Photomask Etch: Addressing the Resist Challenges for Advanced Phase-shift and Binary Photomasks

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ABSTRACT

As lithography requirements mandate ever-thinner resist thickness, the need for in-situ monitoring has become more urgent. In this paper we present an in-situ optical methodology-based system to determine residual photoresist thickness during advanced photomask etch with ≤ 1000 Å photoresist. Several types of phase-shift masks and photoresists were examined. A series of masks were etched to demonstrate the performance of the system. Results show an average accuracy of better than 2%, with a maximum absolute range of all tests within 8%.

Key Words: photomask, mask etch, endpoint, binary, phase-shift, photoresist, in-situ metrology

1. INTRODUCTION

In order to successfully achieve the goals of the 16nm technology node on photomasks, one has to be able to write features down to 40 nm, develop, etch and be able to transfer them on to wafers. The aspect ratios for these features create resolution challenges during the direct write (charging issues) and wet develop processes for photomasks. The photomask industry is addressing this challenge by adopting ultra-thin resists. From a mask etch perspective, the need for improved resist selectivity and an in-situ resist thickness monitoring becomes critical.

During mask etch, we use optical emission spectroscopy and transmission methods to monitor film removal. We outlined one photoresist measurement method previously [1], but it was limited to thick photoresist and binary films such as NTAR7. In this paper, we will outline a novel approach to dynamically monitor resist removal rates for ultra-thin resists on new advanced phase-shift film structures.

We utilize an optical model with real-time data to determine photoresist thickness on substrates for the 22-16nm technology node. The scope includes examining different types of absorber substrates, as well as testing different processes and etch rates on a series of masks of a single substrate type.

2. THEORY

Advanced films may consist of multiple layers with differing compositions. To build an optical model, the characteristic matrix approach is used. The total stack consists of a series of approximate thin film layers. Each layer has a complex refractive index, and is described by a propagation matrix [2].The overall method is analogous to a transmission line model. The propagation characteristic of the stack is the product of the matrices of the component layers.

In the etch plasma environment, calculated transmission and reflection properties can be combined into a computed signal strength versus wavelength. Computations show that this spectral signal is affected by the photoresist thickness, and the signal varies during the etch process in a predictable way.

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In order to create an in-situ photoresist measurement system, a series of steps were identified. The methodology includes creating the optical model for the film stack being etched, together with monitoring changes in the spectral signal during the absorber etch. Subsequently, the relative changes are compared to the model prediction to determine the photoresist thickness. Finally, system algorithms are created to incorporate the model for each film type.

3. EXPERIMENT

During the etch process, the spectral signal changes as the photoresist becomes thinner. Monitoring the relative changes during etch can be used to determine photoresist thickness at any given time after endpoint. Figures 1 and 2 show predicted and experimental signal change with wavelength at the end of etch for one type of phase-shift mask. The prediction agrees with the experimental data and can be used to determine the resist thickness.

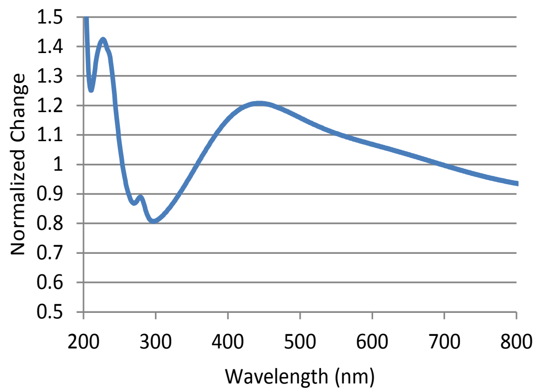

Figure 1. Predicted signal change after endpoint for Type A mask shown at end of etch

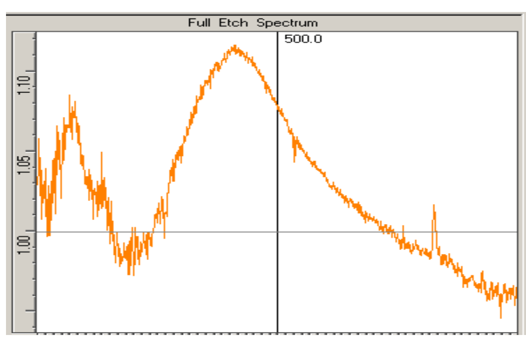

Figure 2. Measured signal change after endpoint for Type A mask shown at end of etch

The system analyzes signal changes in the data during etching and matches the data to the model to determine when the preset photoresist thickness is achieved.

Achieving preset photoresist thickness values can be presented to the user as event markers on the endpoint trace plotted as a function of time. Marker lines showing three different preset resist thicknesses achieved at successive times are shown in Figure 3.

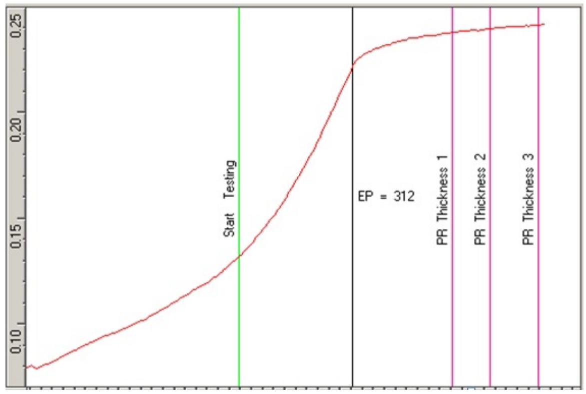

Figure 3. Example endpoint time trace with resist markers illustrating three resist thickness preset levels achieved at successive times.

4. RESULTS

The system was tested by etching a series of masks over an extended period. In order to further test the system, the etch process was modulated to produce large etch rate variations. Predicted photoresist thickness and measured photoresist thickness (by profilometer) is shown for a series of six runs in Table 1. Also noted in Table 1 is the difference between predicted and measured values in percent.

Table 1. In-situ photoresist thickness predicted values compared with post-etch external measurements.

	Final Photoresist Thickness (A)		
Mask	Predicted	Measured	Difference %
1	743	790	-5.9
2	745	760	-1.9
3	845	840	0.6
4	826	810	1.9
5	747	760	-1.7
6	780	800	-2.5
Average			-1.6
Range			8.0

As seen in Table 1, the predicted average value matches within 2% of measured PR thickness. For the series of runs, the predicted values are within an absolute range of 8% over all the varied etch rate conditions.

CONCLUSIONS

In this work, we have shown a novel system for measuring in-situ photoresist thickness on advanced absorber films during plasma etch. The system has been demonstrated on masks with varied etch processes with different photoresist etch rates. This dynamic resist etch rate monitor allows users to stop etch at a predetermined photoresist thickness. The capability has also been demonstrated with different absorber film types, and the system shows excellent correlation between the in-situ and external resist thickness measurements.

REFERENCES

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