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KATE GLEASON
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Process Development of Sidewall Spacer Features for sub-300nm Dense Silicon FinFETs

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MicroE Microelectronic Engineering

I. Project Objectives

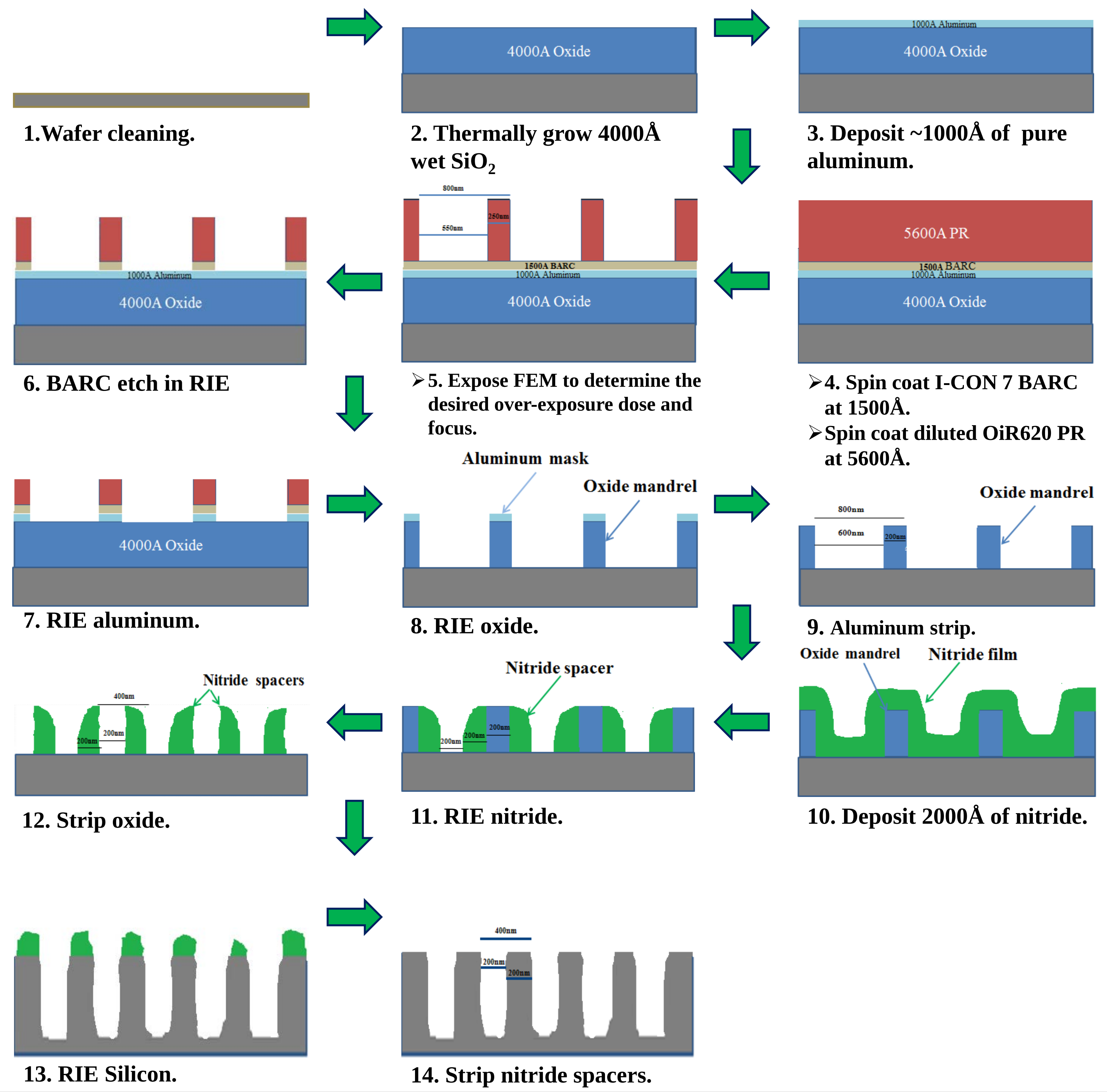
Goal: To achieve uniform sub-300nm critical dimensions for future FinFETs. A process was developed to demonstrate lithography techniques which utilize resist overexposure, an aluminum hard mask, nitride sidewall spacers and, finally, a reactive ion etch to transfer the nitride patterns to the silicon.

II. Motivation

Photolithography techniques continue to enable the semiconductor industry to meet their needs of achieving smaller, thinner, and faster devices for high-performance applications. However, achieving smaller dense features requires novel lithographic techniques combined with both chemical vapor deposition (CVD) and etching processes.

An alternative avenue to achieve smaller and dense features is through sidewall spacers. This approach is well-known in industry; it uses LPCVD to deposit a thin, conformal layer of nitride on top of the thermally grown oxide mask and then utilizes a reactive ion etch to form nitride sidewall spacers on the edges of the oxide fin. This finFET manufacturing process in the SMFL is able to reduce the silicon fin width to a reasonable pitch with current process modules.

III. Proposed Process Flow



1. Wafer cleaning.
2. Thermally grow 4000Å wet SiO_2
3. Deposit ~1000Å of pure aluminum.
- 4. Spin coat I-CON 7 BARC at 1500Å.
- Spin coat diluted OiR620 PR at 5600Å.
- 5. Expose FEM to determine the desired over-exposure dose and focus.

6. BARC etch in RIE
7. RIE aluminum.
8. RIE oxide.
9. Aluminum strip.
10. Deposit 2000Å of nitride.
11. RIE nitride.
12. Strip oxide.
13. RIE Silicon.
14. Strip nitride spacers.

IV. Mask Design and Photolithography

- Design of a simple mask that has an array of vertical and horizontal lines with different critical dimensions and pitch size. This design features a variety of pitch sizes and duty ratios to demonstrate the possible dimensions when fabricating the device. The mask design was drawn in Mentor Graphics and fabricated in the Heidelberg.

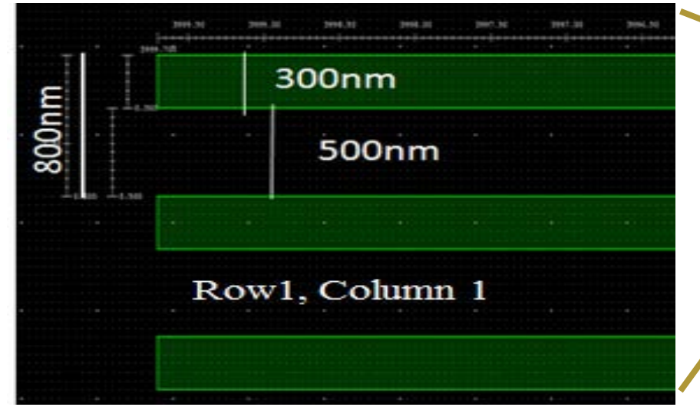


Figure 1. Lines and Spaces.

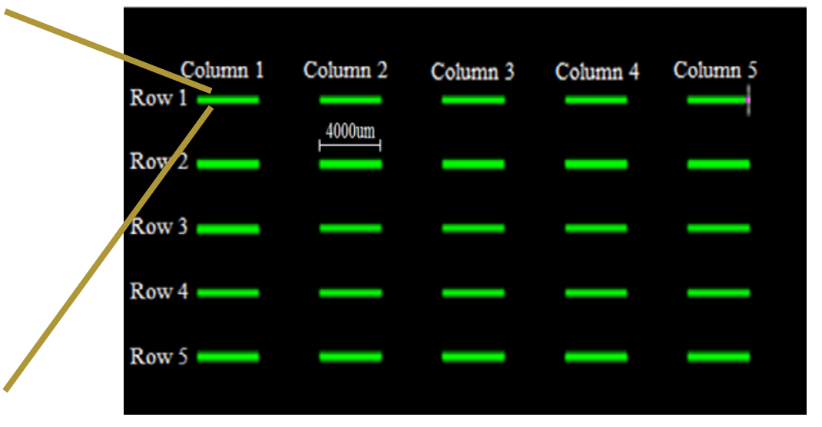


Figure 2. Horizontal Array.

Figure 3. First Level Reticle.

- Diluted Oir620 PR spin curve shown in figure 1 is generated to determine the optimal photoresist thickness.

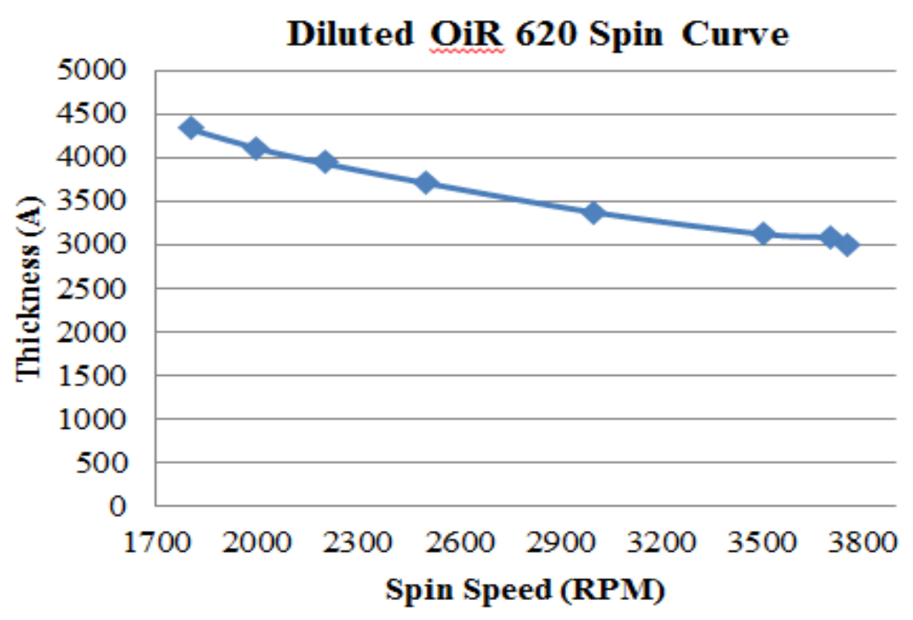


Figure 4. Diluted OiR620 Spin Curve.

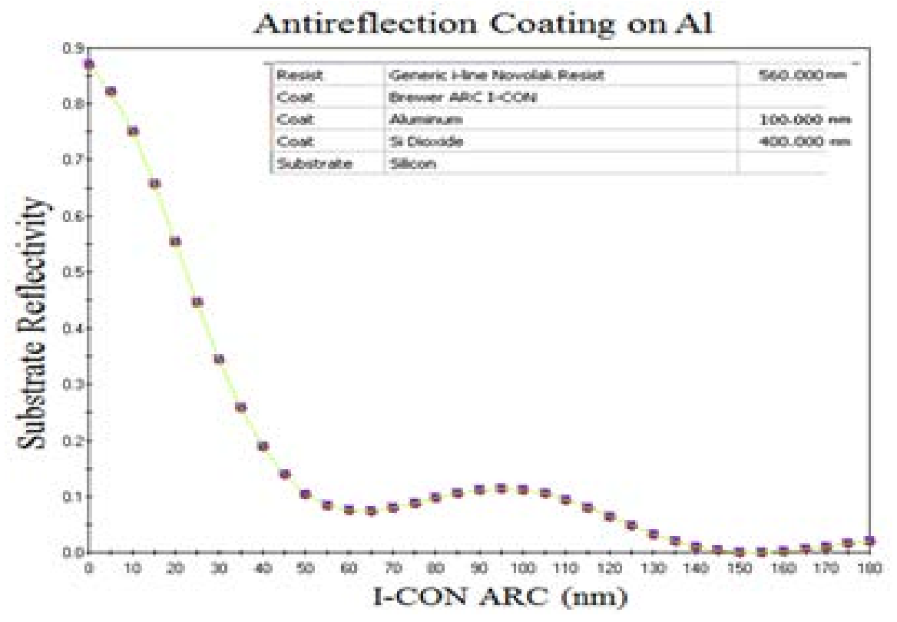


Figure 5. Film Stack Simulation.

- Figure 5 shows the PROLITH swing curve simulation for the film stack used in this process to determine the optimum applied I-CON 7 ARC thickness for the index of the Oir620 photoresist that resulted in high contrast features that can be transferred to the aluminum.

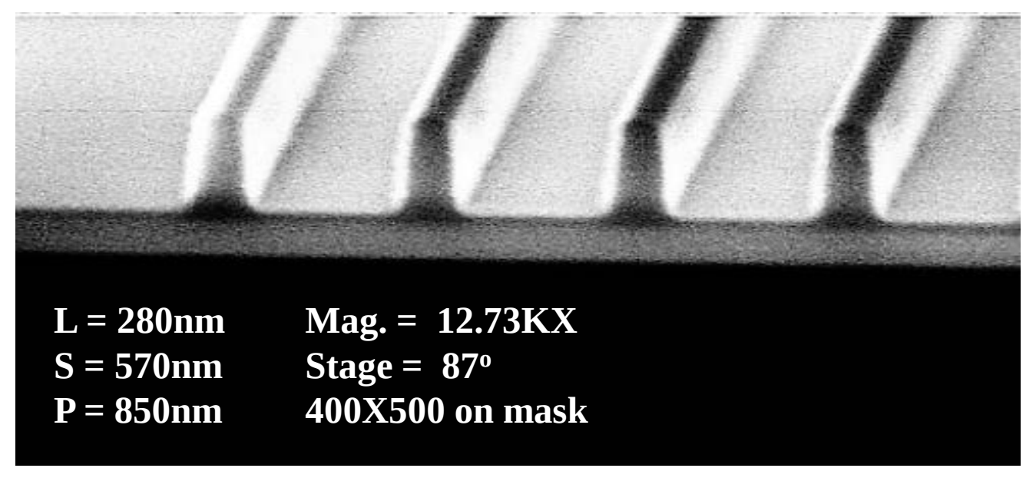


Figure 6. Resist Patterning Through Annular Illumination.

- Figure 7 shows the over-exposure dose through Annular Illumination with NA = 0.6, σ inner = 0.535, and σ outer = 0.9 to successfully image 280nm lines and 570nm spaces. Features on mask are 400X500.

V. Deposition and Reactive Ion Plasma Etch

- Aluminum Etch Recipe (w/PR mask):

Tool: LAM4600.
Recipe: 122122.
Use endpoint detection.

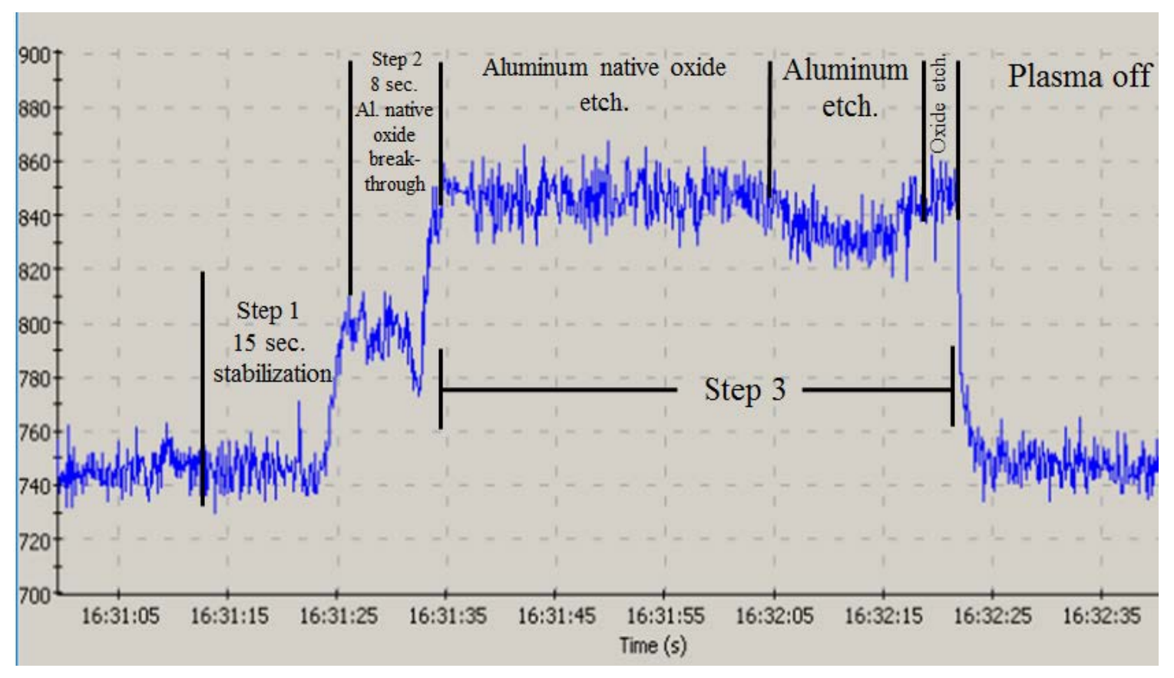


Figure 7. Aluminum Etch Endpoint Detection.

- The photoresist pattern successfully transferred to the aluminum layer creating aluminum lines and spaces with dimensions of 221nm and 612nm, respectively.

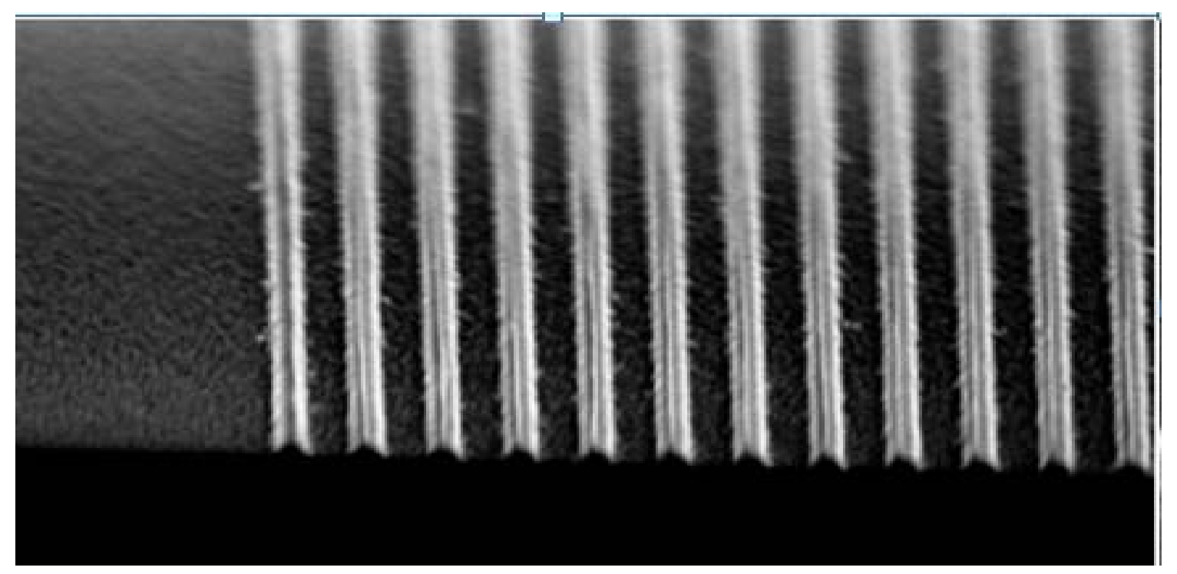


Figure 8. Patterned Aluminum Mask on Oxide Layer.

- Oxide Etch Recipe:

Tool: P-5000 Chamber C.
Power : 500W.
Pressure: 250mT.
O2: 10 sccm.
CHF3: 100 sccm.
CHF4: 100 sccm.
Etch Rate: 1384A/min.

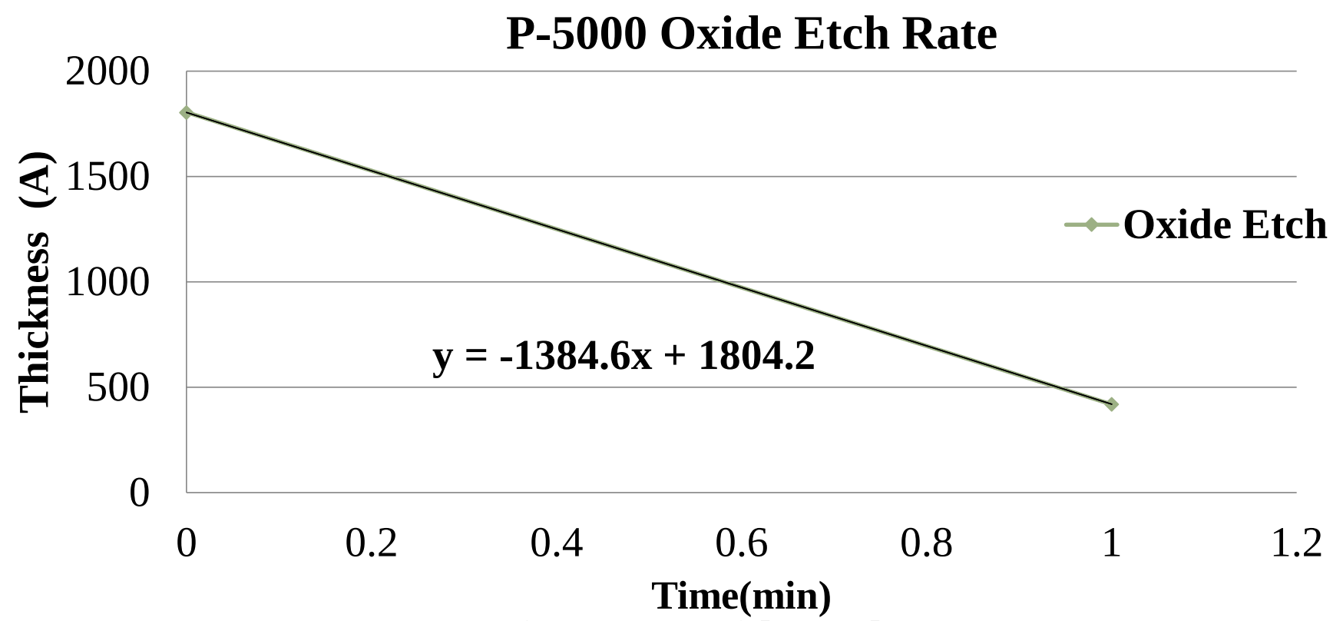


Figure 9. Oxide Etch Rate.

V. Deposition and Plasma Etching (con't)

- Oxide etch utilizing patterned Al mask:

Figure 10 shows the successful transformation of the aluminum patterns to the oxide with an anisotropic profile. SEM CD measurements show 211nm lines and 621nm spaces.

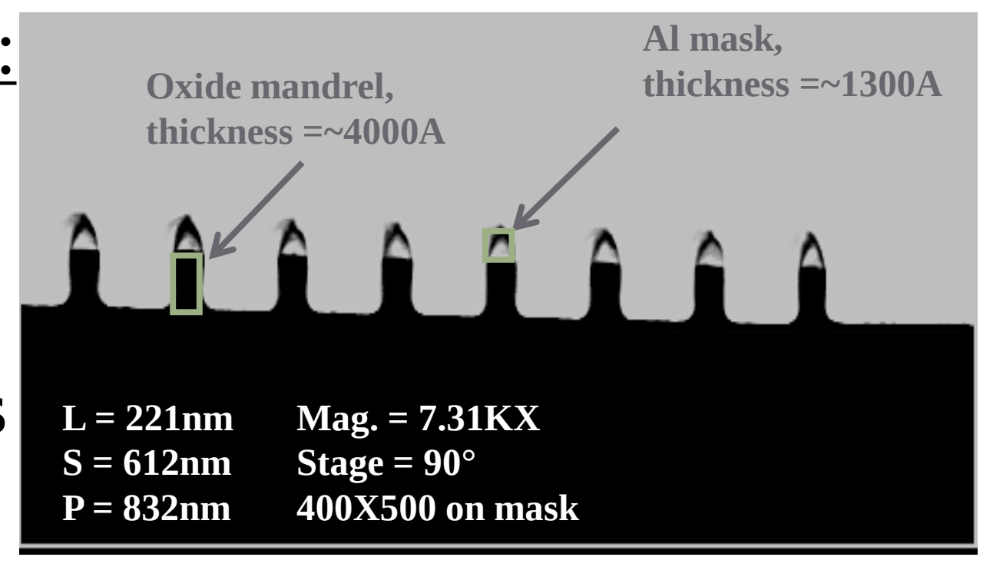


Figure 10. SEM: Aluminum Mask on Oxide Mandrel.

- Nitride Deposition Recipe:

Tool : ASM LPCVD Furnace.
Recipe: Nitride 810ºC.
Base Pressure: 68mT.
Dep. Pressure: 297mT.
DCS: 160sccm.
NH3: 190sccm.
Time: 33min.
Dep Rate: 55Amin.

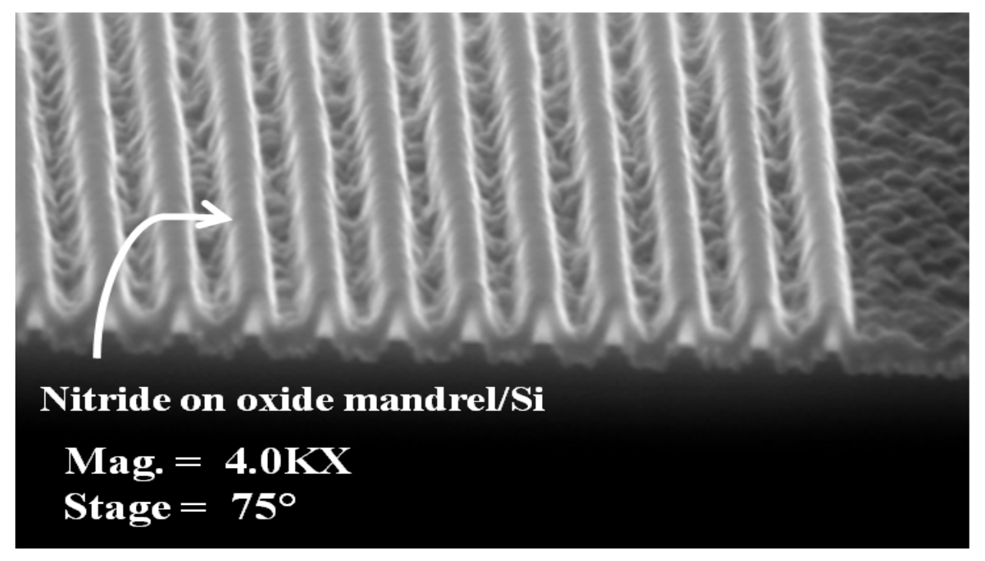


Figure 11. SEM: Nitride Deposition on Oxide Mandrel and Silicon.

- The nitride thickness was measured on a monitor wafer with 380nm of oxide and was found to be approximately180nm.

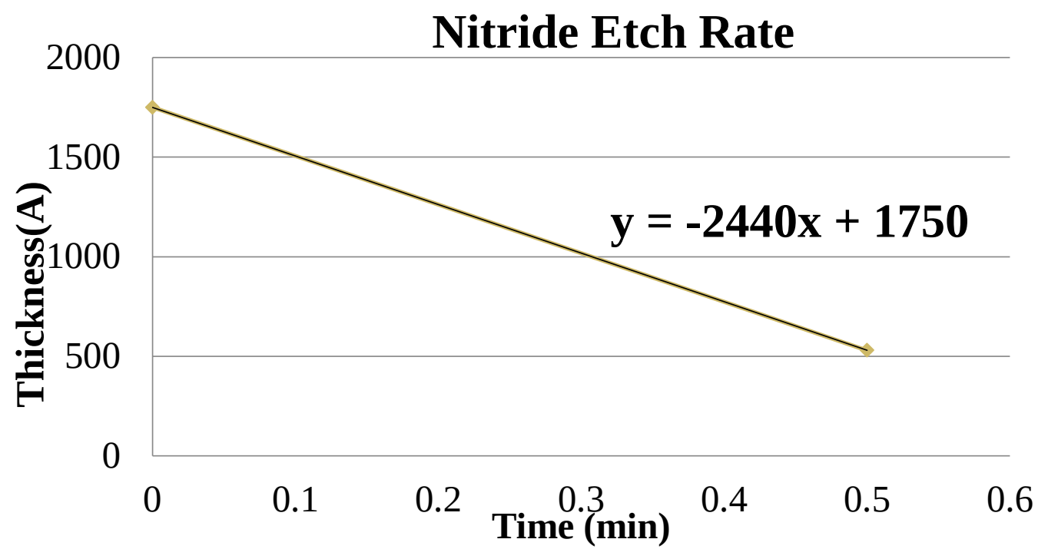


Figure 12. Nitride Etch Rate in Drytek.

- The nitride deposition is conformal around the oxide mandrel as expected, but with a textured surface.
- The texture effect in the nitride film caused a non-uniform spacer etch.

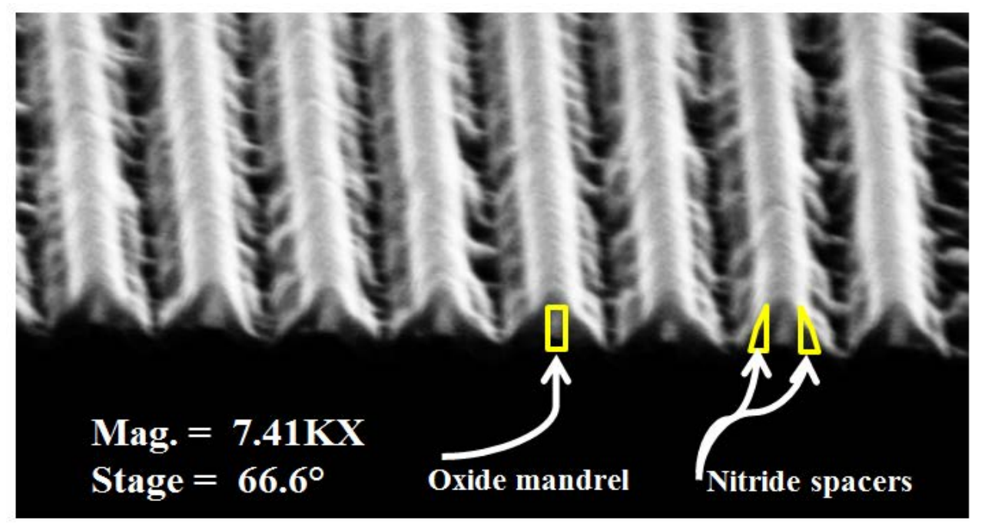


Figure 13. Nitride Etch Result.

VI. Conclusions

- Patterning through annular illumination is successful to image 280nm CD.
- Aluminum hard mask is excellent for oxide patterning with an anisotropic profile.
- Aluminum over-etch proved beneficial for achieving a 211nm mandrel CD.
- Nitride deposition shows a conformal yet textured profile over the oxide mandrel.
- Nitride etch resulted in non-uniform opening between nitride sidewall spacers due to the previous nitride deposition texture.
- DOE is required for the nitride deposition and etch for optimal sidewall profile.
- Due to the project constraints, the silicon etch process was not completed.

Future Work

- Continue this investigation to develop a full fabrication process and electrically characterize finFET devices.
- Consider utilizing a hard mask under the nitride spacer to be transferred to the silicon.

References

[1]C. Shay, "CD Reduction through Annular Illumination and Sidewall Spacer Etch," ed. Rochester Institute of Technology, 2016.
[2]Development and Simulation of Sublithographic Process for nm Scale Features, 1st ed. Rochester: Wallace Memorial Library, 2010, pp. 57 – 84.
[3]E. Bowser, "Double Patterning Isolated and Dense Features With An ASML PAS 5500 i-Line Stepper," ed. Rochester Institute of Technology, 2013.

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