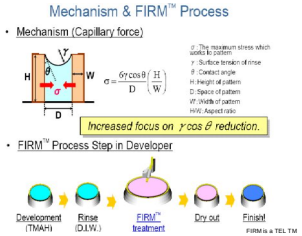
Process Modifications to Reduce Image Collapse

Karen Petrillo, Jacque Georger, Dominic Ashworth, KY Cho,
SEMATECH Inc.

1. Introduction

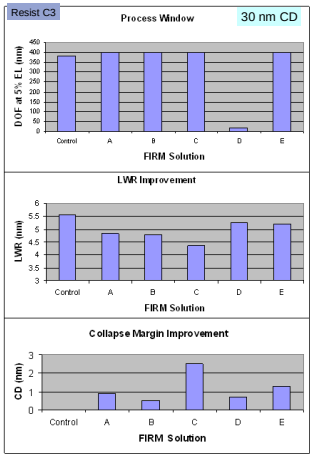
As EUV resist resolution is advancing to enable imaging for 22 nm nodes and beyond, the need to mitigate image collapse becomes evident. Aspect ratios in the 3–4 range, which were typical of many 193 nm and 248 nm resists, are not being achieved with current EUV materials. For many of the advanced EUV resists, a typical aspect ratio is approximately 2. Pattern collapse is influenced by many factors, including substrate adhesion, resist profile, and the mechanical stability of the polymeric film. Changing the resist chemistry or formulation alone may not be sufficient to achieve the combination of resolution needed for the technology node and film thickness required by the etch process.

One method to mitigate pattern collapse includes the use of surfactant rinses. These are applied at the development step, before spin drying. They reduce the capillary forces on the resist by changing the contact angle and reducing the surface tension.



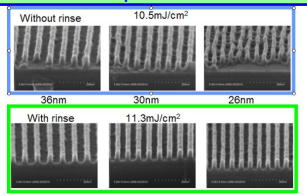
2. Surfactant Rinse Improvements for 75 nm Thick Films

Several FIRM solutions are compared using various high resolution resist materials. Evaluations were conducted at two different film thicknesses. One set of evaluations involved a near-term application targeting a 30 nm critical dimension for which there is a measurable process window on the alpha and pre-production EUV scanners. The resist for this application was 75 nm thick.



- Improvement in process window observed with 4 FIRM solutions
- LWR improvement for 4 of the FIRM solutions
  - Average LWR throughout the process window
- Collapse margin improvement with all rinses
- Rinse C is the best material

2a. Surfactant Rinse Improvements for 75 nm Thick Films

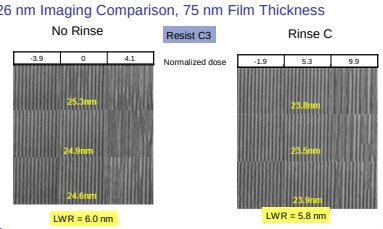


Cross-sections at 3 different pitches reveal the following improvements when FIRM processing is used:

- Better imaging performance with the rinse. 26 nm features are resolved.
- Less residues T
  - The higher dose requirement may be a contributing factor
- Improved LWR

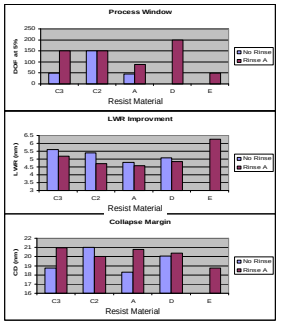
3. Feature Size Effect

Using the same resist / rinse combination, improvements in collapse margin and LWR were minimal as the feature size approaches the resolution limit.



4. Resist thickness effects

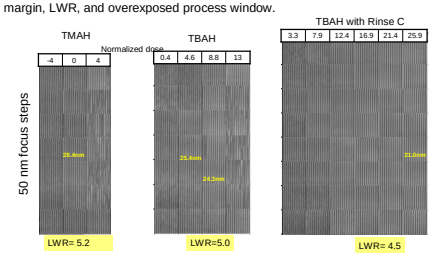
For advanced imaging targeting the 15 nm node and beyond, the highest resolution materials as identified by SEMATECH benchmarking studies were evaluated using a 50 nm thick film.

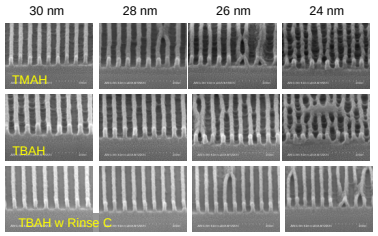


- Process window improvements for all rinses
- LWR improvements with 4 materials
- Collapse margin improvement with only 1 material
- Rinse material needs to be matched to resist
- Mechanism of collapse may be more closely related to swelling then capillary forces in some cases

5. Alternative Developer Enhancements

In an effort to further improve the collapse margin by reducing swelling, a bulkier developer was evaluated. The performance of tetrabutylammonium hydroxide (TBAH) was compared to TMAH, both at a 0.26N concentration. Results indicated that the TBAH developer improved the collapse margin by 2 -3 nm. When used in conjunction with an optimized rinse solution, the TBAH/rinse combination resulted in significant improvement in collapse margin, LWR, and overexposed process window.





Resist profiles indicate less residuals and improved LWR when the TBAH developer is used in combination with an optimized rinse material. The amalgamation yields excellent pattern fidelity for features at the resolution limit, which appears to be related to the mitigation of resist swelling. Although pattern collapse is still present at the smallest feature sizes, this study points to a mechanism that can be addressed by improved resist design.

6. Conclusions

- Image collapse is a major issue limiting resolution for EUV resists.
- Surfactant rinse materials improve the collapse margin by 2–3 nm.
  - Mechanism: reduction of capillary forces
- TBAH developer alone shows a similar magnitude of improvement.
  - Mechanism: reduced developer penetration, which is accomplished by employing a bulkier molecule
- The combination of surfactant rinse and TBAH results in a significant improvement in the collapse margin, LWR, and overexposed process window.

7. References and Acknowledgements

1. Kentaro Matsunaga, et al., "Development of resist material and process for hp-2x-nm devices using EUV lithography," SPIE Proceedings, vol. 7636, 2010
2. Toshiro Itani, et al., "Alternate developer solutions for extreme ultraviolet resist," J. Vac. Sci. Technology. B 27(6), 2009
3. Masahiko Harumoto, et al., Study of post-develop defect on typical EUV resist," SPIE Proceedings, vol 7636, 2010

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