Positive E-Beam Resists AR-P 6200 (CSAR 62)

AR-P 6200 e-beam resists with highest resolution
High-contrast e-beam resists for the production of integrated circuits and masks

Characterisation
- e-beam: layer thickness 0.05-1.6 µm (6000-1000 rpm)
- high sensitivity which can be adjusted via the developer
- highest resolution (< 10 nm) and very high contrast
- highly process-stable, high plasma etching resistance
- easy fabrication of lift-off structures
- poly(α-methyl styrene-co-α-chloroacrylate methyl ester) and an enhancer of sensitivity
- safer solvent anisole

Properties I

<table>
<thead>
<tr>
<th>Parameter / AR-P 6200</th>
<th>.18</th>
<th>.13</th>
<th>.09</th>
<th>.04</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solids content (%)</td>
<td>18</td>
<td>13</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>Viscosity 25 °C (mPas)</td>
<td>29</td>
<td>11</td>
<td>6</td>
<td>2</td>
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<tr>
<td>Film thickness/4000 rpm (µm)</td>
<td>0.80</td>
<td>0.40</td>
<td>0.20</td>
<td>0.08</td>
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<tr>
<td>Resolution best value (nm)</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Flash point (°C)</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Storage 6 month (°C)</td>
<td>8 - 12</td>
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</table>

Spin curve

Structure resolution

Resist structures

Properties II

<table>
<thead>
<tr>
<th>Glass trans. temperature (°C)</th>
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</thead>
<tbody>
<tr>
<td>Dielectric constant</td>
<td>2.8</td>
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<tr>
<td>Cauchy coefficients</td>
<td>N0</td>
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<tr>
<td></td>
<td>N1</td>
</tr>
<tr>
<td></td>
<td>N2</td>
</tr>
<tr>
<td>Plasma etching rates (nm/min)</td>
<td>Ar-sputtering</td>
</tr>
<tr>
<td>(5 Pa, 240-250 V Bas)</td>
<td>O2</td>
</tr>
<tr>
<td></td>
<td>CF4</td>
</tr>
<tr>
<td></td>
<td>80 CF4 + 16 O2</td>
</tr>
</tbody>
</table>

Process parameters

Substrate | Si 4” wafer |
Tempering | 150 °C, 60 s, hot plate |
Exposure  | Raith Pioneer, 30 kV |
Development| AR 600-546, 60 s, 22 °C |

Process chemicals

Adhesion promoter | AR 300-80 |
Developer         | AR 600-546, 600-549 |
Thinner           | AR 600-02  |
Stopper           | AR 600-60  |
Remover           | AR 600-71, 300-76 |

Process conditions

This diagram shows exemplary process steps for AR-P 6200 resists. All specifications are guideline values which have to be adapted to own specific conditions. For further information on processing, see “Detailed instructions for optimum processing of e-beam resists”. For recommendations on waste water treatment and general safety instructions, see “General product information on Allresist e-beam resists”.

Coating

AR-P 6200.09
4000 rpm, 60 s
0.2 µm

Tempering (+- 1 °C)

150 °C, 1 min hot plate or
150 °C, 30 min convection oven

E-beam exposure

Raith Pioneer, 30 kV
Exposure dose (E0): 65 µC/cm²

Development (21-23 °C ± 0,5 °C) puddle

AR 600-546
1 min
AR 600-60, 30 s / DI-H2O, 30 s

Stopping / Rinse

AR 600-60, 30 s / DI-H2O, 30 s

Post-bake (optional)

130 °C, 1 min hot plate or 130 °C, 25 min convection oven for slightly enhanced plasma etching resistance

Customer-specific technologies

Generation of semiconductor properties

Removal

AR 600-71 or O2 plasma ashing

Plasma etching resistance

CSAR 62 is characterized by a high plasma etching resistance. In this diagram, plasma etching rates of AR-P 6200.09 are compared with those of AR-P 3740 (photoresist), AR-P 679.04 (PMMA resist) and ZEP 520A in CF4 + O2 plasma.
E-beam exposure: The required e-beam exposure dose for structural imaging mainly depends on the desired minimum structure size, the developer, the acceleration voltage (1 - 100 kV), and the film thickness. The exposure dose for AR-P 6200.09 was in this experiment (Φ diagram comparison of CSAR 62 and PMMA) 55 µC/cm² (dose to clear D 0, 30 kV, 170 nm layer, developer AR 600-546, si wafer). The contrast was determined here to 14.2.

CSAR 62 is thus 3x more sensitive as compared to the standard PMMA resist AR-P 679.03 (developed in AR 600-56), or 6x more sensitive if developed in AR 600-60. Also the contrast is higher by a factor of 2 and 1.4, respectively.

An additional increase in sensitivity due to addition of sensitivity-enhancing components occurs already during exposure. A post-exposure bake is thus not required.

For the fabrication of 10-nm trenches (174 nm film, 100 nm pitch), AR 6200.09 requires a dose of approx. 220 pC/cm² (30 kV, developer AR 600-546).

Development: For the development of exposed resist films, developers AR 600-546, 600-548 and 600-549 are recommended. As weaker developer, AR 600-546 provides a wider process window. If the stronger developer AR 600-548 is used, the sensitivity can be increased 6-fold to < 10 µC/cm². The intermediate developer AR 600-549 renders the CSAR 62 twice as sensitive as compared to AR 600-546, it shows also no dark erosion and has a contrast of 4.

For immersion development, generally development times of 30 - 60 seconds are recommended. If developer AR 600-546 is used, even after 10 minutes at room temperature no erosion of unexposed areas is detected.

Developing AR 600-548 in contrast attacks resist surfaces already after two minutes visibly. If however the development process is carried out at temperatures of approx. 0 °C, even after 5 minutes (which is however associated with a reduction of sensitivity).

The development procedure should be stopped quickly. For this purpose, the substrate is moved for 30 seconds in stopper AR 600-60. Optionally, the substrate may then after be rinsed for 30 seconds with DI water to remove all residual solvent.

Note: Please take into account that rigid rinsing procedures may lead to a collapse of smaller structures (Φ see image below).

A post-bake for special working steps at max. 130 °C results in a slightly improved etching stability during wet-chemical and plasma-chemical processes.
As of January 2016

to all customers in the near future.

Currently test coatings of mask blanks with CSAR 62 are conducted, and samples will be offered by our partners.

To date, 100 nm lines and above are used on masks.

The working group “Quantum Detection” at the Aarhus University Denmark which has already for many years successfully promoted electron beam projects for nanostructuring emphasised in particular the high process stability of CSAR 62 in comparison with ZEP 520A.

CSAR 62 is able to balance out small process fluctuations and still reliably provides the desired high resolution. The „resolution reserve“ of CSAR 62 however allows for significantly improved structure accuracy and faster design with less iteration.

The goal in the lift-off of metal structures is however not to always go beyond the limits of resolution. Typical applications for example in the contacting of nanowires require dimensions in a range of 30-50 nm, which can also be realised with other resists. The „resolution reserve“ of CSAR 62 however allows for significantly improved structure accuracy and faster design with less iteration.

Application examples for CSAR 62

Circuits for the 5 GHz range which are primarily needed for wireless Bluetooth or Wi-Fi technologies can in future be produced with CSAR 62. E-beam lithography is also required for the research on nanomaterials like graphene, for three-dimensional integrated circuits as well as for optical and quantum computers. The computing power or memory density is constantly increased in each of these technologies. Applications with the highest demands on computing power (supercomputers), e.g. in computational fluid dynamics or in space applications, thus also demand microchips with highest integration density.

CSAR 62 on mask blanks

Experts at the HHI Berlin have already tested CSAR 62 on mask blanks (Fig. 1). They immediately achieved a resolution of 50 nm which is an excellent value for masks. To date, 100 nm lines and above are used on masks. Currently test coatings of mask blanks with CSAR 62 are conducted, and samples will be offered by our partners to all customers in the near future.

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Innovation
Creativity
Customer-specific solutions

Positive E-Beam Resists AR-P 6200 (CSAR 62)

A similar objective was pursued by this working group with respect to the fabrication of square structures. The aim was again to obtain corners with particularly high resolution. For this purpose a CSAR 62 film with a thickness of 100 nm was irradiated with 50 kV and developed with developer AR 600-546. In addition to the excellent properties of CSAR 62, also the irradiation design is of vital importance (see Fig. 13, centre: A; right: B).

High-precision lift-off structures with the two-layer system CSAR 62/AR-P 617

The task in the IAP of the Friedrich Schiller University of Jena was to produce very small, high-precision rectangular structures. For this purpose, a two-layer system composed of AR-P 6200.09 as top layer and AR-P 617.06 as bottom layer was established. After exposure with e-beam writer Vistec SB 3500S, CSAR 62 was patterned with developer AR 600-546. The bottom layer was subsequently developed with developer AR 600-55, followed by coating with gold. The lift-off was performed with a mixture of acetone and isopropanol. The resulting structures are shown in Fig. 12. The structure sizes are 38 nm with structure intervals of approximately 40 nm. In particular to be regarded positively are the small radii of curvature at the corner of the inside of the “L”.

Fig. 11 Sensitivity ZEP 520 A, 200 nm, ZED-N50 as well as AR-P 6200.09, 200 nm, AR 600-546 and 600-549

3. Sensitivity (dose to clear): The diagram (Fig. 11) demonstrates a good range for the required dose for both resists. Again however, the CSAR resist-developer systems (with AR 600-549 12 % and AR 600-548 51 %) are more sensitive than the ZEP resist-developer system. All three studies come to the conclusion that CSAR 62 can very well compete with ZEP 520 and partly has even more favourable application parameters which also result from the variety of suitable developers.

Fig. 12 High-precision L-shaped structures, produced with the two-layer system AR-P 6200.09/AR-P 617.06; right 2 Layer systems

CSAR 62 – High-precision square structures

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Fig. 13 Different irradiation designs and resulting square structures (centre: A; right: B)

CSAR 62 – Development at lower temperatures

The sensitivity of CSAR 62 is strongly influenced by the choice of the developer. In comparison to the standard developer AR 600-546, the sensitivity can almost be increased tenfold if AR600-548 is used which is however accompanied by an incipient erosion of unexposed resist areas. This is tolerable to a certain extent: If, for example, always 10 % of the layer is lost, can this effect be compensated for in advance. Erosion can also be avoided if the development is carried out at lower temperatures, but this is again associated with a certain loss of the previously gained sensitivity. It thus comes down to the fact that an optimisation of the process is required. The lower temperatures offer, due to the more gentle development step, the possibility to increase the contrast or reduce the edge roughness.

Fig. 14-16 show the sensitivities and resolutions of AR-P 6200.04 at 6 °C and 21 °C (room temperature). Due to the high contrast at 6 °C, a resolution of 6 nm could be achieved. The doses used (e.g. #1 = 45 µC/cm²) are listed in the table in Fig. 17.

Fig. 14 CSAR 62 structures at 6 °C, opt. dose 195 pC/cm

Fig. 15 CSAR 62 structures at 21 °C, opt. dose 121 pC/cm

Fig. 16 Max. resolution of 6 nm at 235 pC/cm and 6 °C

Number to Dose Conversion

<table>
<thead>
<tr>
<th>Number</th>
<th>Dose (µC/cm²)</th>
<th>Dose (pC/cm)</th>
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<tr>
<td>1</td>
<td>45.0</td>
<td>100.0</td>
</tr>
<tr>
<td>2</td>
<td>40.5</td>
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<td>12</td>
<td>4.4</td>
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</table>

Fig. 17 Dose values for Fig. 14-15

Application examples for CSAR 62