Contact Hole Resist Solutions for 45-90nm Node Design Rules

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Target contact hole (C/H) CD sizes for 45-90nm node design rules range from 70 to 130nm with defect levels of one failure per billion contacts. Achieving these C/H design rule targets is a challenging task for the lithographers and the resist chemists. The issue is lack of high resolution and DoF especially for the 65 and 45nm node targets, low depth of focus (DoF) for the isolated contacts even for the 90nm node targets (hence the loss of desired overlap process windows) and high mark error factor (MEF) for the dense contacts. Several resolution enhancement techniques (RETs) such as chromeless phase lithography (CPL), double exposure technique IDEAL and IDEAL-Smile, use of high transmission attPSM have been proposed but none of them have been proven in real production and comes with compromises. The best option and expectation is 193nm resist formulations to deliver the desired targets. While improvements in resolution and process margins are seen and more progress will come as the maturity of the 193nm resists continue, use of resist flow process (RFP) and chemical shrink processes are also being considered at least for the 65nm node and above. Undoubtedly, the resist flow process is the easiest one to implement but it is pitch dependent and therefore does not find global acceptance. Shrink processes such as Resolution Enhancement of Lithography Assisted by Chemical Shrink (RELACS™) in combination of a high performance 193nm resist offers the best promise for the 65-45nm node targets and may be extendable to beyond 45nm node design targets. This paper provides the current status and performance of advanced 193nm single layer resist and the developments in the RELACS™.

Keywords: 193nm contact resists, RELACS™

1. Introduction

Meeting the contact and via layer through pitch common process window of 0.3μm depth of focus (DoF) at 8% exposure latitude for 100nm and sub 100nm CDs is a challenge for semiconductor manufacturers, tool and resist suppliers. As the 193nm resist development matures similar to the level of 248nm, there is scope for improvement in the resolution and process latitudes. However, it is questionable, only the resists could provide the required process windows. Various RETs are being explored and are published [1-6]. Table 1 summarizes the pros and cons of various RETs. It is clear that these RETs are not going to be enough and comes with trade-offs. A most viable approach, at least as of now, is the use of single layer resist combined with shrink technologies. Several shrink techniques such as Resolution Enhancement Lithography Assisted by Chemical Shrink (RELACS™) [7], Resist Flow Process (RFP) [8], Water Soluble Organic Over-Coating Material (WASOOM) [9], Shrink Assist Film for Enhanced Resolution (SAFIER) [10], and Contact hole resolution enhancement by Post Exposure Amine
Treatment (CONPEAT) [11] are reported. Among these, the authors are aware that resist flow process and RELACS™ are production proven starting from 248nm lithography. One of the biggest disadvantages of resist flow process is its pitch dependency. Also in the 193nm resists, CD uniformity becomes very difficult to achieve. On the other hand, RELACS™ process offers good CD uniformity with no pitch dependency and its extension to 193nm lithography is widely published [10, 12-14].

<table>
<thead>
<tr>
<th>RET</th>
<th>Advantage</th>
<th>Trade offs</th>
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<tbody>
<tr>
<td>High (&gt;6 %) transmission attPSM [1] with conventional illumination</td>
<td>Improved image contrast (resolution, DoF and EL)</td>
<td>Partial coherency between dense and isolated contacts. Side lobes vs. mask CD (bias)</td>
</tr>
<tr>
<td>High NA (&gt;0.85)</td>
<td>Resolution</td>
<td>DoF through pitch</td>
</tr>
<tr>
<td>Chromeless phase lithography (CPL) [2-4]</td>
<td>Resolution enhancement in all layers</td>
<td>Mask making, phase defect inspection and strong proximity effects.</td>
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<tr>
<td>IDEAL and IDEAL-Smile[5-6]</td>
<td>100nm CD demonstrated using 248nm</td>
<td>No reports yet using 193nm resists.</td>
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2. Performance of single layer 193nm contact resists

2.1 Chemistry of 193nm resists:

Several polymer platforms such as pure cyclo-olefins (CO) [15-16], Cyclo-olefin/Maleic anhydride (COMA)[17-18], ring opened maleic anhydride and norbornene copolymers (ROMA)[19], COMA/acylate hybrid [20] and acrylates [21-22] have been reported.

Acrylates are becoming one of the dominant platforms for both line and space and contact hole applications. The first generation polymers and the resists consisted of simple 1:1 copolymer of 2-methyl-2-adamantane methacrylate (2-MAdMA) and a lactone type monomer such as mevalonic lactone methacrylate (MLMA) or γ-butyrolactone methacrylate (GBLMA) (Fig. 2). MAdMA provides the etch resistance as well as acid sensitive cleaving group, lactone monomers balance the hydrophilic nature of the polymer and help dissolve the polymer in safe resist solvents.

Second and third generation polymers are mostly terpolymers or even tetrapolymers consisting of three or more different monomers (Fig. 3). The additional monomers provide improvement in terms of resolution and DoF as well as surface roughness. Polymer blending is also an option to improve the performance.
Etch stability equal to 248nm resists is expected but also depends on the etch process and substrates (hard mask etc.). The thickness needs are very dependent on the substrates (hard mask, bilayer) and etch process but for 90 nm node it is 350-240 nm, for 65 nm nodes it ranges from 280-200 nm.

2.3 Performance of AZ® EXP T8373 Resist for 90 nm node:

AZ® EXP T8373 is an optimized acrylate polymer based advanced formulation targeted for 90nm node applications with potential for 65nm depending on the target CDs. The resist was processed on silicon wafer coated with 39nm AZ ArF 1C5D using Nikon 306C exposure tool at 0.75 NA, 0.7 sigma, 6% attenuated and conventional illumination. The resist film thickness was 300nm. Soft bake of 115°C for 60 seconds and a PEB of 110°C for 60sec were used. The film was developed for 60 seconds using surfactant solution. Figure 4 shows the common process window for 120 nm CDs. While the dense contacts (mask bias 40nm) have more than 0.3μm DoF (mask bias 40nm), the isolated contacts (mask bias 45nm) limit the DoF to 0.3μm at 48.5 mL/cm². The resist has an average MEEF value of 3.0 calculated through pitch. Use of 2/3 annular illumination increases the dense DoF to 0.45μm but isolated contact DoF remains around 0.3μm. Cross section SEMs of dense features are shown in figure 5. The resist has smooth profiles. The side lobe margin was found to be >1.7 times the dose to print showing good surface inhibition properties.
2.4 Performance of AZ® EXP T8373 Resist for 65nm node:

Figure 6 shows the performance of T8373 for 100 nm targets, exposed using Nikon 306C, 0.78 NA, conventional illumination and high sigma of 0.9. The high sigma was used to get required dense performance. The dense contacts have a DoF of 0.3μm (10nm mask bias) at 39mJ/cm². As expected the isolated contact hole DoF (35nm bias) was found to be only 0.2μm at 39mJ/cm². Thus the resist meets the needs of 90nm node but isolated contact DoF is insufficient for 65nm node applications. Further optimization of resist is on-going to improve the resist performance for 65nm and 45nm node targets. However, it may be difficult to meet these targets using single layer 193nm resists and alternative techniques such as thermal flow and shrink techniques are very much considered.

3. Resolution Enhancement Lithography Assisted by Chemical Shrink (RELACS™)

3.1 RELACS™ Process:

In the 1990’s Mitsubishi Electric Co., and Clariant developed the RELACS process and materials applicable for 248nm lithography [7, 23]. AZ® R200 and AZ® R500 are commercial materials applicable for 248nm lithography [13]. AZ® R200 for example is made from water soluble polymer and a crosslinker [23]. The process has three steps, schematically represented in figure 7.
A resist patterned wafer is spin coated with RELACSTM material. The RELACSTM film thickness is 300-350nm. It is then baked (mix bake) at optimized temperature. Acid present on the resist after develop diffuses in to the RELACSTM film and a water insoluble crosslinked layer is formed on the resist surface. The crosslink reaction is controlled by the mix bake temperature (acid diffusion) and can thus the shrink can be controlled. The non cross-linked portion of the RELACSTM material is simply removed using DI water as a developer. In 248nm RELACSTM process, the extent of shrink depends on the type of resist (acetal or ESCAP), type of PAG or the acid generated, quenchers used in the 248nm formulations [23].

3.2 Application of RELACSTM Process to 193nm lithography:

As described in the previous sections, single layer 193nm resists have resolution and over lap DoF issues. At first RELACSTM materials developed for 248nm applications, AZ® R200 and AZ® 500 were tried on 193nm resist materials such AZ® AX™ 1020P an acrylate type resist. No shrink was observed even though AZ® R200 can shrink as high as 110nm when applied on a 248nm resist [14]. Since the cross-linking reaction needs acid to diffuse into AZ® R200 film, it is believed that the acid levels and the diffusion of acid in to AZ® R200 film from 193nm resist is not enough to enable the cross-link reaction to occur. It is therefore essential to develop a new formulation applicable to 193nm formulations.

3.3 Chemical concept of new 193nm RELACSTM materials:

A new series of RELACSTM materials R60x that shows good shrink capability with 193nm resists were developed. The formulation consists of water soluble polymer possessing hydrophilic as well as hydrophobic units (Fig. 8), thermal acid generator and a crosslinker. Acid generated during mix bake step opens the pyrrolidone moieties to generate carboxylic acid crosslink sites. Unlike 248nm RELACSTM materials which uses diffused acid from the resist for cross-linking, the new 193nm RELACSTM formulations are self crosslinkable. They also intermix with 193nm resists and the level of intermix depends on the type and polymer composition of the polymers used in 193nm resists. Hence the level of shrink depends on the chemistry of 193nm resists. Type and diffusion characteristics of thermal acid generators (TAG) influence the shrink [12]. In addition Terai et al. [14] describe use of cross-linker enhance to
get reasonable shrink with 193nm resist materials.

3.4 Shrink capability of 193nm RELACS™ AZ® R602-S3A:

A RELACS™ formulation R602-S3A has been developed for 193nm resist applications. The mix bake dependency and shrink capability of optimized formulation AZ® EXP R602-S3A on T8373 contact resist (resist film thickness 250 nm) is shown in figures 9 and 10, respectively. Shrink increases from 20 nm at 140°C/70 seconds to 30nm at 180°C/70 seconds. T8373 does not show any thermal degradation (as tested on thermo gravimetric analyzer and differential scanning calorimetry) up to 170°C. Hence 160°C mix bake temperature is recommended for this resist and RELACS™ combination. Increase of mix bake time did not influence the shrink at these temperatures. Figure 9 also indicates the shrink of dense (140nm CD, 240nm pitch) and isolated (140nm CD, 720nm pitch) contacts. Unlike thermal shrink, RELACS™ process shrink does not depend on the pitch and is considered as one of the big advantages among the shrink processes reported. In addition, the process also eliminates the surface roughness of the profiles. It is however important to point out that the amount of shrink depends on the resist polymer chemistry as the 193nm RELACS™ formulations intermix with the resist at the surface. This is a major difference compared to 248nm RELACS™ formulations.

Fig. 9. Mix bake temperature (@ 70 sec) dependency of AZ® EXP R602-S3A with EXP T8373 contact resist.
3.5 193nm RELACSTM with greater than 25nm shrink:

R602-S3A could be used to shrink up to 20-25nm. Further shrink is possible if > 160°C is used but thermal degradation of the resist above 160°C becomes a concern. High shrink RELACSTM formulations are necessary to shrink 100nm CDs to 70nm or less than 70nm CDs. Modification of existing and development of new RELACSTM materials are in progress. Figure 12 shows the performance of a modified version of R602-S3A with 35nm shrink capability at 160°C/90 seconds (130nm CD 260nm pitch shrunk to 95nm CD 260nm pitch).

4. Conclusions

Progress in the 193nm contact resists and RELACSTM materials are presented. While the 90-65nm node CD targets could be lineated with single layer contact resists, 45nm node CD targets would require either RET’s or shrink process. AZ® EXP T8373 contact resist offer good resolution capability down to 100nm. RELACSTM R602-S3A provides 25nm shrink capability in combination with AZ® EXP T8373. Thus 140nm CDs could be shrunk down to 115nm leading to big process window gains. Use of high resolution resist AZ® EXP T8837 in combination with either R602-S3A or modified versions with better shrink would make it possible to achieve CDs less than 100nm with good process margins.
Fig. 12. Pre and Post RELACSTM CD & X-SEM contacts of AZ® EXP T8373 and a high shrinkage modified version of AZ® EXP R602-S3A.

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References