SURFACE AND LINE-EDGE ROUGHNESS (SR & LER) IN PLASMA-DEVELOPED RESISTS

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PURPOSE of the work

- Evaluation of model Si-containing polymers (siloxanes) as resists for 157-nm lithography (co-polymers of siloxanes can be aqueous-base developed)
- Study of SR and LER in plasma- and solution-developed resists
- Investigation of whether plasma-developed resists can have small LER, comparable to solution-developed resists
- *Simulation of SR & LER (see paper R-10P)*

EXPERIMENTAL

Materials:

- Bilayer siloxane-based resists (poly-dimethyl-siloxane, PDMS)
  Commercial PDMS (Aldrich) M_w/M_n=2
  Synthesized PDMS (University of Athens) M_w/M_n=1
- Single layer resists (epoxy chemically amplified negative-tone resist, EPR*)
  Silylated plasma-developed EPR (positive-tone)
  Solution-developed EPR (negative-tone)

* P. Argitis, I. Raptis, C.J. Aidinis, N. Glezos, M. Bacciochi, J. Everett, M. Hatzakis, *J. Vac. Sci. Technol.* **B13** (1995) 3030

Process for bilayer resist:

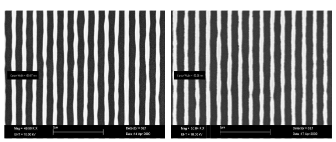
- Exposure: E-beam Vector scan Leica EBPG-3, 50 keV, beam diam. 50nm
- Development: Solution development for PDMS, and Plasma development for the bottom layer (AZ5214): RIE, 10 mTorr O_2 plasma with or without BTS etch
  BTS: F-containing mixture for 5-6% of etch time

Measurements: SEM, AFM

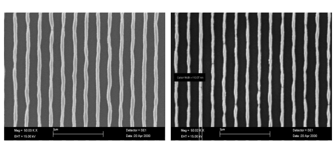
WHY SILOXANES?

- 157 nm transparency
- Resolution capabilities

PDMS with narrow MW distribution | PDMS with broad MW distribution



Dose: 5.75μC/cm² L/S: 0.15/0.30μm | Dose: 8.75μC/cm² L/S: 0.15/0.30μm



Dose: 7.75μC/cm² L/S: 0.1/0.45μm | Dose: 12μC/cm² L/S: 0.1/0.45μm

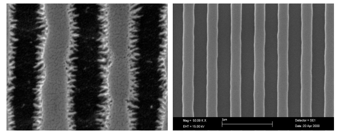
50keV electron beam with a 50nm diameter was used for exposures. Plasma development of the bottom layer in two steps included a first BTS etch. Some line flickering is mostly due to the beam diameter. Some swelling due to the use of organic developer for the top layer.

- Need to be copolymerized to be aqueous developable

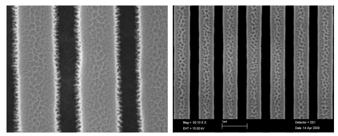
RESULTS: Role of BTS

LER of PDMS

without BTS | with BTS



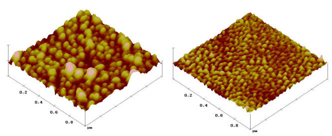
Dose: 4.2 μC/cm² | Dose: 4.25 μC/cm²



Dose: 5.4 μC/cm² | Dose: 7 μC/cm²

100nm thick PDMS material (synthesized at the University of Athens) e-beam exposed, wet developed in MIBK, and dry developed in O_2 plasma for the 8000A thick bottom layer (nominal 0.5μm 1:1 L/S).

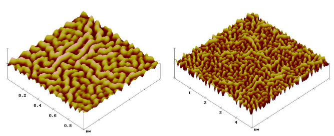
SR of PDMS without BTS



z=150nm/div, dose=0 | z=20nm/div, dose=2.4μC/cm²

High roughness due to residues after solution-development of PDMS

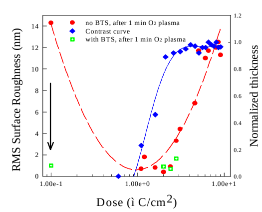
Small roughness at useful doses



z=40nm/div. dose=2.8μC/cm² | z=100nm/div. dose=9.1μC/cm²

At very high doses, the SR is high due to the highly cross linked siloxane surface.

SR and Contrast Curve of PDMS



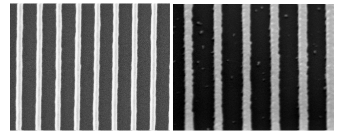
PDMS synthesized at the University of Athens. Conditions: BTS etch with 20% SF_6 + 20% CHF_3 + 60% O_2 plasma for 6% of the total development time, followed by 1 min plasma etch in pure O_2.

BTS reduces SR and thus LER at zero doses

DISCUSSION: Comparison with EPR

LER of EPR

Solution-developed EPR | Silylated Plasma-dev. EPR



0.10 μm / 0.20 lines/spaces of solution-developed negative tone EPR. Conditions: PAG content: 1%, PAB: 120°C (4min), e-beam lithography: dose=1 μC/cm², PEB: 90°C (4min)

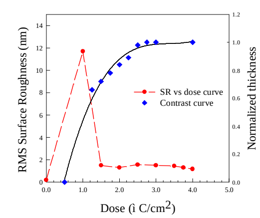
0.17 μm / 0.48 μm lines/spaces of plasma-developed positive tone EPR. Conditions: PAG content: 0.75%, PAB: 130°C, 4 min, e-beam lithography: dose=1.6 μC/cm², PEB: 100°C (4 min), HDP development with BTS (not optimized)

Small LER from wet process

LER from dry process depends on amount of BTS

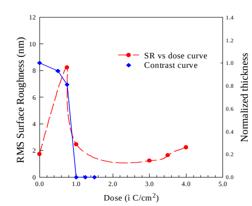
SR and Contrast Curve of EPR

Solution-developed EPR



Surface roughness of solution-developed Epoxy Resist (negative tone) as a function of exposure dose. PEB was 110 C. The contrast curve is also shown.

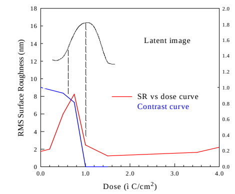
Plasma-developed silylated EPR



Surface roughness and remaining thickness versus dose for a plasma-developed silylated epoxy resist. A two step plasma development has been used (BTS and main etch).

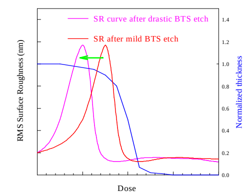
BTS reduces SR/LER at clearing doses

DISCUSSION: Explanation of effect of BTS on LER



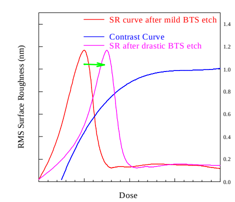
Schematic indicating the relation between SR and LER. LER corresponds to SR at smaller dose due to aerial image. Thus, the closer the max of SR is to clearing doses, the higher is LER.

For a positive-tone resist: more drastic BTS moves the max in SR towards smaller doses (further away from clearing doses), thus reducing LER



Schematic of the SR vs dose and the contrast curve for a positive-tone resist scheme

For a negative-tone resist: more drastic BTS moves the max in SR towards higher doses (further away from clearing doses), thus reducing LER



Schematic of the SR vs dose and the contrast curve for a negative-tone resist scheme

CONCLUSIONS

- Plasma and solution-developed resists can have similarly low values of SR at useful doses, provided appropriate BTS etch is performed
- Minimization of LER can happen by shifting the max of SR further away from clearing doses
- Siloxanes exhibit good resolution, small SR at useful doses, small LER (with BTS), and are thus good candidates as copolymers of 157 nm resists

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