ANTI-REFLECTIVE COATINGS

The thickness of thin photoresist films and their homogeneity lies in the order of magnitude of the exposure wavelength. Because photoresists are usually exposed at discrete wavelengths or monochromatically, interference effects between the incident light and light reflected on the resist surface or substrate lead to an inhomogeneous distribution of the light intensity in the incidence direction.

This chapter describes the physical basis of this effect, explains under what circumstances its impact can be especially disruptive to the developed resist image, and what countermeasures are possible.

Reflection on the Resist Surface and Top-layer Anti Reflection Coatings

Theory

With the exposure of the photoresist, the incident light ($I_0$ in Fig. 77) is partially reflected both on the air/photoresist as well as at the photoresist/substrate interface. For vertically incident light, the difference in the distance of both beams is the doubled resist film thickness. If this path difference of the two reflected beams $I_{R1}$ and $I_{R2}$ is an integer multiple of the exposure wavelength in the photoresist film, the interference is constructive and thus reflected overall intensity maximal. With a change the path difference by only a half wavelength, this destructive interference is a minimisation of the total reflectivity.

This effect is more pronounced, the greater the intensities $I_{R1}$ and $I_{R2}$ relative to the intensity $I_0$ of the incident light, and the less the intensities $I_{R1}$ and $I_{R2}$ differ, which depends on the optical thickness of the resist film and the reflectivity of the substrate among other things.

Effect in Practice

With an i-line exposure (365 nm wavelength), the half wavelength in a photoresist with a typical refractive index 1.6 is approx. 114 nm. A similar path difference between $I_{R1}$ and $I_{R2}$ is thus already attained by changing the resist film thickness by just 57 nm. A corresponding inhomogeneity in the thickness of the resist film over the wafer surface or between two wafers changes via this interfering effect, the exposure dose effectively received by the resist film at the respective location.

This relationship between resist film thickness and the light absorbed by the resist film is transferred into the development rate or the light dose necessary for a rapid development of the resist film, as shown by the so-called swing curve (Fig. 78): A hardly avoidable variation of the (local) resist film thickness of a few 10 nm has the effect of a necessary light dose fluctuating by several 10% or correspondingly different development rates, which can make the reproducibility of critical lithography processes difficult.

With a broadband exposure (e.g. h- and i-lines together), this effect occurs much less pronounced in contrast to monochromatic exposure because several swing curves with their respectively different periods overlap and smoothen in total.

Corrective Action

Applying an anti-reflective coating to the photoresist film (Top layer Anti-Reflective Coating TARC) reduces the reflection $I_{R0}$ of the incident light at the air/photoresist interface analogue to the optical coating of a lens. Thus, the beam $I_{R2}$ can, in fact, continue to interfere with $I_{R1}$ constructively or destructively, due to the low intensity $I_{R0}$ but only with more greatly reduced amplitude where the differences between the minima and maxima of the swing curve are also compared.

AZ® Aquatar is an optimised TARC for AZ® and TI resists. This coating is simply applied in a spin coater onto the already coated and softbaked resist film, dried, and after the exposure, au-

![Fig. 77: The partial beams $I_0$, $I_{R1}$, and $I_{R2}$ reflected at the interfaces of air/photoresist and photoresist/substrate can interfere all the more strongly with each other, the more equal their intensities are (left). Right: Through an anti-reflective coating (TARC, shown in blue) on the resist surface, $I_{R0}$, and thus the interference effect between $I_{R1}$ and $I_{R2}$ is minimised.](image-url)
Reflection on the Substrate and Bottom Layer Anti-reflective Coatings

Theory

During the exposure of a resist film (Fig. 79), the light beam $I_T$ penetrating into the resist film and running in the direction of the substrate interferes with the beam $I_R$, which is reflected from the substrate and directed back towards the resist surface. For each wavelength, a variation of the light intensity periodically fluctuates perpendicularly to the substrate, parallel to the incident direction of the light. The period of this energy distribution is half the wavelength of the light in the photoresist medium; for an i-line (365 nm) exposure in a photoresist with a typical refractive index of 1.6, is approx. 114 nm.

The resulting interference pattern is all the more pronounced, the more equal the intensities of the beam $I_T$ running to the substrate and the beam $I_R$ reflected from it, are. This condition $I_T = I_R$ is all the better satisfied the stronger the substrate reflects and the less the resist film absorbs.

With an optically thinner resist film, this $\sin^2$ modulation of the resist film thickness would be even more pronounced since the condition $I_T = I_R$ applies with missing absorption in the resist regardless of the distance to the resist surface.
Effect in Practice

The intensity distribution in the resist film during exposure, which is caused by the interference of the light beams travelling to the substrate and reflected from there, translates into the development rate attained with various consequences.

On the one hand, the developed resist sidewalls show ripples running parallel to the substrate surface, which represent the period of the \( \sin^2 \) distribution of the light intensity (Fig. 81).

On the other hand, the development rate changes in the depth periodically and can reach the value zero in the extreme case (100% reflection on the substrate) in the vicinity of the substrate seam as it passes through the minima of the \( \sin^2 \) distribution of the received light intensity.

While in the case of a broadband exposure, the different periods of the \( \sin^2 \) patterns of the g-, h- and i-lines become superimposed in a relatively homogeneous pattern, the effects described here become increasingly apparent during monochromatic exposure.

Corrective Action

An anti-reflective coating between the substrate and the resist film (Bottom layer Anti-Reflective Coating, BARC) minimises the intensity of the light reflected from the substrate and thus the amplitude of the interference-related \( \sin^2 \) light intensity distribution.

AZ® Barli II is an optimised BARC for monochromatic i-line exposed AZ® and TI resists. This anti-reflective coating is spun onto the substrate before resist coating and baked at 200°C to ensure sufficient stability against the solvent of the photoresist applied afterwards. This cross-links AZ® Barli thermally and thus can be removed from the freely developed places as well as after resist stripping only by dry etching.

As the REM images in Fig. 81 show, when the AZ® Barli is used correctly, the standing \( \sin^2 \) waves in the resist profile as well as exposure artefacts and the unintentionally freely developed hole in the resist structure are reduced by reflections on textured substrates.
Fig. 81: The use of an anti-reflective coating on the substrate reduces on the one hand interference-related artefacts such as the periodic groove structures on the resist sidewalls as well as an unwanted exposure and subsequent development of nominally unexposed areas by reflections on substrate textures. Source: AZ® Barli Product Data Sheet by the manufacturer.
Our Photoresists: Application Areas and Compatibilities

Recommended Applications

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<td>AZ® 1500</td>
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<td>= 0.5 µm</td>
<td>AZ® 351B, AZ® 326 MIF, AZ® 726 MIF, AZ® 826 MIF</td>
<td>AZ® 100 Remover, TechniStrip® P1316, TechniStrip® P1331</td>
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<td>AZ® 4000</td>
<td>AZ® 4533, AZ® 4562</td>
<td>= 2 - 5 µm</td>
<td>AZ® 400K, AZ® 326 MIF, AZ® 726 MIF, AZ® 826 MIF</td>
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<tr>
<td>AZ® 4999</td>
<td>AZ® PL 177, AZ® PL 177</td>
<td>= 5 - 8 µm</td>
<td>AZ® 351B, AZ® 400K, AZ® 326 MIF, AZ® 726 MIF, AZ® 826 MIF</td>
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<tr>
<td>Dip coating</td>
<td>MC Dip Coating Resist</td>
<td>= 2 - 15 µm</td>
<td>AZ® 351B, AZ® 400K, AZ® 326 MIF, AZ® 726 MIF, AZ® 826 MIF</td>
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<td>Spray coating</td>
<td>AZ® ECI 3000, AZ® ECI 3012, AZ® ECI 3027, AZ® 9200, AZ® 9245</td>
<td>= 0.7 - 4 µm</td>
<td>AZ® 351B, AZ® 326 MIF, AZ® 726 MIF, AZ® 826 MIF, AZ® 9200, AZ® 9245</td>
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</tr>
<tr>
<td>AZ® 701 MR</td>
<td>AZ® 701 MR (40 cPs), AZ® 701 MR (29 cPs)</td>
<td>= 0.8 - 2.3 µm</td>
<td>AZ® 400K, AZ® 326 MIF, AZ® 726 MIF</td>
<td>AZ® 100 Remover, TechniStrip® P1316, TechniStrip® P1331</td>
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<tr>
<td>AZ® XT</td>
<td>AZ® 12 XT-20PL-05, AZ® 12 XT-20PL-10, AZ® 12 XT-20PL-20, AZ® 40 XT</td>
<td>= 3 - 5 µm</td>
<td>AZ® 400K, AZ® 326 MIF, AZ® 726 MIF</td>
<td>AZ® 100 Remover, TechniStrip® P1316, TechniStrip® P1331</td>
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<td>= 20 - 100 µm</td>
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Inorganic Developers

AZ® Developer is based on sodium phosphate and –metasilicate, is optimized for minimal aluminum attack and is typically used diluted 1 : 1 in DI water for high contrast or undiluted for high development rates. The dark erosion of this developer is slightly higher compared to other developers.

AZ® 351B is based on buffered NaOH and typically used diluted 1 : 4 with water, for thick resists up to 1 : 3 if a lower contrast can be tolerated.

AZ® 400K is based on buffered KOH and typically used diluted 1 : 4 with water, for thick resists up to 1 : 3 if a lower contrast can be tolerated.

AZ® 303 specifically for the AZ® 111 XFS photoresist based on KOH / NaOH is typically diluted 1 : 3 - 1 : 7 with water, depending on whether a high development rate, or a high contrast is required.

Metal Ion Free (TMAH-based) Developers

AZ® 326 MIF is 2.38 % TMAH- (TetraMethylAmmoniumHydroxide) in water.
**Our Removers: Application Areas and Compatibilities**

**AZ® 100 Remover** is an amine solvent mixture and standard remover for AZ® and Ti photoresists. To improve its performance, AZ® 100 remover can be heated to 60 - 80°C. Because the AZ® 100 Remover reacts highly alkaline with water, it is suitable for this with respect to sensitive substrate materials such as Cu, Al or ITO only if contamination with water can be ruled out.

TechniStrip® P1316 is a remover with very strong stripping power for Novolak-based positive resists (including all AZ® positive resists), epoxy-based coatings, polyimides and dry films. At typical application temperatures around 75°C, TechniStrip® P1316 may dissolve cross-linked resists without residue also, e.g. through dry etching or ion implantation. TechniStrip® P1316 can also be used in spraying processes. For alkaline sensitive materials, TechniStrip® P1313 would be an alternative to the P1316. Nicht kompatibel mit Au oder GaAs.

TechniStrip® P1331 can be an alternative for TechniStrip® P1316 in case of alkaline sensitive materials. TechniStrip® P1331 is not compatible with Au or GaAs.

TechniStrip® N555 is a stripper with very strong dissolving power for Novolak-based negative resists such as the AZ® 15 nXT and AZ® nLOF 2000 series and very thick positive resists such as the AZ® 40 XT. TechniStrip® N555 was developed not only to peel cross-linked resists, but also to dissolve them without residues. This prevents contamination of the basin and filter by resist particles and skins, as can occur with standard strippers. TechniStrip® N555 is not compatible with GaAs.

TechniClean™ CA25 is a semi-aqueous proprietary blend formulated to address post etch residue (PER) removal for all interconnect and technology nodes. Extremely efficient at quickly and selectively removing organo-metal oxides from Al, Cu, Ti, TiN, W and Ni.

TechniStrip™ NFS2 is a highly effective remover for negative resists (liquid resists as well as dry films). The intrinsic nature of the additives and solvent make the blend totally compatible with metals used throughout the BEOL interconnects to WLP bumping applications.

TechniStrip™ Micro D2 is a versatile stripper dedicated to address resin lift-off and dissolution on negative and positive tone resist. The organic mixture blend has the particularity to offer high metal and material compatibility allowing to be used on all stacks and particularly on fragile III/V substrates for instance.

TechniStrip™ MLO 07 is a highly efficient positive and negative tone photosistoer remover used for IR, III/V, MEMS, Photonics, TSV mask, solder bumping and hard disk stripping applications. Developed to address high dissolution performance and high material compatibility on Cu, Al, Sn/Ag, Alumina and common organic substrates.

**Our Wafers and their Specifications**

**Silicon-, Quartz-, Fused Silica and Glass Wafers**

Silicon wafers are either produced via the Czochralski- (CZ-) or Float zone- (FZ-) method. The more expensive FZ wafers are primarily reasonable if very high-ohmic wafers (> 100 Ohm cm) are required.

Quartz wafers are made of monocrystalline SiO$_2$, main criterion is the crystal orientation (e. g. X-, Y-, Z-, AT- or ST-cut)

Fused silica wafers consist of amorphous SiO$_2$. The so-called JGS2 wafers have a high transmission in the range of $\approx 280 - 2000$ nm wavelength, the more expensive JGS1 wafers at $\approx 220 - 1100$ nm.

Our glass wafers, if not otherwise specified, are made of borosilicate glass.

**Specifications**

Common parameters for all wafers are diameter, thickness and surface (1- or 2-side polished). Fused silica wafers are made either of JGS1 or JGS2 material, for quartz wafers the crystal orientation needs to be defined. For silicon wafers, beside the crystal orientation ($<100>$ or $<111>$) the doping (n- or p-type) as well as the resistivity (Ohm cm) are selection criteria.

**Prime-, Test-, and Dummy Wafers**

Silicon wafers usually come as „Prime-grade“ or „Test-grade“, latter mainly have a slightly broader particle specification. „Dummy-Wafers“ neither fulfill Prime- nor Test-grade for different possible reasons (e. g. very broad or missing specification of one or several parameters, reclaim wafers, no particle specification) but might be a cheap alternative for e. g. resist coating tests or equipment start-up.

**Our Silicon-, Quartz-, Fused Silica and Glass Wafers**

Our frequently updated wafer stock list can be found here: Ø www.microchemicals.com/products/wafers/waferlist.html

**Further Products from our Portfolio**

**Plating**

Plating solutions for e. g. gold, copper, nickel, tin or palladium: Ø www.microchemicals.com/products/electroplating.html

**Solvents (MOS, VLSI, ULSI)**

Acetone, isopropyl alcohol, MEK, DMSO, cyclopentanone, butylacetate, ... Ø www.microchemicals.com/products/solvents.html

**Acids and Bases (MOS, VLSI, ULSI)**

Hydrochloric acid, sulphuric acid, nitric acid, KOH, TMAH, ... Ø www.microchemicals.com/products/etchants.html

**Etching Mixtures**

for e. g. chromium, gold, silicon, copper, titanium, ... Ø www.microchemicals.com/products/etching_mixtures.html
Further Information


Our Photolithography Book and -Posters

We see it as our main task to make you understand all aspects of microstructuring in an application-oriented way. At present, we have implemented this claim with our book Photolithography on over 200 pages, as well as attractively designed DIN A0 posters for your office or laboratory. We will gladly send both of these to you free of charge as our customer (if applicable, we charge shipping costs for non-European deliveries):

www.microchemicals.com/downloads/brochures.html
www.microchemicals.com/downloads/posters.html

Thank you for your interest!

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