Low-Energy Electron Exposure and Dry Etching Characteristics of Hybrid Thin Films Prepared by Molecular Atomic Layer Deposition for EUV Lithography

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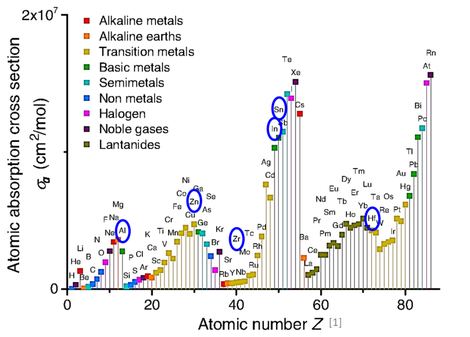
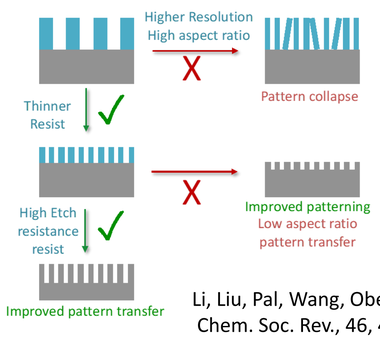
1. Introduction

- Organic-inorganic hybrid photoresists are being investigated for EUVL patterning since they can offer higher resist sensitivity (inorganic elements have high EUV absorption) and robust etch resistance .with thin resist for patterning high-aspect ratio structures.



Fallica, Stowers, Grenville, Frommhold, Robinson, Ekini, J. Micro/Nanolith. MEMS MOEMS 15(3) 033506 (2016)

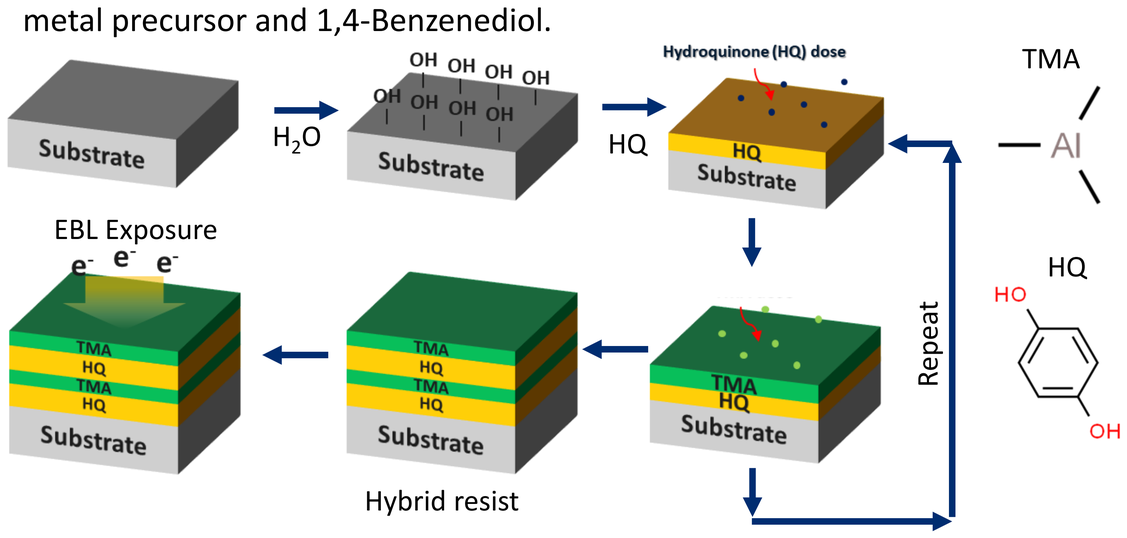


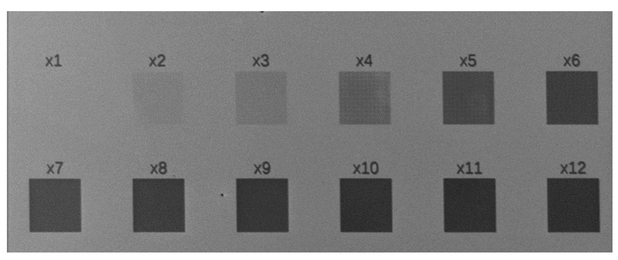
Li, Liu, Pal, Wang, Ober, Giannelis, Chem. Soc. Rev., 46, 4855 (2017)

- A challenge in high-resolution nanopatterning is that the conventional wet development can result in pattern collapse due to capillary forces during the development, which can be mitigated with reactive ion etching based dry development process.
- In this work, we investigate electron-beam lithography (EBL) characteristics and possibility towards dry development of Hybrid Resists Deposited by Molecular Atomic Layer Deposition (MALD)

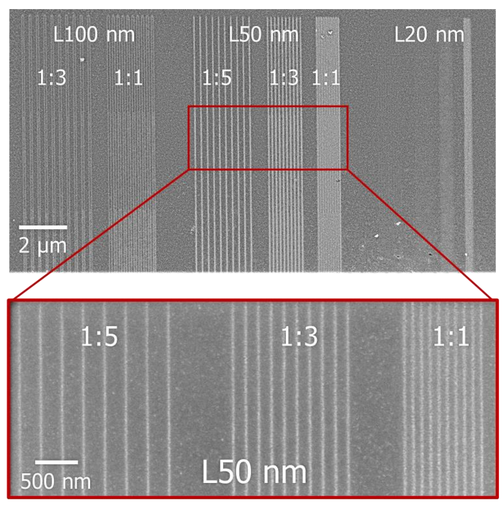
2. TMA/HQ Hybrid resist synthesis and EBL feasibility

- TMA/HQ hybrid resist was synthesized by sequential exposures to TMA metal precursor and 1,4-Benzenediol.

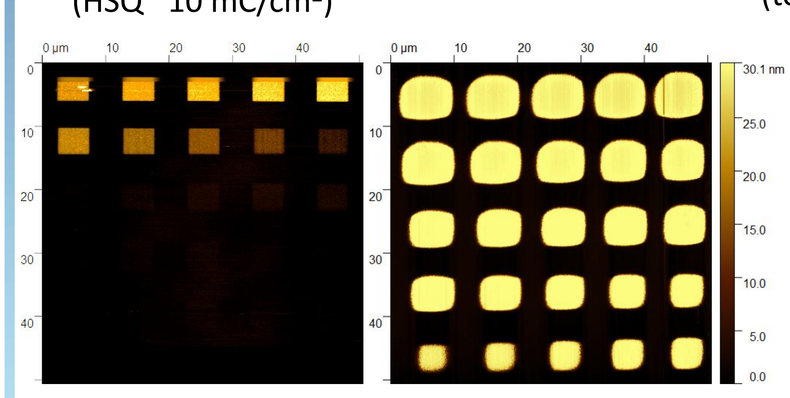




- E-beam exposure: 100 kV JEOL JBX-6300FS; Dose: 25 – 300 mC/cm^2 (25 mC/cm^2 step)
- Development: AZ 300 MIF (1:100 dilution in H_2O) for 1 min, DI H_2O
- Sensitivity ~100 mC/cm^2
- Comparable to inorganic resists (HSQ ~10 mC/cm^2)

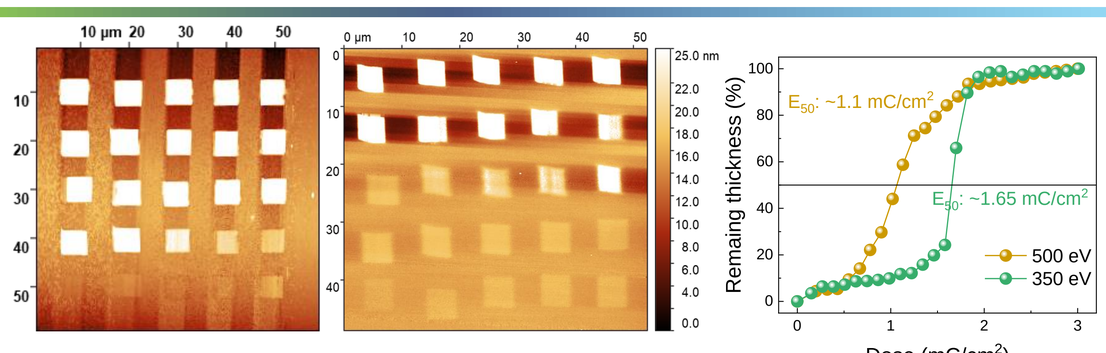


- Resolution ~ 50 nm HP (to be further optimized)

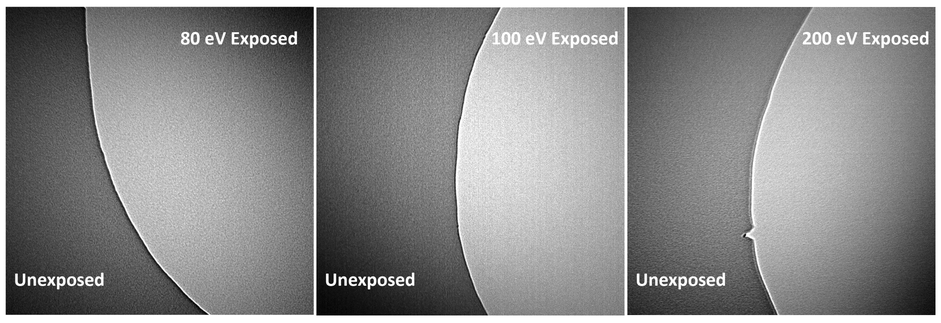


- E-beam exposure: Helios G5 dual beam FIB/SEM
- Dose: 1.5 – 4.5 mC/cm^2 (exponential dose step multiplier of 1.04)
- Development: AZ 300 MIF (1:100 dilution in H_2O) for 1 min, DI H_2O
- Sensitivity ~3.4 mC/cm^2 at 1000 eV
- Lowest dose of 1.5 mC/cm^2 at 250 eV is sufficient to fully crosslink the MALD resist.

3. Low KV EBL feasibility test

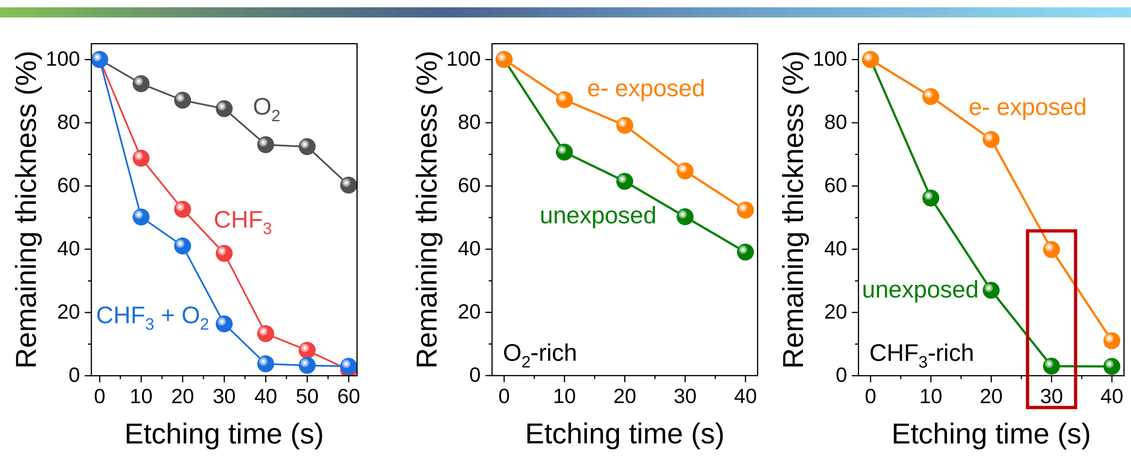


- E-beam exposure: Helios G5 dual beam FIB/SEM
- Dose: 0.15 – 3.0 mC/cm^2 (0.115 mC/cm^2 step)
- Development: AZ 300 MIF (1:100 dilution in H_2O) for 1 min, DI H_2O
- Sensitivity ~1.1, and 1.65 mC/cm^2 at 500, and 350 eV, respectively



- E-beam exposure: Elmitec LEEM V; Exposure time: 1 hour
- Clearly distinguish between the exposed and unexposed regions of MALD resist using LEEM image even at 80 eV

4. Dry Etching of MALD Resist



- Reactive ion etching: Trion phantom etcher
- RF power: 200 W, Pressure: 30 mTorr, Gas flow rate: 50 sccm, E-beam exposure: 400 eV
- Changing gas composition enable tunability to preferentially etch the inorganic (TMA/AlO_x) and the organic (HQ) part of the hybrid resist.
- Increase etch resistance after e-beam exposure
- Under CHF_3-rich condition (4:1 of CHF_3:O_2) after 30 s etching, the unexposed resists was completely removed, while ~10 nm thickness remained for the 400 eV exposed counterpart.

5. Conclusions and future work

- E-beam Lithography patternability of TMA/HQ hybrid resist
  - TMA/HQ hybrid photoresist showed EBL patterning capability with sensitivity (~100 mC/cm^2, 100 kV) and showed 50 nm HP resolution.
- Low KV EBL feasibility of TMA/HQ hybrid resist
  - As the accelerating voltage decreases, the critical dose decreases.
  - Even when exposed to 80 eV, which corresponds to the EUV secondary electron range, hybrid resist showed a visual contrast.
- Dry-development using reactive ion etching process
  - Tuning gas composition (e.g.,: CHF_3/O_2) gas mixture shows additional tunability of etch recipe, potentially useful to dry development of TMA/HQ hybrid resist.
- Future work
  - Low-energy e-beam exposed TMA/HQ resist to be tested for dry development using the developed CHF_3-based RIE process.
  - Systematically extract dose-exposure characteristics of the MALD resist with EBL as well as EUV patterning.

Acknowledgement

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