Materials and Resists for 193 and 157nm Applications

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Polymeric materials and resists for 193 and 157 nm applications have shown good progress. Improvements and status in the area of methacrylate, cyclo-olefin/maleic anhydride (COMA), hybrid polymers and resists derived from these polymers are highlighted. While methacrylate polymers based on 2-methyl adamantyl methacrylate (MAdMA) continue to show excellent performance for contact and dense line and space applications, hybrid type polymers consisting of (among others) t-Butyl-5-norbornene-2-carboxylate (BNC), MAdMA and maleic anhydride exhibit the best performance for semi-dense and isolated line and space applications. Lithographic performance of representative formulations AZ® EXP AX™1020P, AZ® EXP AX™1040P, and AZ® EXP AX™2020P derived from each type of polymers are provided. A first 157 nm resist system based on copolymers of norbornene-5-methylenehexafluoroisopropanol (NMHFA) and BNC, formulated with an additive obtained by copolymerization of t-butyl norbornene-5-trifluoromethyl-5-carboxylate (BNTC) with carbon monoxide demonstrating dense L/S resolution down to 90 nm with >85° wall angle is also presented.

Keywords: Polymers, resists, 193nm, 157 nm, AX™1020P, AX™1040P, AX™2020P.

1. Introduction

Process and resist selections for CDs ≤0.13µm is ongoing at several semiconductor research fabs. The most advanced 248nm resists may satisfy the necessary process windows up to 0.13µm (by using optical enhancement techniques) but 193nm resists are the choice of materials for CDs ≤0.13µm. 193nm resist development work by several groups is focused on fine tuning the materials and resists addressing issues such as line-edge roughness, smaller process windows, and etch related problems.1-14 Beyond 193nm, intensive research work is also being carried out on the polymeric materials and resists useful for 157nm applications. While the polymer platforms and specific polymers are almost fixed for 193nm resists a lot of research work is being carried out to tackle the absorption of most of the polymers at 157nm by incorporating fluorine or silicon on to the polymers.15-29 In this paper developments in the resists and chemistry of polymeric materials for 193nm and 157nm are presented.

2. Polymeric materials for 193nm applications and their lithographic properties

Four broad classes of polymer platforms - methacrylates with alicyclic pendant groups1-4, cyclo-olefin/maleic anhydride alternate polymers,5-6 cyclo-olefin addition polymers,7-8 cyclo-olefin/maleic anhydride/ methacrylate hybrid polymers11-12 - have emerged as viable materials for 193nm applications. Except for the
cyclo-olefin addition polymers, the rest are prepared using free-radical polymerization techniques. The cyclo-olefin addition polymers are synthesized either ring-opening metathesis or metal (group VIII e.g. palladium compounds) catalyzed polymerization techniques. But the complex nature and high Tg of the polymers prepared from these methods have shown not so big advances in the lithographic performance compared to the most straightforward and versatile free radically prepared polymers. This study focuses on the free-radically polymerized methacrylate, cyclo-olefin/maleic anhydride, and cyclo-olefin/maleicanhydride/methacrylate hybrid polymers.

2.1 Methacrylate polymers
Poly(2-methyladamantylmethacrylate-co-mevalonic lactone methacrylate) polymerized from 2-methyladamantyl methacrylate (MAdMA) and mevalonic lactone methacrylate (MLMA) or poly(2-methyladamantylmethacrylate-co-γ-butyrolactone methacrylate) obtained by the polymerization of MAdMA and γ-butyrolactonemethacrylate (GBLMA) has demonstrated as a very useful polymer for the 193nm applications (scheme I).

Since MAdMA is too hydrophobic, an hydrophilic monomer such as MLMA is copolymerized to balance the polarity of the polymer. Polymers reported in this paper were prepared by using AIBN \([N,N'-azobis(isobutyronitrile)]\) initiator in THF solvent at 68°C. The yields were typically above 65 % after precipitation in methanol and vacuum drying. Some general characteristics of this type of polymers are that the molar ratio of the monomers needs be close to 1:1 to meet the solubility properties for resist applications. For example polymers from 1:3 or 3:1 mol ratios of MAdMA:MLMA are insoluble in common resist solvents (Table 1).

![Scheme I. MAdMA containing 193nm applications.](image)

<p>| Table 1. Characteristics of 2-MAdMA/MLMA copolymers |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>MAdMA (mole % in feed)</th>
<th>MLMA (mole % in feed)</th>
<th>Mw</th>
<th>Tg</th>
<th>Tg'</th>
<th>Resist formulation</th>
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<tr>
<td>100</td>
<td>0</td>
<td>3,122</td>
<td>226</td>
<td>160</td>
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<td>75</td>
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<td>14,338</td>
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<td>162</td>
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<tr>
<td>50</td>
<td>50</td>
<td>18,100</td>
<td>204</td>
<td>154</td>
<td>-</td>
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<td>25</td>
<td>75</td>
<td>11,357</td>
<td>198</td>
<td>143</td>
<td>Solubility issues</td>
</tr>
</tbody>
</table>

a) by GPC, b) on MT/DSC

The glass transition temperature of the 1:1 polymer is 154°C and the MAdMA and MLMA homopolymers have Tg’s of 160 and 110°C, respectively. Detailed thermal studies on these polymers are provided elsewhere.13 In order to improve upon the resolution, line-edge roughness, up to 15 mol% of a third acrylate type monomer shown in scheme II may be incorporated.

![Scheme II. Structures of some third monomers](image)

2.2 Lithographic performance of methacrylate based resists
Methacrylate based polymers in general show good performance for dense and contact hole applications. Figure 1 shows the linearity of 1:1 dense line and spaces (L/S) for AZ® EXP AX™1020P methacrylate based resist formulated using ethyl lactate solvent and triphenylsulfonium nonaflate photoacid generator and a quencher. The 350 nm resist film coated on a bottom antireflective coating (B.A.R.C) was processed at...
SB and PEB temperatures of 115°C and 110°C, respectively for 60sec, exposed on a ASML scanner (NA=0.63, 0.55/0.856) developed using Ag. 2.38 wt % TMAH. The resist has a DoF of 0.8-0.9 µm (Figure 2) an exposure latitude (EL) of more than 13 % (Figure 3) for 120 nm equal L/S.

The poly/AXTM 1020P etch selectivity was found to be 3.49 (measured on LAM 9400 at 450W/45W/20mT/200sccm HBr/75sccm C12/10 He-O2 / 65 °C). This compares with a value of 3.79 for APEX DUV resist and 5.98 for 510L I-line resist under identical conditions. The oxide etch selectivity (measured on AMT-5300 machine at 2800W/1400W/5mT/40sccm C2F6/95sccm Ar/10°C ) for AXTM1020P, APEX and 510L were 3.76, 3.54 & 4.73 respectively.

A slightly modified formulation, AZ® EXP AXTM 1040P shows excellent contact hole (C/H) capabilities. After oxide etch, DoF performance of 160 nm isolated (1:6) C/H of this resist exposed on a ASML scanner (NA=0.6, σ=0.4) using a binary mask and processed using a 400 nm resist film, 130°C/60sec SB, 120°C/60sec PEB and 60sec development in 2.38 wt % TMAH is shown in Figure 4. The dense C/H DoF and the overlap DoF is summarized in Table 2.

2.3 Cyclo-olefin/maleic anhydride polymers

The poly/AX™1020P etch selectivity was found to be 3.49 (measured on LAM 9400 at 450W/45W/20mT/200sccm HBr/75sccm C12/10 He-O2 / 65 °C). This compares with a value of 3.79 for APEX DUV resist and 5.98 for 510L I-line resist under identical conditions. The oxide etch selectivity (measured on AMT-5300 machine at 2800W/1400W/5mT/40sccm C2F6/95sccm Ar/10°C ) for AXTM1020P, APEX and 510L were 3.76, 3.54 & 4.73 respectively.

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As the copolymer of BNC and MA has poor adhesion problems, it is necessary to include HNC and NC in order to improve adhesion. Small amounts of NC also improve the dissolution characteristics of the polymer. A number of tetrapolymers of BNC/HNC/NC/MA useful for resist applications were prepared. NC contents of above 3 mol % leads to film thickness losses of more than 30 nm/minute in 2.38 wt% TMAH. Hence, the amount of NC in the polymer should be less than 3 mol %. A polymer with a BNC/HNC/NC/MA composition of 41/6/3/50 mol% (Mw=8,000) has a glass transition temperature of 208 °C.

2.4 Lithographic performance of poly(BNC/HNC/NC/MA)

Resist performance of poly(BNC/HNC/NC/MA) in propyleneglycol monomethyl ether acetate (PGMEA), triphenylsulfonium nonaflate PAG and a base is shown in figure 6. The 390nm resist film was processed at SB and PEB temperatures.
of $110^\circ C$ and $130^\circ C$ for 90 sec, respectively and exposed on a Ultratech ministepper with a NA and $\sigma$ of 0.6 developed for 30 sec using 2.38 % aq. TMAH. The resist shows good performance for semidense and isolated L/S up to 100 nm with no optical enhancements.

Compared to methacrylate type resists, the profiles are slightly tapered due to higher absorption at 193nm for COMA type resists. Detailed investigation of shelf-life stability were carried out since the polymer contains a potentially self-reactive hydroxyethyl group (in HNC) with the maleic anhydride moieties. Model studies with HNC and succinic anhydride even at elevated temperature did not react. In presence of acid however the ring opening reaction occurs. One observation was that strict moisture exclusion is necessary during polymerization and after the polymer has been formulated in to resist avoiding hydrolysis. Otherwise a large shift in the dark film loss of the resist was observed (see below).

2.5 Hybrid polymers from BNC/HNC/NC/MA/MAdMA/MLMA

The copolymerization of norbornene and maleic anhydride with acrylate or methacrylate monomers has been reported by the research group at Lucent Bell Labs where it was demonstrated that the yields of this type of copolymers can be quite comparable to those of other families of polymers for lithographic applications. In this study, a hybrid COMA/methacrylate system (Scheme 4) in which one part of MAdMA and MLMA mixed with one part of norbornene derivatives (BNC, HNC, and NC) and two parts of maleic anhydride. These were reacted in the presence of AIBN in THF solvent. The isolated yield of this polymer is about 70% and Mw in the 6000-10,000 Dalton target range for lithographic applications can be achieved. We have developed varieties of hybrid polymer systems by changing the cycloolefin/methacrylate ratio. The yields, molecular weight, and the dark film loss of the few selected hybrid polymers with different ratios of cyclo-olefin/ methacrylate monomers are shown in Table 3. The desired molecular weights of the hybrid polymers were easily achieved. The low molecular weight polymers can be obtained by increasing the amount of initiator, decreasing solid content (reducing gel effect) or using chain transfer reagents. With the increase of the methacrylonomer feed in the hybrid polymers, dark erosion decreases significantly, as expected from dilution of cycloolefins, especially HNC and NC. It is not surprising to see that the last two entries of Table 3 where HNC and NC are absent in the hybrid copolymer result in a very low dark erosion.

The most striking feature in Table 3 is the dramatic increase in isolated yield of polymers with increasing amounts of methacrylate monomers. This observation led us to characterize the polymers more thoroughly. We have analyzed an aliquot of the reaction products by gas chromatography using internal standards of the reacted monomers. The total amount of unreacted monomers was quantitatively measured to be about 10%, whereas the amount of maleic anhydride was about 1%. Typically, during the isolation process, about 15 to 20% of the starting materials are removed, which include oligomers/low molecular weight polymers and about 10% of unreacted monomers. We believe that maleic anhydride acts as a chain transfer reagent to yield relatively low molecular weight polymers since under similar conditions free radical reactions of methacrylates (MAdMA and MLMA) were found to give very high molecular weight polymers (Mw >40,000). It is not clear at this point whether an alternate copolymer of maleic anhydride and methacrylate is formed, though it is strongly believed that methacrylate and maleic anhydride react to contribute to the polymer chain formation. A fundamental study of synthesis and characterization of the hybrid polymers including reaction kinetics is under way.
and the results will be reported in a future communication. Composition analysis of hybrid polymers by NMR analysis is very difficult because of the complicated nature of the polymer. However, $^{13}$C-NMR analysis of the hybrid polymer recorded in d-6 DMSO clearly shows two resonances at low field. A broad band which appears at 172 to 177 ppm is attributed to the carbons of the C=O groups of the carboxylate moieties, while a sharp peak at 169 ppm can be assigned to the carbonyl C=O of MLMA. A broad band of carbon attached to oxygen of HNC and MLMA appears at 79 to 81 ppm, whereas a sharp peak of carbon attached to oxygen (MLMA ring) appears at 64.3 ppm. There are three sharp peaks at 27.5 ppm, 24.5 ppm, and 20.7 ppm that can be assigned to the methyl groups of BNC, the polymer chain, and MAdMA and MLMA, respectively.

Apart from the increase in the polymer yield and control of dark erosion another important advantage of introduction of the methacrylate monomers in to COMA polymers is the decrease in the absorption due to the dilution effect. (Fig. 7). It was found that the absorption of the polymer film at 193 nm decreases linearly with the decrease of cycloolefin monomer in the feed ratio, as shown in figure 7.

Though the absorbance of the hybrid polymer is still high, it has been reduced significantly with respect to pure COMA polymers by increasing the methacrylate components in the monomer feed. However, with even a minimum amount of cycloolefin moieties, the absorption of hybrid polymer is still significantly higher than that of methacrylate copolymers due to the presence of maleic anhydride units. Therefore, the resist prepared from this polymer system may still show low wall angles and a tendency towards top loss during exposure because of higher absorption.

2.6 Lithographic performance of hybrid type resist AZ® EXP AX™2020P

Figures 8 and 9 show the lithographic performance of a resist formulation consisting of hybrid polymer, triphenylsulfonium nonaflate PAG, and a quencher in PGMEA. The resist was processed at SB and PEB temperatures of 110 and 130°C for 90 sec and developed with 2.38 wt% aq. TMAH for 30 sec. It can lineate semi-dense and isolated L/S down to 80 nm with a DoF of about 0.5µm for 100nm CDs under conventional illumination conditions using a binary mask. The shelf-life stability of hybrid polymers containing formulations were found to be far superior to that of resists from pure COMA polymers. Figure 10 compares the real time aging preparation.

### Table 3. Synthesis and characteristics of COMA and hybrid type polymers

<table>
<thead>
<tr>
<th>Run #</th>
<th>Composition of Monomers [mole (%)]</th>
<th>Mw (GPC)</th>
<th>Dark Film Loss</th>
<th>Yield (%)</th>
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<tbody>
<tr>
<td></td>
<td>BNC</td>
<td>HNC</td>
<td>NC</td>
<td>MAdMA</td>
</tr>
<tr>
<td>1</td>
<td>85.00</td>
<td>10.00</td>
<td>5.00</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
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<td>10.00</td>
<td>5.00</td>
<td>0</td>
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<td>3</td>
<td>46.55</td>
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<td>6.65</td>
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<td>7</td>
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<tr>
<td>10</td>
<td>33.34</td>
<td>0</td>
<td>0</td>
<td>33.33</td>
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</table>
behavior of one pure COMA resist and two hybrid polymer based resists stored at 23°C and opened every two weeks. A large shift in the dark film loss was observed for the COMA based resist while the hybrid polymer based resists had no change. Forced aging study done at 40°C for 77 hours on the hybrid based resist also showed no change in film thickness, dark erosion, and photospeed.

3. Materials for 157nm applications
In the last three years, 157 nm lithography has seen an extraordinarily rapid progress in developing every technology component necessary for 157 nm device manufacturing. The greatest advances have been in the areas of exposure tools and masks, and while supply of CaF₂ is still a logistical problem for the lens manufacturers, there is no doubt that 157 nm optics can be built to the required specifications. Similar advances have been achieved in the F₂ laser and photomask substrate areas, so that many of the key components are either in place or can be assumed to be in place by the time they are needed. Two of the major areas in which invention is still required are pellicles and photoresist materials. The earlier optical technologies down to 193 nm used organic polymers for both of these applications, and it is no coincidence that it is these two that are now perceived to be among the major potential technology showstoppers. In both areas, it has proven very difficult to design organic polymers that have the requisite transparency and other properties required for the use at 157 nm.

On the photoresist side, the first exposures with 157 nm light were carried out at MIT Lincoln Laboratories in 1998 using thin DUV resists and contact exposure. Synthetic efforts aimed at synthesizing tailor-made, more highly transparent resins began in 1999 at the University of Texas at Austin under the auspices of a SEMATECH program and at DuPont in Wilmington, Delaware. Work by Kunz et al. at MIT Lincoln Laboratories had established early on that carbonyls and other unsaturated bonds are highly absorbing at 157 nm, but that high fluorine or silicon content can lead to substantial increases in transparency. This work suggested that fluorooxohols would have the required acidity to act as base-soluble groups in chemically amplification schemes, replacing the phenols and carboxylates used at longer wavelengths.

Further work on the gas phase spectra of model compounds by Willson and his group at the University of Texas at Austin indicated that simple, unfunctionalized hydrocarbons are already too absorbing to be considered as backbones for high-resolution resists without modifications. The same work showed that fluorination can substantially increase transparency, especially if the fluorine is introduced adjacent to or directly in the
ring of a norbornane structure. Another important result obtained by Willson was that carbonyl functions can be tolerated if there is a geminal trifluoromethyl substituent, e.g., the absorption of poly(methyl 2-trifluoromethyl-acrylate) is about 3 \( \mu m^{-1} \), whereas that of PMMA is of the order of 8 \( \mu m^{-1} \).

Based on this work, it is possible to write down a number of substituted norbornene structures that can be expected to combine high transparency at 157 nm with aqueous solubility and high dry etch resistance (Scheme 5). These norbornenes can then be polymerized either through metal-catalyzed addition reactions or through free radical pathways. The metal-catalyzed reactions have been described in detail by BF Goodrich,\( ^{19} \) and these polymers have been used as the basis for a 193 nm resist system developed at IBM Almaden research laboratories.\( ^{21} \)

However, one of the limitations of this approach is that 5,5-disubstituted norbornenes are essentially impossible to polymerize if the substituents impose even moderate steric demands. For example, methyl norbornene-5-methyl-5-carboxylate or methyl norbornene-5-trifluoromethyl-5-carboxylate can not be polymerized with the standard catalyst systems effective for the 5-monosubstituted derivatives. The reasons for this behavior are still somewhat unclear and may involve, among others, the exo/endo directing properties of such substituents in the Diels-Alder reactions used to make these precursors.

In the case of the free radical approach, the limitation lies in the small number of monomers that are known to copolymerize with norbornenes. Maleic anhydride, which has been used to good effect in 193 nm resists of this type, is prohibitively absorbing at 157 nm. Copolymerizations of norbornenes with tetrafluoroethylene (TFE) have been described by JSR\( ^{22} \) and were suggested by Willson for use in 157 nm resists. This approach forms the basis for a recent European patent application by DuPont.\( ^{23} \) Similar work has also been carried out at the Univ. of Clemson as part of the SEMATECH 157 nm program.\( ^{18} \)

In separate developments, Ober’s group at Cornell has reported encouraging results with a methacrylate route using a bis-hexafluoro-isopropanol-substituted cyclohexane.\( ^{24} \) Both the group at IBM Almaden\( ^{25} \) and the one at MIT Lincoln Laboratories\( ^{26} \) have taken a fresh look at the first fluoroalcohol-substituted lithographic polymers, the bis-(trifluoro-}

\[ \text{Scheme 5. Proposed norbornene structures with increased transparency at 157 nm} \]

\[ \text{Scheme 6. Alternative free radical routes to fluorinated polymers for 157 nm lithography.}^{24-27} \]

While polymers using this chemistry typically have shown absorbances of 4 \( \mu m^{-1} \) or more at 157 nm, their precursors are be easily synthesized and polymerization is readily carried out via the free radical route.

The large number of different approaches with intrinsically different absorbances at 157 nm have led to the question of just how much absorbance can be tolerated in a 157 nm single layer resist. For DNQ-type systems, an optimum film optical density of 0.4 \( \mu m^{-1} \) is usually quoted; however, these systems differ from 157 nm resists in that they are...
photobleaching and their photospeed is directly coupled to the absorbance. It is therefore necessary to take a fresh look at the impact of absorbance on resist performance for the specific case of chemically amplified resists at 157 nm.

Modeling studies\textsuperscript{16b,28} have been carried out for 157 nm resists using typical resist parameters as measured for 193 nm or 248 nm materials, with the one change that the B parameter (i.e., the unbleachable absorption component) was continuously varied. The main result of these studies has been that the resist wall angle is strongly dependent on the resist absorbance (figure 11): for a target wall angle of 85°, the absorbance has to be in the 1 to 1.5 µm\textsuperscript{-1} range, irrespective of film thickness (Figure 12). These findings show that a total film transmittance criterion is insufficient to assure the required structure quality and wall slope.

Our recent work has focused on a first 157 nm resist system based on copolymers of norbornene-5-methylenehexafluoropropanol (NMHFA) and t-butynorbornene carboxylate (BNC), formulated with an additive obtained by copolymerization of t-butyl norbornene-5-trifluoromethyl-5-carboxylate (BTNC) with carbon monoxide. The details of the preparation and chemistry of these compounds have been described elsewhere.\textsuperscript{18,29} Scheme 7 shows the structure of the NMHFA-BNC copolymer and the BTNC-carbon monoxide additive. The use of BNC as a photo-switchable group entails a certain amount of compromise in the absorbance characteristics.

For the NMHFA-BNC 80:20 copolymer, the increase in absorbance is about 20% over the NMHFA homopolymer, resulting in an absorbance of 2.3 µm\textsuperscript{-1}. At higher loadings of the C=O copolymer additive, the resist shows very high contrast (γ values in excess of 30). Imaging of the 80:20 copolymer based formulation with a strong phase shift mask at low ς opened dense features down to 90 nm (Figure 13) as well as semi-dense features down to 80 nm with clean sidewalls and good focus latitude. For isolated

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig11_results.png}
\caption{Results of Prolith simulations for 100 nm dense lines and spaces at 150 nm film thickness. Simulation parameters are the same as AZ\textsuperscript{R}AX\textsuperscript{TM} 1000P resist, except for the B value. The low wall angle leads to top loss beginning at B=7 (film thickness = 200 nm: B=5, 100 nm: no top loss).\textsuperscript{28}}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig12_resist_wall_angle.png}
\caption{Resist wall angle of 100 nm dense L&S as a function of resist absorbance for three different film thicknesses. B = A ln10.}
\end{figure}
features, a final resolution of 60 nm could be obtained, although there seems to be some positive resist bias for the finest features (i.e., the feature is wider than that on the mask).

One of the most striking features of these images is not only the relatively high final resolution that could be obtained, but the unexpectedly high wall angle that is evident in the cleaved structures of Fig. 13. Simulations shown in figures 11 & 12 indicate that a high wall angle (>85°) would require a resist absorbance about two times lower than achieved with the polymers of scheme 7. It would appear that the high wall angle achieved with the present systems is due to a non-isotropic effect not accounted for in the modeling, for example, surface contamination, a depth sensitivity of the photosensitivity through segregation of the PAG, or a similar phenomenon. This hypothesis is tentatively corroborated by the observation that exposures of these systems at 193 nm, where they are very highly transparent, frequently show a tendency towards re-entrant slopes.24

4. Conclusions
193 nm materials and resists have shown improvements in resolution, depth of focus and line-edge roughness. It may be said that methacrylate and hybrid polymer based resists are preferable to that of COMA based resists on several lithographic parameters (Table 4). Although not discussed in detail in this paper, issues such as line-edge roughness and pattern profile degradation during etch etc., needs to be improved for versatile implementation in mass production.

<table>
<thead>
<tr>
<th>Property</th>
<th>Acrylate resist</th>
<th>Hybrid resist</th>
<th>COMA resist</th>
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<tbody>
<tr>
<td>Transparency</td>
<td>excellent</td>
<td>good</td>
<td>poor</td>
</tr>
<tr>
<td>Dense L/S</td>
<td>excellent</td>
<td>poor</td>
<td>poor</td>
</tr>
<tr>
<td>Semi/ iso L/S</td>
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<td>excellent</td>
<td>excellent</td>
</tr>
<tr>
<td>Contact hole</td>
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<td>poor</td>
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<tr>
<td>Shelf stability</td>
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</tr>
<tr>
<td>Cost</td>
<td>expensive</td>
<td>affordable</td>
<td>cheap</td>
</tr>
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</table>

Fig. 13: Results with 80:20 NBMHFA-BNC copolymer and strong phase shift mask (NA=0.60, σ=0.3). 90 and 100 nm features through pitch
As for 157 nm resists, it may be said that it is still at an early stage but the rapid pace of recent improvements justifies the hope that the resist chemistry will soon no longer have to be considered a potential showstopper. It is expected that systems will soon be available that meet the basic requirements for a first generation 157 nm resist system suitable for lens testing, tool qualification and early development work.

5. Acknowledgements
The authors acknowledge C.G. Willson, his group at the University of Texas at Austin, and his collaborators in the SEMATECH 157 nm project. We would like to thank Sony Jindal, John Mullen, Marjorie Williams and Karen Dempkowski of Clariant Corporation for CD measurement and cross-section SEM work.

6. References
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