# Optimizing EUV Imaging on Spin on Hard Mask Under-layers

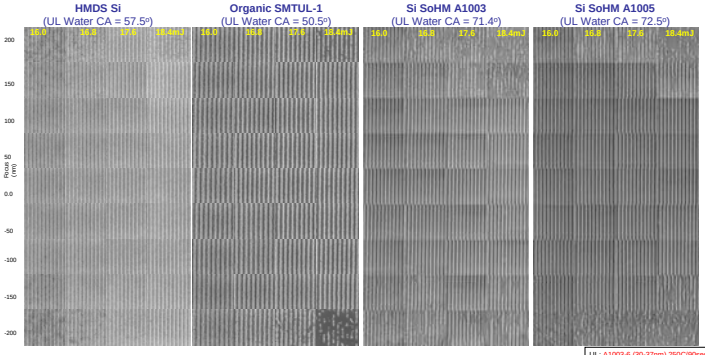
Jacque Georger[1], Do Kim[2], Sang Kyun Kim[2], James Chung[2], Rick Uchida[3], Taku Hirayama[3], Craig Higgins[4], Robert Brainard[4], Dominic Ashworth[1], Warren Montgomery[1]

[1] SEMATECH, Inc., [2] Cheil Industries, [3] TOK, [4] CNSE, University at Albany

## Motivation

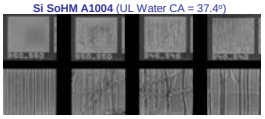
Imaging of EUV resists at 30nm half pitch (hp) and below is requiring thinning of resist thickness down to ~50nm. In order to successfully transfer patterns into IC substrates at these resist thicknesses imaging on Hard Mask (HM) under-layers (UL) will be required. Spin on silicon containing HM are used in combination with spin on carbon HM stacks materials in other imaging technologies today. This work evaluates EUV imaging on commercial spin on HM UL formulations with commercial resist and an open source CAR resists Vs HMDS treated bare silicon and organic UL using SEMATECH Albany e-MET.

## SMT-3 (Water CA = 65.4º) 30nm hp Process Windows Vs UL

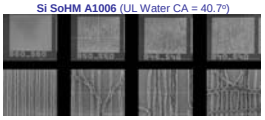



UL: A1003-6 (30-37nm) 250C/90sec
UL-1 (20nm) 205C/90sec
Resist: SMT3 (50nm)
PAB: 110C/90sec
PEB: 100C/60sec
Dev: 2.38% TMAH / 30sec
Exp: Albany E-MET 0.3NA Quad

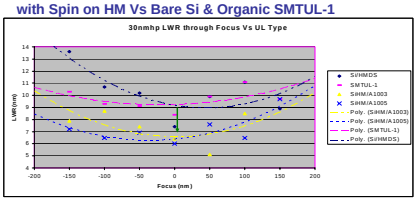
Si SoHM A1004 (UL Water CA = 37.4º)



Si SoHM A1006 (UL Water CA = 40.7º)

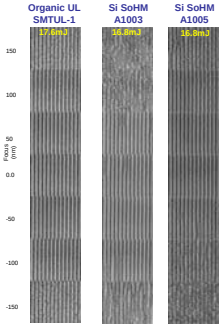


### Improvement in 30nm hp LWR with Spin on HM Vs Bare Si & Organic SMTUL-1

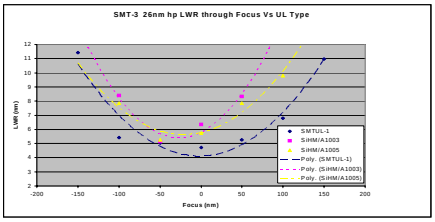



- ULs where processed per manufactures recommended conditions on bare Si as shown in process box above.
- EUV resist SMT-3 was coated to 50nm thickness and processed identically on all ULs investigated.
- Static water contact angle was measured for each UL and SMT-3 post coat and bake.
- Hydrophilic Si containing HM ULs gave poor adhesion with SMT-3, resulting in lifting resist lines below 60nm hp.
- HMDS primed silicon and organic spin on UL SMTUL-1 had good adhesion and best DOF at 30nm hp with minimum adhesion failure at defocus or overexposure.
- Hydrophobic Si containing HM ULs with contact angles of ~71º give good adhesion at 30nm hp but show more adhesion failure thru focus.
- Line width roughness (LWR) showed improvement by ~25% on the hydrophobic Si HM ULs Vs HMDS and organic spin on SMTUL-1 at 30nm hp.

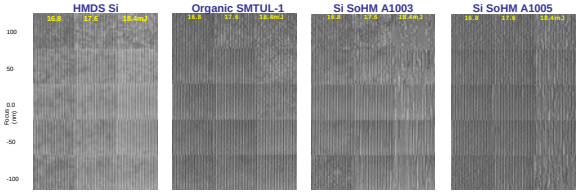
## SMT-3 26nm hp DOF & LWR through Focus on Organic & Hydrophobic Si containing UL




### 26nm hp LWR with Spin on HM Vs Organic SMTUL-1

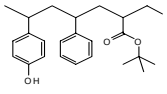



## SMT-3 24nm hp Process Windows on HMDS/Si, Organic UL & Hydrophilic Si containing UL

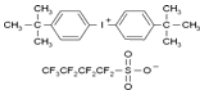



- At 26-24nm hp the organic UL SMTUL-1 gave significantly better adhesion than the hydrophobic Si containing spin on HM ULs A1003 and A1005.
- SMTUL-1 better adhesion results in greater DOF, exposure latitude and improved LWR through focus at these smaller nested features.
- SMT-3 on Si spin on the hydrophobic HM ULs fail by pattern collapse and lifting resist lines through focus and increased dose.

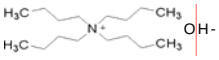
## *Open Source EUV Resist (OS2) Formulation*



ESCAP Ter-Polymer
65/20/15



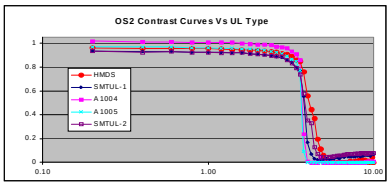
Iodonium PAG (DTBI-PFBS)
15 wt%

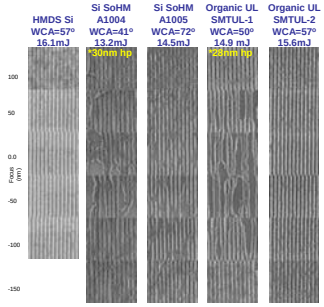


Base (TBAH)
1.5 wt%

- The OS2 formulation consists of above ESCAP polymer, iodonium PAG, and base additive shown above.
- The solvents used are 50/50 ethyl lactate and propylene glycol monomethylether acetate.
- OS2 was coated to 46nm thickness and processed identically as shown in process box below on all ULs investigated.
- OS2 was imaged on HMDS/Si, two organic UL and two Si HM UL materials.
- The static water contact angle for OS2 was measured post coat bake and found to be 74.1º which is more hydrophobic than SMT-3 which was 65.4º.
- Contrast curves for OS2 were also evaluated on each UL investigated.

## OS2 26nm hp Imaging on HMDS/Si, Organic ULs & Si containing ULs




UL: A1004 / A1005 (30/37nm) 250C/90sec
UL-1 / UL-2 (20/35nm) 205C/90sec
Resist: OS2 (46nm)
PAB: 130C/60sec
PEB: 120C/60sec
Dev: 2.38% TMAH / 45sec
Exp: Albany E-MET 0.3NA Quad

- The comparison of OS2 contrast curves imaged on HMDS primed silicon to organic UL and silicon contain HM UL, clearly shows that the dose to clear is decreased and the contrast of the resist is higher when imaged on the ULs.
- OS2 demonstrates 26nm hp resolution and ~150nm DOF at ~16mJ/cm² on HMDS primed silicon and on commercial organic UL SMTUL-2 which both have matching water contact angles of 57º.
- OS2 imaging performance on the commercial organic SMTUL-1 which has a water contact angle of 50º significantly degraded due to poor adhesion which resulting in the resist not able to resolve 30nm hp features due to lifting resist lines.
- The imaging performance of OS2 on spin on the hydrophilic silicon containing HM material A1004, which has a water contact angle of 41º, also suffers from poor adhesion and is not able to resolve features less than ~50nm hp with out lifting resist lines.
- On the more hydrophobic silicon containing spin on HM material A1005, 28-30nm hp features were resolved with pattern collapse prevalent through focus but did not resolve 26nm hp features due to lifting resist lines.

## Summary and Discussion

The commercial EUV resist SMT-3 and open source EUV resist OS2, image performance was evaluated on various silicon containing spin on HM layers that had ranges of surface polarity as determined by static water contact angle and compared to imaging on bare silicon primed with HMDS and organic under-layers. Both resists had significant adhesion issues on the more hydrophilic spin on silicon containing HM materials with static water contact angles of ~40º resulting in lifting of resist lines features less than 60nm hp. The silicon containing spin on HM under-layers with increased hydrophobicity (static water contact angles of ~71º) showed significantly improved adhesion for both resists. SMT-3 resist has a static water contact of 65.4º and has a more polar surface than OS2 resist, which has a static water contact angle of 74.1º.

At 30nm hp SMT-3 process windows on the hydrophobic silicon containing spin on HM resulted in acceptable process windows with slightly less depth of focus than HMDS primed silicon and organic under-layer SMTUL-1 due to pattern collapse and lifting resist line failure at increasing defocus and over exposure. Interestingly, at 30nm hp the LWR on the hydrophobic silicon containing HM materials was reduced by ~25% Vs both the organic SMTUL-1 and HMDS primed silicon substrates. A possible explanation for this is resist footing may be reduced on these HM substrates or resist footing could be masked by a slightly reentrant resist profile, both of which could lead to reduced LWR and adhesion of the resist to the substrate. At 26-24nm hp resolution the DOF, and over exposure capability for SMT-3 resist on the hydrophobic silicon containing HM materials drops off significantly compared to the organic under-layer SMTUL-1 and HMDS primed silicon substrate. The LWR performance at 26nm hp also degrades relative to the performance on organic under-layer SMTUL-1, particularly as the image is further from best focus. This drop off in performance on the silicon containing HM layers is due to the increased adhesion failure at these smaller features resulting in pattern collapse and lifting resist.

The open source resist OS2 is more hydrophobic than SMT-3 and this may lead to the differences seen on both organic and inorganic under-layers evaluated. OS2 has demonstrated 26nm hp resolution with ~150nm DOF on the organic under-layer SMTUL-2 and HMDS primed silicon, both of which have the same static water contact angle of 57º. However, OS2 litho performance drops off significantly on organic under-layer SMTUL-1 (water contact angle 50º) and silicon containing HM A1004 (water contact angle 37º) and is not capable of resolving 30nm hp features due to adhesion failure. On the hydrophobic silicon containing HM material 28nm hp features are resolved but show significant pattern collapse and lifting through focus.

Further optimization of silicon containing spin on HM surfaces to improve adhesion of EUV resists is needed, fortunately material suppliers have demonstrated ability to very surface properties over a wide range and should be able to better tune these materials to improve resist adhesion.

### Acknowledgments

Thanks to SEMATECH RMDC Techs Dave Amedure, Sandy Finkey, Rob Gantt, Khurshid Anwar, Scott Wright, and Paula Yergeau for their excellent support of this work.



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