

Amorphous Carbon Hard Mask for Multiple Patterning Lithography

Timothy D. Horn
Microelectronic Engineering
Rochester Institute of Technology
Henrietta, New York 14623

Abstract—Amorphous carbon may be used as a hard mask alternative to nitride in conjunction with multiple patterning lithography and line-width trimming applications. This work focuses on the simulation and deposition for optical optimization of a carbon hard mask using plasma enhanced chemical vapor deposition (PECVD). By creating a central composite design centered about pressure, power, and gas flow and analyzing the results, it was found that the optical parameters were dependent primarily on power and chamber pressure while the deposition rate varied with all three parameters. This film can enable sub-lithographic patterning of lines approaching 100 nm using an i-line (365 nm) stepper.

I. INTRODUCTION

Amorphous carbon (a-C) has found a niche in industry over the last several years due to some of its unique physical and optical properties. This film can be deposited using plasma enhanced chemical vapor deposition (PECVD), where the film properties are primarily controlled by substrate bias conditions [1]. By using a tool called the Drytek Quad, this PECVD process may be controlled in terms of pressure, flow, and power (substrate bias).

One of the unique mechanical properties that have driven the development of this film is its ability to resist many dry etch chemistry with excellent selectivity [2], [3] while still being capable of being easily removed in an oxygen plasma [4], thereby enabling line-width trimming [5].

A primary motivation for this paper is to show simulated and experimental results which demonstrate the ability to enhance the capability of the lithography by reducing the amount of reflection from the film stack by modifying the optical properties of the carbon film. These optical properties will change depending on the stoichiometry of the film, a parameter that is expected to have strong dependence on the substrate bias [1].

Using this enhanced lithographic capability in conjunction with the idea of line-width trimming (see Fig. 1), this film can be expected to produce features on the order of 100 nm in width (see Fig. 2). This is brought about by nearly eliminating all stack reflectivity by using a bottom anti-reflective coating (BARC) with the absorbing a-C hard mask and performing the line-trimming step once the features have been exposed.

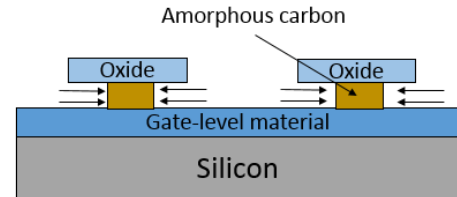


Fig. 1. Line-width trimming performed by over-etching carbon in oxygen plasma. Oxide capping layer preventing complete removal of carbon.

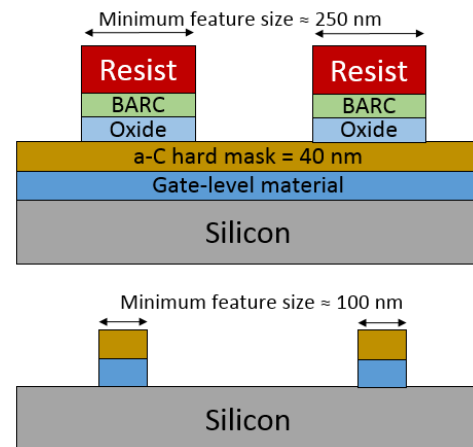


Fig. 2. Amorphous carbon hard mask capability for reducing line width significantly by line-width trimming.

II. SIMULATIONS AND EXPERIMENT

A. Simulations

In order to determine what the output variables ultimately need to be modeled to target, simulations were performed using the PROLITH lithography modeling software to determine stack reflectivity for varying thickness, n , and k (see Fig. 3 and 4). Noting that the dark blue areas correspond to lowest stack reflectivity, it was found that target thickness for the a-C film is 40 nm for a BARC thickness of 20 nm and the target n and k are 1.9 and 0.4, respectively.

B. Experimental

By designing an experiment centered around the three primary controls for the Drytek Quad (pressure, flow, and

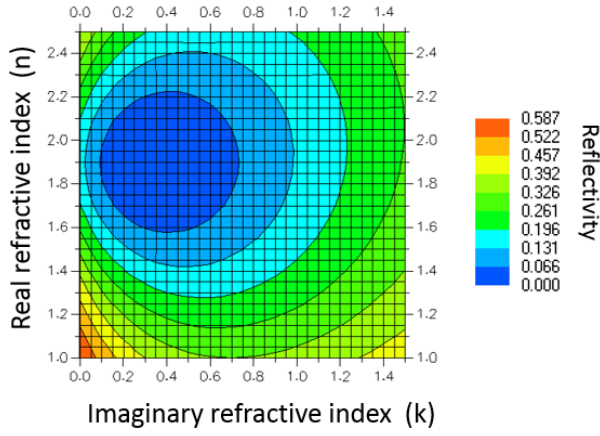


Fig. 3. Optical variables n and k output for a given a-C layer thickness. Determined by an iterative approach, modifying a-C thickness based on a-C vs. BARC reflectivity to determine thickness.

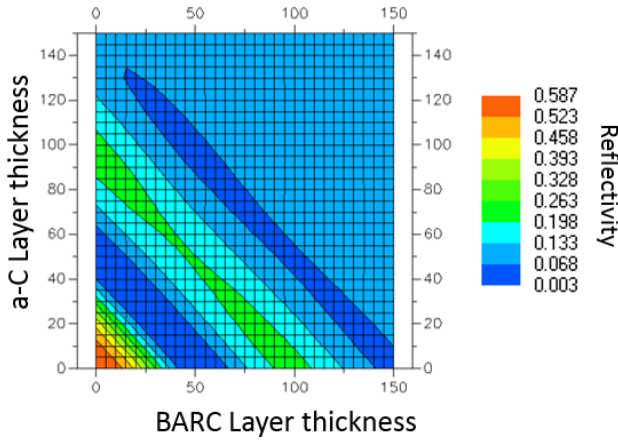


Fig. 4. Thickness of both a-C film and BARC for a given optical parameters. Determined by an iterative approach, modifying a-C thickness based on n vs. k reflectivity to determine optical values.

power) for a constant time, output variables n , k , and thickness could be modeled using JMP IN statistical analysis software. To determine the approximate tool operating regime, a preliminary experiment was done to test tool limits in terms of pressure and flow, and based on these results, Table I shows the limits for the central composite design that is responsible for determining final optical characteristics.

TABLE I
EXPERIMENTAL BOUNDS FOR CENTRAL COMPOSITE DESIGN

Sample Level	Pressure (mT)	Flow (sccm)	Power (W)
High	125	45	100
Mid	162.5	60	150
Low	200	75	200
$+\alpha$	228	84	240
$-\alpha$	97	36	60

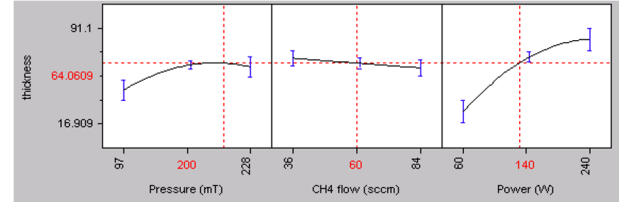


Fig. 5. Model for thickness based on experimental outputs.

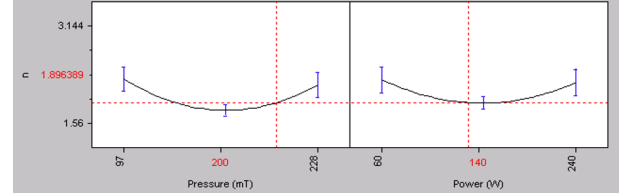


Fig. 6. Model for n based on experimental outputs.

C. Experimental Set-up

For each experimental run, time was set to a constant 105 seconds for all samples. Because PECVD of a carbon film does not coat only the wafer, a 5 minute oxygen plasma clean was run between every sample to ensure cleanliness of the chamber. Once all depositions had been performed, thickness, n , and k could be measured using a tool called the variable angle spectroscopic ellipsometer (VASE).

III. RESULTS AND DISCUSSION

By measuring all the films on the VASE, the output variables n , k , and thickness could be determined, analyzed in JMP, and used to create a model which characterizes the effect of the inputs on each output independently. It was found that power was the most significant factor in determining the thickness (deposition rate), but chamber pressure became significant when attempting to characterize the optical parameters (see Fig. 5-7).

Using these models, the optical parameters are able to be optimized according to the standards determined by the simulated reflectivity plots. It was found that for a pressure setting of 200 mT and a power of 140 W, the film meets the specifications outlined earlier. Gas flow was shown to be an insignificant factor in modifying optical parameters, but was a small factor in determining the output film thickness (deposition rate). Final deposition rate was determined to be 36.6 nm/min.

The simulated results show several areas where stack reflectivity is at an equal minimum. The "ideal" area of operation is chosen in terms of process latitude which the area allows for. As seen in Fig. 3 and Fig. 4, the area of interest (AOI) is selected in the centers of the regions where the broadest range of low reflectivity can be found, without minimizing the carbon layer thickness.

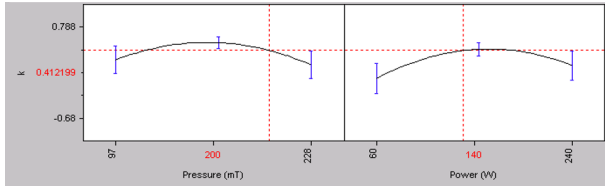


Fig. 7. Model for k based on experimental outputs.

IV. CONCLUSIONS

The amorphous carbon film has been optimized to nearly eliminate stack reflectivity in the samples. The results of this work allow for optimization over a large range of desirable refractive index values while still providing information on the deposition rate.

The RIT SMFL is now capable of depositing carbon hard masks which will allow for sub-lithographic patterning techniques like line-width trimming, while enabling reduction in reflectivity and improving existing processes.

ACKNOWLEDGMENT

The author would like to thank the RIT SMFL staff for all their support in maintaining tools and providing training and certifications for the tools required to complete the process. Special thanks to Dr. Robert Pearson and Dr. Dale Ewbank, without their support and guidance, none of this would have been possible. Finally, thanks to KLA Tencor for the use of their PROLITH lithography simulation software for reflectivity simulations.

REFERENCES

- [1] A. Grill, "Diamond-like carbon: state of the art," *Diamond and Related Materials*, vol. 8, no. 2-5, pp. 428–434, 1999.
- [2] M. Kakuchi, M. Hikita, and T. Tamamura, "Amorphous-carbon films as resist masks with high reactive ion etching resistance for nanometer lithography," *Applied Physics Letters*, vol. 48, no. 13, pp. 835–837, 1986.
- [3] C. Y. Ho, X. J. Lin, H. R. Chien, and C. Lien, "High aspect ratio contact hole etching using relatively transparent amorphous carbon hard mask deposited from propylene," *Thin Solid Films*, vol. 518, no. 21, pp. 6076–6079, 2010.
- [4] K. A. Pears, "A new etching chemistry for carbon hard mask structures," *Microelectronic Engineering*, vol. 77, no. 3-4, pp. 255–262, 2005.
- [5] S. Pauliac-Vaujour, P. Brianceau, C. Comboroure, and O. Faynot, "Improvement of high resolution lithography by using amorphous carbon hard mask," *Microelectronic Engineering*, vol. 85, no. 5-6, pp. 800–804, 2008.