Optimization of Patterned Thin Films of Photoresist for Plasma Etching Applications

Irving Garduno and Jeffrey Clarkson

2015 Transfer-to-Excellence Research Experiences for Undergraduates Program (TTE REU Program)

Abstract - The process performance of photoresist coatings on SiO_2 coated substrates and how it relates to plasma etching in the Marvell Nanofabrication Laboratory is reported. Process specification (PS) sheets and statistical process control (SPC) charts were used to monitor the thickness and uniformity of photoresist films as-coated, post-developed, and post-UV stabilized. The photoresist stabilization process highly influences the characteristics of patterned photoresist films and plays an important role in determining SiO_2 plasma etch selectivity. Finally, the most robust photolithography process input parameters for plasma etching are defined. It was found that a standard oven hard bake at 120 C for 30 min. yielded the most vertical resist sidewalls and superior etch robustness. By using optimized photoresist coatings, the etch selectivity was increased ~ 15% and ~ 20% for DUV and i-line resist respectively. This research provides the Marvell Nanofabrication Laboratory with a better understanding of how photolithography affects etching applications and enhances on-going research throughout the lab.

Introduction

Data sheets provided by photoresist manufacturers only provide limited information about the photoresist's optical characteristics. This limited amount of information can lead to error in resist thickness measurements on the order of several percent. To reduce this measurement error it is important to consider the refractive index of the photoresist as it goes through the photolithography process. Specifically, the index of refraction of the material changes due to a change in the concentration of volatile organic compounds and cross linking of polymer chains. To this end, the soft bake, exposure, post exposure bake, and UV-stabilization changes the optical properties of the material, and specialized optical models are needed to account for this.

Being able to monitor the process performance of photoresist coatings allows for improved characterization of different stabilization processes used on pattered photoresist films. Analysis with contact profilometry was used to determine the thickness lost in patterned films that underwent stabilization. The sidewall angle of photoresist lines were measured with a scanning electron microscope. Lastly, the same processes used for the characterization of photoresist coatings and stabilization processes were also used to determine the SiO_2 to photoresist etch selectivity.

Experimental

During the photolithography process wafers had the resist film thickness observed at three different steps and is labeled as monitoring measurements one through three in Figure 1. The first monitoring measurement was performed with both the Nanospec optical interferometer and ellipsometer in order to calculate an accurate starting film thickness and index of refraction. The second and third measurements were obtained with the use of the Alpha Step IQ contact profilometer. These measurements were monitored with SPC charts as shown in Figure 2. These profile measurements were then compared to Nanospec measurements and newly optimized optical models that better represented the films with more appropriate refractive indices. After this, the new optical models were used to monitor ten silicon wafers with ~5000 A of oxide on them. Being sure that all ten wafers had been treated similarly, we were able to investigate the affect of different photoresist stabilization processes. The investigation included two different programs from Axcelis and Uvbake and a hard bake in a box oven. Figure 3 specifies the details of the recipes used during stabilization. Five wafers were inspected with the scanning electron microscope to characterize the different profiles and the other five wafers were etched in Centura MXP+ with recipe MXP-OSX - VAR. Etch recipe parameters are listed in Figure 4. The etched wafers were measured twice more with the contract profilometer (post etch and post resist strip). These measurements are listed as 2nd and 3rd Selectivity Measurements on Figure 1. Once obtained, the step measurements were used to calculate the SiO_2 to photoresist etch selectivity. Not reported herein, SiO2 etch profiles were also characterized.

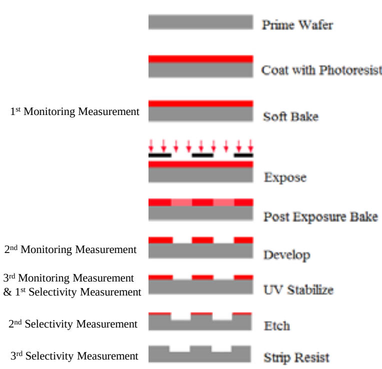


Fig. 1 - Cross-sectional schematics of the photolithography process [1]

Fig. 2 – Photoresist thickness statistical process control charts [2]

Program U	Program J	Hard Bake
0-10 sec: lamp off, 110 C/10-20 sec: lamp low, 110 C 20-40 sec: lamp low, ramp 110 to 140 C/40-70 sec: lamp low, 140 C	0-10 sec: lamp off, 110 C/10-20 sec: lamp low, 110 C 20-90 sec: lamp high, ramp 110 to 230 C/90-100 sec: lamp high, 230 C	120 C for 30 min

Fig. 3 – Photoresist stabilization programs

MXP-OXSP-VAR-EP
Time = 60 sec
Pressure = 200 mT
Power = 500 W
Field = 30 Gauss
CF4 = 10 sccm
CHF3 = 50 sccm
AR = 120 sccm

Fig. 4 – SiO_2 plasma etch recipe

Results and Discussion

Process Specification	Index of Refraction	Cauchy Coefficients (n1,n2,n3)	As Coated Index	Post Development Index	Post UV Stabilization Index
4.2.1 DUV UV-210-0.6 (0.42nm)	1.532	1.532, 8.97E5, 3.00E10	n = 1.58	n = 1.58	n = 1.60
4.2.2 DUV UV-210-0.6 (0.9nm)	1.532	1.532, 8.97E5, 3.00E10	n = 1.58	n = 1.56	n = 1.6C
4.3.1 i-line OiR906-12 (1.2nm)	1.67	None Provided	n = 1.6C	n = 1.59	n = 1.69
4.3.2 i-line OiR906-12 (2.8 nm)	1.67	None Provided	n = 1.6C	n = 1.6C	n = 1.69
4.4.1 g-line OCG 825 (1.3nm)	1.64	None Provided	n = 1.6C	n = 1.62	n = 1.658

Fig. 5 – Change in photoresist index of refraction

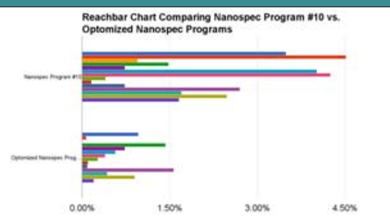
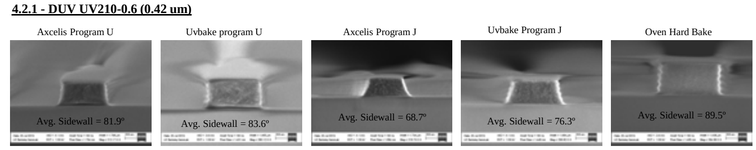


Fig. 6 – Reduction in measurement error

The change in photoresist film thickness, as a result of out diffusion of volatile organics and crosslinking of polymer chains, causes the refractive index to change. Thus, a single optical model is unable to accurately measure the film thickness throughout the different parts of the process. By comparing measurements from the Nanospec, ellipsometer, and Alpha Step IQ profilometer, new optical models were created to measure film thicknesses with less error. Figure 5 shows the index of refraction that was determined for each resist as it goes through photolithography . The subsequent measurement error, comparing the original method of using a single conventional measurement program, compared to using the newly created optimized optical models in different measurement programs, is shown in Figure 6. Below in Figure 7, electron microscope images of DUV photoresist line profiles are shown. It is clear that the thin DUV resist experienced more reflow than its thick counterpart. Also, the oven hard bake exhibited the least amount of reflow and maintained line profile fidelity.

4.2.1 - DUV UV210-0.6 (0.42 um)



4.2.2 - DUV UV210-0.6 (0.90 um)

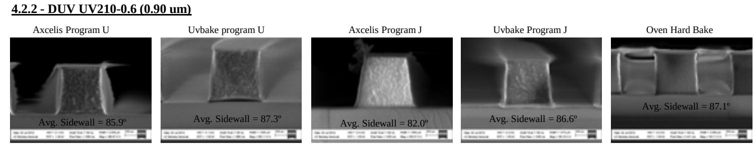
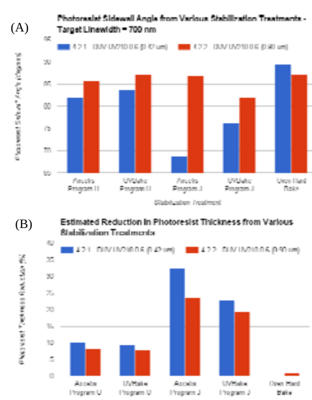


Fig. 7 – Cross-sectional scanning electron microscope images of photoresist line profiles



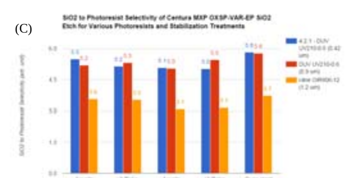


Fig. 8 A, B, and C shows, with respect to the Centura OXSP-VAR-EP SiO_2 etch recipe, the oven hard bake yields the steepest sidewalls, least change in film thickness, and best etch selectivity. Program J on the other hand resulted in the most tapered sidewalls, largest reduction in film thickness, and the lowest selectivity for both i-line and thin DUV films. Program U performed better than program J with respect to sidewall angle, thickness change, and selectivity.

Fig. 8 – Post stabilization photoresist characteristics

Conclusion

A family of optimized programs was created for the Nanospec using the refractive indices that were determined by unifying different metrology equipment. The new programs have lower error and under worst case measurement conditions were reduced from 4.5% to 1.6%. These optimized programs help monitor the process performance of photolithography on silicon wafers. Wafers were then used to characterize the affects of different stabilization processes on line profiles and etching selectivity. It was shown that the oven hard bake resulted in the steepest photoresist sidewall angle while program J on Axcelis and Uvbake result in the least desirable sidewall profile. The best etch selectivity is obtained with the use of the DUV resist and the oven hard bake.

Acknowledgements

I would like to thank Bill Flounders for affording me the opportunity to be a part of the Marvell Nanofabrication Laboratory this summer. A special recognition to my mentor Jeffrey Clarkson for guiding me and giving me advice throughout this project. Kim Chan, Greg Mullins, and Francesca Calderon for helping me with various stages of the photolithography process. Finally, I would also like to thank the E3S and TTE-REU staff for giving me the opportunity to be a part of this internship. None of this would have been possible without any of the people mentioned.

References

[1] "Semiconductor Lithography." *The Basics of Microlithography*. N.p., 23 Nov. 2006. Web. 03 Aug. 2015.
[2] https://docs.google.com/spreadsheets/d/1tn35v825ROm7TWNFZKRIwT2I2CZuAwIGaqykNOsrpbg/edit#gid=0

Contact Information
irving.garduno@gmail.com (323)-383-5561

Support Information
This work was funded by National Science Foundation Award ECCS-0939514 & ECCS-1157089 & ECCS-1461157