is evenly loaded with less than 1% exposed quartz load.

2.3 Metrology

The initial and post etch resist measurements were made using a reflectance based thin film measurement system. Etch depth uniformity was measured using N&k1700RT .A 64 point evenly distributed pattern that covered a 132 x 132 mm area was used for the uniformity measurement. The etch depth was averaged over a line space grating and feature size of ~600 nm. Multiple measurements were made to reduce measurement error. The Cr and the resist were removed using a standard Cl_2/O_2 and O_2 chemistry respectively before etch depth measurements.

A Digital Instruments 5000 Atomic Force Microscope (AFM) was used for etch depth linearity measurement. Using a high aspect ratio FIB tip, features in the range 400 nm to 1500nm were measured at a die located in the center of the mask. A 5 x 2 μm area of a line space grating was scanned for feature sizes and the etch depth over this scanned area was averaged for each feature size using bearing analysis in the AFM.

The quality of the etch with respect to profile and microtrenching was determined by cross section analysis. using an Amray 3300 field emission SEM

3. RESULTS

3.1 Identification of process parameter space – Bias Coupling

The primary factor found to influence linearity is the substrate RF bias[5]. This is expressed by the bias-coupling factor that is simply a normalized value. The trends of linearity and profile show strong correlation to this factor. Three screening experiments were performed with different bias coupling factors. Etch depth linearity was measured as a range of etch depths over feature sizes of 400 nm to 1500 nm. Cross sections of a 600 nm trench were obtained from all three masks etched.
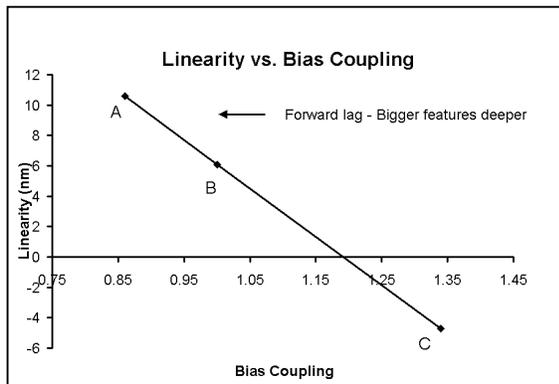

Fig.1. Etch Depth Linearity as a function of the bias coupling factor

In figure 1, the trend of etch depth linearity with the bias coupling factor is shown. At lower bias coupling, the bigger features etched faster than the smaller ones. This is labeled conventional RIE lag or forward lag. Not surprisingly, in this process regime, the etch rates were lower and the selectivity was high. The feature profiles also showed more slope in this regime. The cross section corresponding to this data point is shown in figure 2. The absence of microtrencing is also consistent with the lower bias.

As the bias coupling is increased, the forward lag is reduced as the difference in etch rates between the smaller and bigger features is reduced. This is represented by data point B in figure 1. This trend is reflected in the cross section analysis of this mask. Any changes in sidewall slope are minimal and the absence of trenching is representative of this process regime.
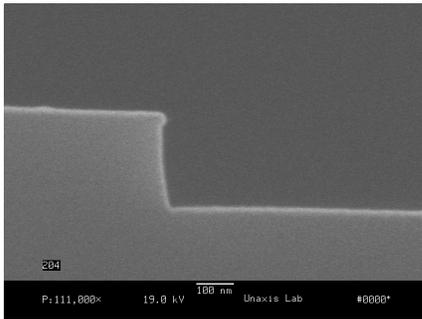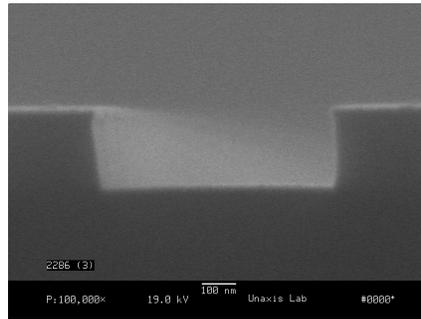

Fig. 2. Cross Section – Data point A
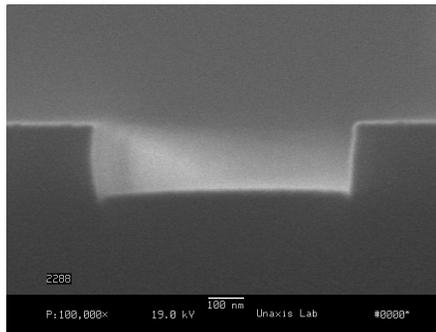

Fig. 3. Cross Section – Data point A

Fig. 4. Cross Section – Data point C

As the bias in increased further, the etch depth linearity reverses. The smaller features measure deeper as shown by data point C in figure 1. Corresponding to this trend, the cross section analysis reveals a trenched profile. This is illustrated in figure 4. Based on these screening experiments, bias coupling was determined to be a strong factor in controlling both etch depth linearity and microtrenching. The process regime where the linearity reverses from forward RIE lag to reverse RIE lag was the ideal operating regime since it is in this regime that good profiles without microtrenching are obtained.

3.2 Baseline Hardware configuration

A baseline hardware configuration was used to characterize the etch depth uniformity. The etch rate of quartz is lower in this process regime which allows for mean to target performance of the etch. The etch rate on the smaller features is greater than the etch rate on the bigger features although as noted above, this can be optimized by modifying the bias-coupling factor.

The etch depth signature obtained from data point C in figure 1 is illustrated in figure 5. While the linear component of asymmetry can be reduced by careful design of the plasma source, the center fast etch signature is an attribute of the bulk plasma characteristics which dictate that the charged species flux is greater at the center than at the edge. This, we believe, leads to a greater etching yield at the center than at the edge of the mask
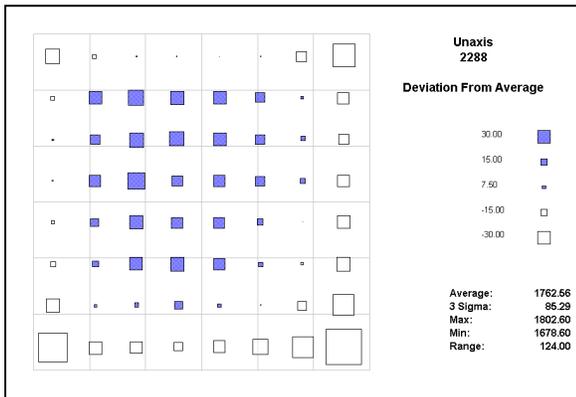

Fig. 5. Etch Depth signature – Baseline hardware configuration

	Baseline Results
Quartz Etch Rate	5.8 A/sec
Selectivity (Qtz:PR)	0.7:1
Etch Depth Uniformity, % 3 sigma	4.8%
% Rng	7.0%
Etch Depth Linearity	4.5 nm rng

Fig. 6. Table of Gen IV baseline results

3.3 Hardware Modification – Etch Depth Uniformity

The difference in etch rates between the center and the edge of the mask can be remedied with a hardware modification which works towards eliminating the radial etch signature. With the hardware modification in place, initial optimization experiments were performed.
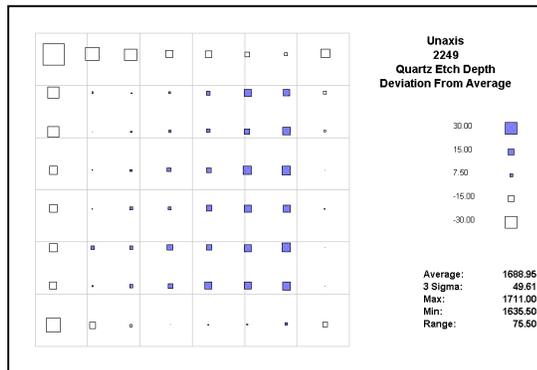
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Fig. 7. Etch Depth signature – Hardware Modification – Process A

Importantly, we found that with the hardware modification in place, the radial uniformity signature can be changed by changing only process parameters. This is illustrated in figures 7 and 8 which shows that the etch signature can be bracketed from an edge fast to a center fast pattern by moving one factor within the process.
The influence of this process parameter in modifying the etch signature is only evident with the hardware modification. The radial contributions of the etch depth uniformity signature are then eliminated by using an optimized process recipe
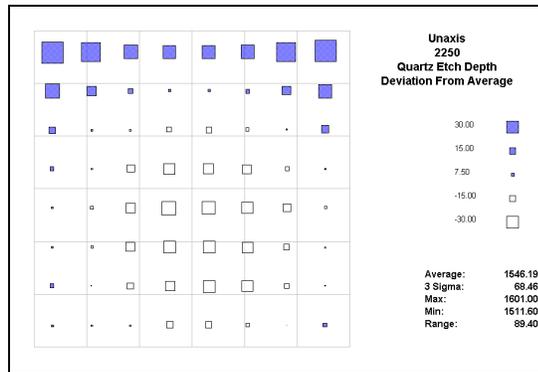

Fig. 8. Etch Depth signature – Hardware Modification – Process B

By further tuning the linear uniformity parameter within the ICP source, an optimized hardware configuration is obtained.

3.4 Process Optimization
Both high load and low load parts were etched using this optimized hardware and process recipe. The etch depth linearity across various feature sizes was obtained. This is illustrated in figure 9. Both the high load and low load parts show good etch depth linearity. The etch depth signature of the high load mask is illustrated in figure 10. The corresponding cross section image of the high load part is figure 11. The etch depth signature shows good uniformity with 1.5 % non-uniformity across the mask. The vertical microtrenching is estimated to be less than 2 nm.
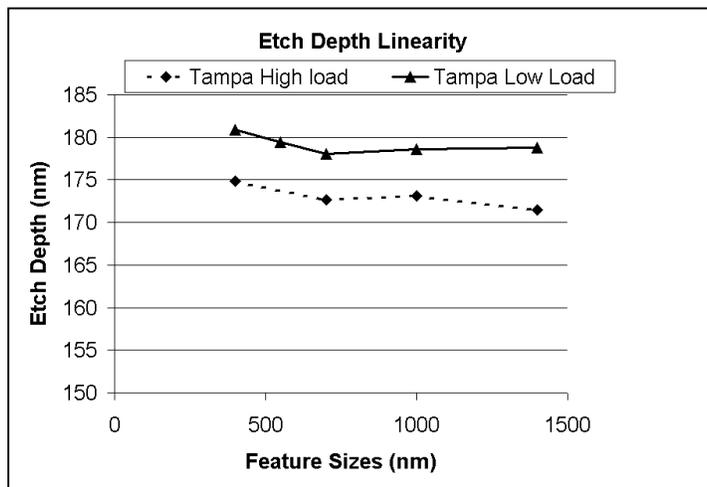

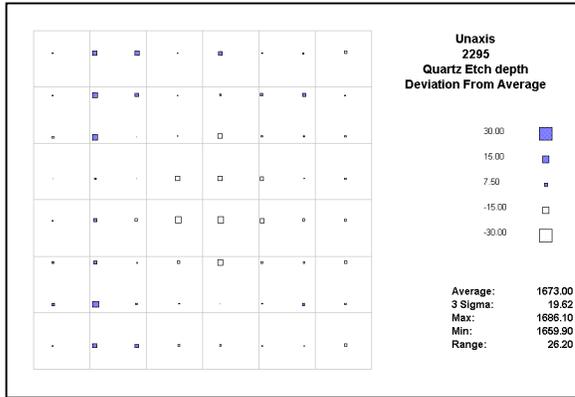Fig. 9. Optimized process – Etch Depth linearity

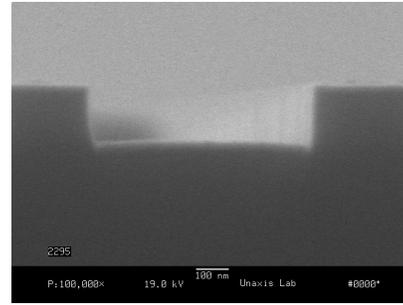Fig. 10. Optimized process – Etch Depth uniformity – High Load
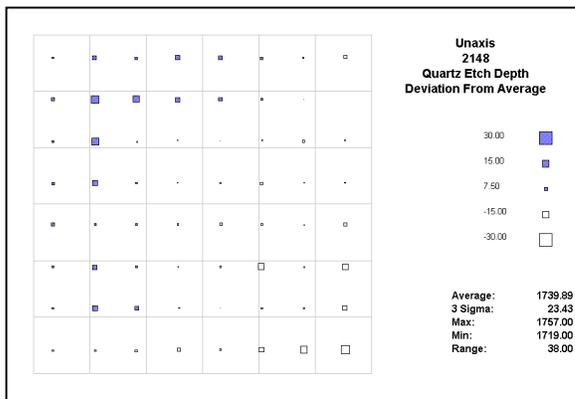

Fig. 11. Cross Section – High load

Fig. 12. Optimized process – Etch Depth uniformity – High Load
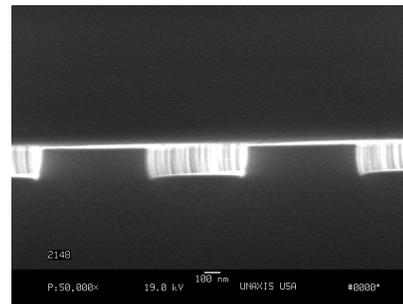
Fig. 13. Cross-Section – Low load

	Tampa High Load	Tampa Low Load
Quartz Etch Rate	4.1 A/sec	4.63 A/sec
Selectivity (Qtz:PR)	0.65:1	0.5:1
Etch Depth Uniformity, % 3 sigma	1.1%	1.30%
% Rng	1.5%	2.20%
Etch Depth Linearity	3.4 nm rng	3 nm rng

Fig. 14. Table of Optimized process results

The etch depth uniformity signature for the low load part is shown in figure 12. The cross section shown in figure 13 shows good profile with minimal microtrenching. The correlation between the high load and low load parts is good. Since the etch rate of the low load parts is slightly higher than the high loads, a minor process adjustment is necessary. The common hardware suite and the agreement in process space are encouraging. Figure 14 is the table of optimized results for both the high load and low load masks. With a minor process change, wide ranges of quartz loads can be etched with good etch performance.

There is overall improvement in the quartz etch performance from the Gen III Mask etcher. Figure 15 compares the performance of the Gen III Mask Etcher to the Gen IV Mask Etcher. The improvement in etch depth uniformity and linearity will meet the quartz dry etch requirements for AAPSM applications.

	Gen III Performance	Gen IV Performance
Quartz Etch Rate	15 A/sec	4 A/sec
Selectivity (Qtz:PR)	0.4:1	0.65:1
Etch Depth Uniformity, % 3 sigma	2.1%	1.10%
% Rng	3.5%	1.50%
Etch Depth Linearity	7 nm rng	3.5 nm rng
Surface Roughness	< 1nm, RMS	< 1nm, RMS
Profile	Est.88 degrees	Est. 87 degrees
Microtrenching	Yes	Minimal

Fig. 15. Comparisons – Gen III Mask Etcher and Gen IV Mask Etcher Results

4. SUMMARY AND CONCLUSIONS

Using a fluorocarbon based chemistry, quartz etch results are obtained for high load and load masks. By adjusting process parameters, forward and reverse RIE lags are observed. Using a proprietary hardware modification, the etch depth uniformity can be controlled across the mask. Process parameters are used to bracket the uniformity signature. Using an optimized hardware configuration and process recipe, good etch depth uniformity and etch depth linearity can be obtained across the mask. The occurrence of microtrenching is not completely eliminated but is al acceptable levels. With further experimentation in this process space, improvements in etched profile can be obtained.

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