Flow Simulation: Advanced Dielectric Etch Equipment Design and Process Development

Kallol Bera[1], Jim Carducci, Daniel Hoffman, and Shawming Ma
Applied Materials, Inc., 974 E. Arques Ave., M/S 81323, Sunnyvale CA 94085, USA
[1]E-mail: Kallol_Bera@amat.com

Abstract **- With shrinkage in device size, use of new materials in multiple layers, and larger wafer size, control of process uniformity across the wafer becomes crucial in semiconductor manufacturing. Flow simulation has been used to design advanced dielectric etch equipment to achieve better flow uniformity. The ability to tune flow uniformity helped us to achieve various desired process characteristics, such as CD bias, profile, and etch stop across the wafer.**

I. INTRODUCTION

As the semiconductor industry approaches smaller technology nodes (65 nm and beyond) with multi-layer device structures using different types of films, control of process uniformity at every level becomes crucial to achieve the desired device functionality and productivity, especially for 300 mm wafers. The design of our advanced dielectric etch equipment allows us to control the relative amount of species fluxes and energies, and their uniformities. Improved understanding of the plasma and flow behaviors has been achieved using simulation [1-3]. The flow related challenges for the design of the process chamber are to achieve desired flow conductance, and velocity and pressure uniformities for a wide operational window. Flow simulation has been used to design a structure to achieve azimuthally symmetric flow even with side pump port. The residence time of species flow from the showerhead to the wafer was calculated. Simulated velocity and pressure distributions helped us to design a Neutral Species Tuning Unit (NSTU™) so that we can vary the neutral flow from the center to the edge of the wafer. The NSTU™ tunes local velocity distribution, hence neutral species flux distribution that can affect process characteristics, such as CD bias and profile uniformities, and etch stop.

II. SIMULATION AND EXPERIMENTAL METHODOLOGY

Three-dimensional flow simulation was performed using CFD-ACE+ [4] for different pressures and flow rates. A combination of structured and unstructured meshes was used to accurately perform simulation with a reasonable number of meshes. A momentum resistance method was implemented to calculate pressure drop as needed for certain complex structures. Flow simulations were performed under various etch process conditions. The chamber flow characteristics were evaluated under extreme conditions based on the pumping curve. Simulation results were used to characterize velocity and pressure distributions across the wafer, and to calculate residence time. Patterned wafers were used to verify the effects of NSTU™ on CD bias uniformity as measured using Vera-SEM™ U502. Scanning electron microscope (SEM) pictures of the wafer sections were taken using SEMVision™ to measure etch profile. The effects of NSTU™ on etch profile and etch stop were evaluated.

III. RESULTS AND DISCUSSIONS

For an advanced dielectric etch chamber, the flow distribution is inherently asymmetric due to the side pumping. With the help of flow simulation, we designed an optimized structure to compensate for the asymmetry so that pressure and velocity distributions are symmetric as shown in Fig. 1.

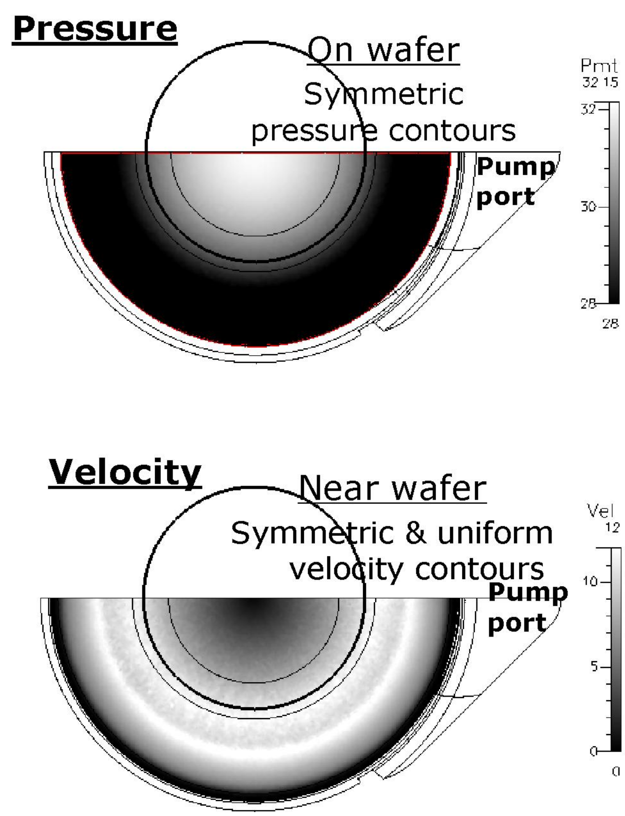

Fig. 1. Azimuthally symmetric pressure and velocity distributions with side pump port.

Figure 2 shows normalized pressure along the wafer edge with and without the optimized structure. With the structure, azimuthal pressure uniformity improves substantially. We are able to achieve azimuthally symmetric flow even with the side pump port. The normalized pressure profile across the wafer is also shown in Fig. 2. With the simulated optimized structure, the pressure drop across the wafer has become much smaller.

 1-4244-0404-5/06/$20.00

This smaller pressure drop across the wafer can be tuned such that uniformly spaced velocity contours (Fig. 1) produce uniform residence time across the wafer as shown in Fig. 3. The residence time determines the speed at which the species can reach different locations of the wafer for etching to occur. The chamber is designed to achieve desired residence time over a wide process window.

We designed the NSTU to control neutral species flux distribution from the showerhead across the wafer. Species residence time can be adjusted by an order of magnitude using the NSTU to compensate for species non-uniformities in the process chamber (Fig. 4). These can occur due to non-uniformities in species generation in the plasma or in byproducts from the wafer that need to be removed. The NSTU can change the flow profile to facilitate uniform distribution of species to and from the wafer.

The NSTU can be set in forward or reverse order. The forward NSTU setting allows larger variation of the residence time near the wafer center, while the reverse setting enables more variation of the residence time near the wafer edge.

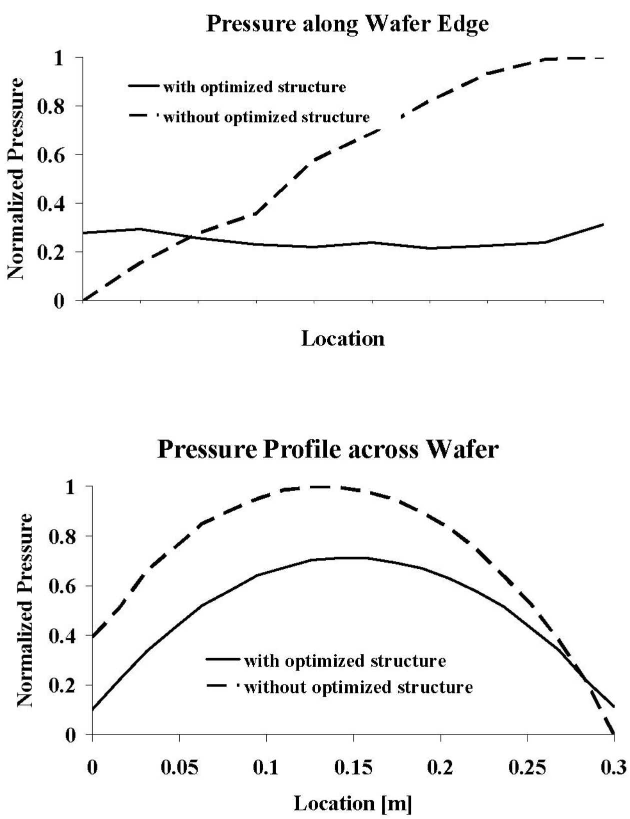

Fig. 2. Normalized pressure along wafer edge, and across wafer with and without optimized structure.

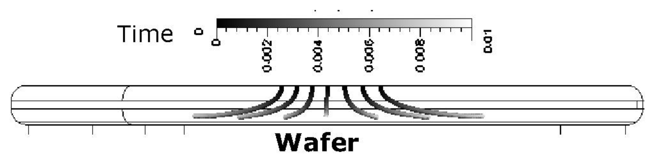

Fig. 3. Stream trace showing uniform residence time across wafer.

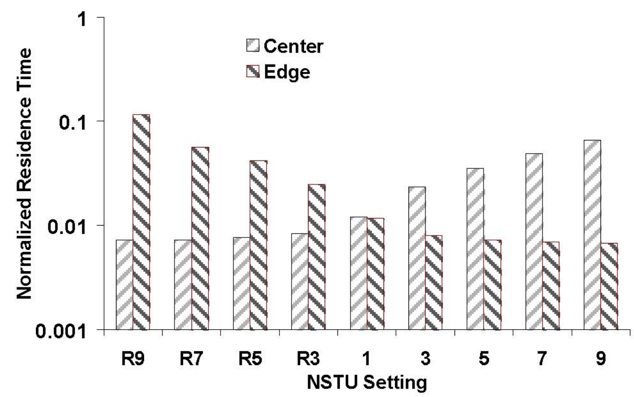

Fig. 4. The NSTU tunes residence time uniformity across wafer for forward and reverse (R) settings.

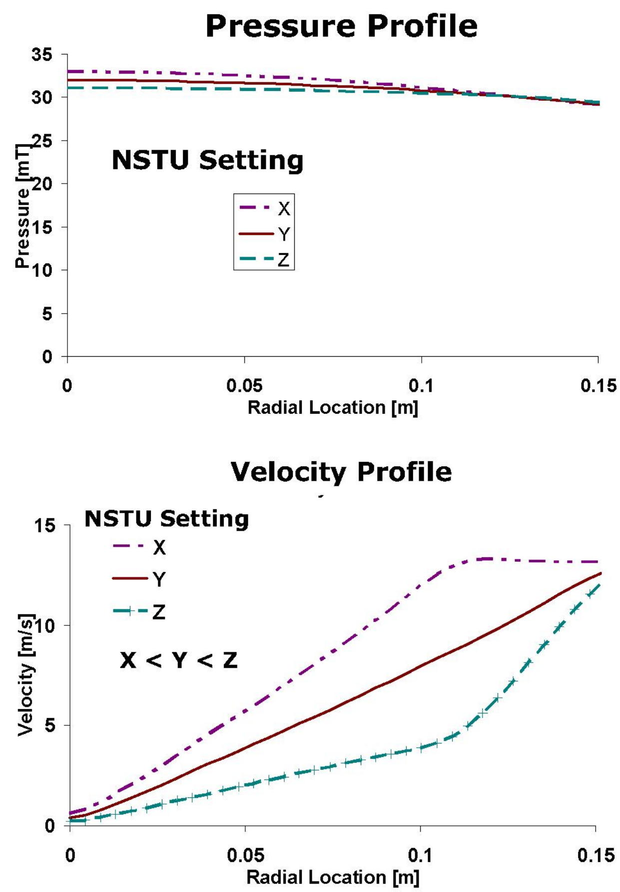

Fig. 5. Pressure and velocity profiles across the wafer for different NSTU settings.

 1-4244-0404-5/06/$20.00

The pressure and velocity profiles using different NSTU settings [5] are shown in Fig. 5. With an increase in NSTU, the change in pressure profile across the wafer is small for the same flow rate. However, the velocity profile that is used to tune species residence time across the wafer changes substantially. By increasing the NSTU, we can reduce velocity near the wafer center; decreasing it has the opposite effect. Therefore, we can adjust residence time dynamically across the wafer as needed during the etch process.

With a change in NSTU, the residence time distribution, and hence the active species flux distribution across the wafer, changes. The uniformity of the active species flux to the wafer determines process characteristics, such as CD bias uniformity for a low-κ dielectric trench etch process as illustrated in Fig. 6 [5, 6]. With an increase in NSTU (Y > X), residence time near the wafer center increases; hence, active species flux decreases. Therefore, negative CD bias increases. The tunability of CD bias using NSTU enables us to achieve uniform CD bias across the wafer for different etch processes.

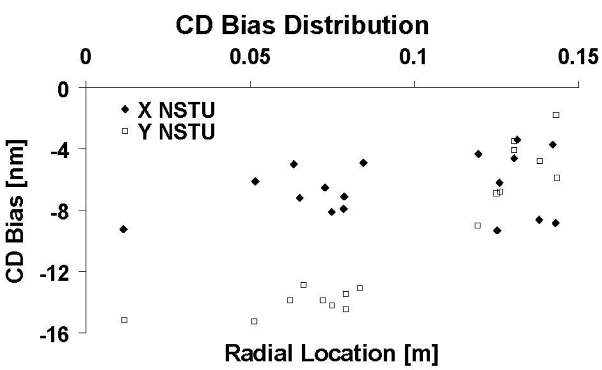

Fig. 6. CD bias uniformity variation with NSTU (Y > X) for a low-κ dielectric trench etch process.

The active species flux plays important role in determining etch profile and etch stop window. During the etch process, etch by-products need to be removed by fluid flow. This is particularly important in high aspect ratio etching. Figure 7 shows that at high NSTU (A), fluid flow near the wafer center is low and is unable to entrain and remove etch by-products from the contact bottom, leading to etch stop near the wafer center. Etch stop is prevented with proper choice of NSTU (B < A). Flow velocity is adequate everywhere on the wafer to remove etch by-products from the contact bottom both at the center and the edge of the wafer. The etch profile also improves, thus the use of NSTU widens the etch process window.

IV. CONCLUSIONS

Flow simulation has been used in the design of advanced dielectric etch equipment. It helped us to design the chamber with symmetric velocity and pressure distributions in spite of a side pump port. The residence time of species flow from the showerhead to the wafer was calculated, and designed to achieve the desired process window. The residence time can be varied across the wafer by an order of magnitude using NSTU, thereby enabling us to tune active species flux across the wafer. The residence time across the wafer can be tuned that correlates well with CD bias profile for a low-κ dielectric trench etch process. The use of NSTU enables us to tune active neutral species flow to the wafer and etch by-product removal from the wafer. It also improves etch profile and prevents etch stop, hence widening the process window.

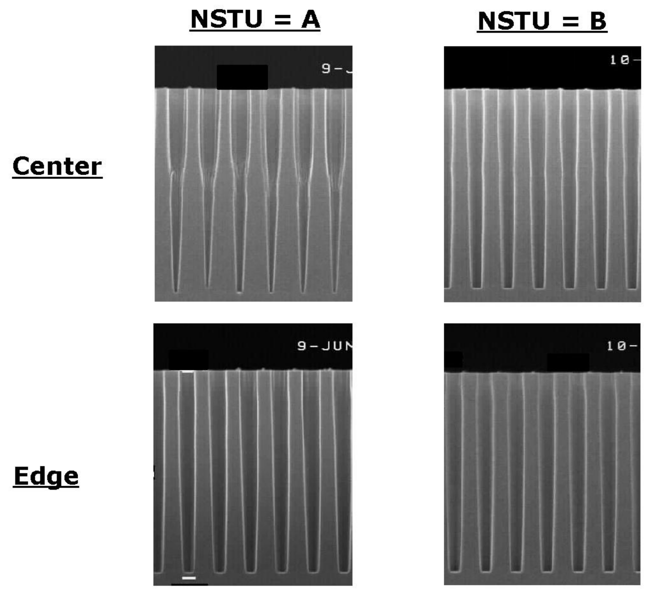

Fig. 7. NSTU (B < A) improves etch profile and prevents etch stop for a high aspect ratio process.

ACKNOWLEDGMENTS

The authors would like to thank Judy Wang and Gerardo Delgadino for providing SEM pictures and CD bias data.

REFERENCES

[1] K. Bera, D. Hoffman, S. Shannon, G. Delgadino and Y. Ye, “Frequency Optimization for Capacitively Coupled Plasma Source,” *IEEE Transactions on Plasma Science*, vol. 33, No. 2, pp. 382-383, 2005.

[2] K. Bera, G. Delgadino, A. Zhao and Y. Ye, “High Source Power Dual Damascene Trench Etch Process Development using an Advanced Dielectric Etch Tool,” *Proceedings of International Symposium on Dry Process*, Tokyo, pp. 197-202, 2003.

[3] K. Bera, D. Hoffman, Y. Ye, S. Shannon, G. Delgadino, and B. Gu, “Plasma Simulation for High Frequency Plasma Source Design and Process Development,” *IEEE International Conference on Plasma Science*, Monterey, CA 2005.

[4] "CFD-ACE+ User Manual Version 2006," Advanced Computational Fluid Dynamics Division of ESI-Group, Huntsville, AL.

[5] K. Bera, D. Hoffman, G. Delgadino, J. Carducci, Y. Ye and S. Ma, "Simulation in Advanced Dielectric Etch Equipment Design and Process Tuning," *52nd International Symposium of American Vacuum Society*, Boston, MA, 2005.

[6] G. Delgadino, K. Bera, D. Hoffman, R. Hung, A. Zhao, and Y. Ye, "Process Tunability for Advance Dielectric Etch Applications," *International Symposium on Semiconductor Manufacturing- JSAP, IEEE & SEMI*, San Jose, CA, 2003.

