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 incidental 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_{R1} 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_{R1} 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-

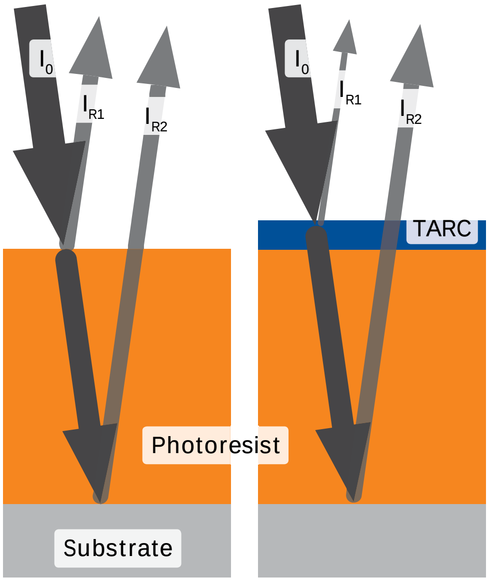


Fig. 77: The partial beams I_{R1} and I_{R2} reflected at the interfaces of air/photoresist and photoresist/substrate can interfere all the more stronger with each other, the more equal their intensities are (left). Right: Through an anti-reflective coating (TARC, shown in blue) on the resist surface, I_{R1} and thus the interference effect between I_{R1} and I_{R2} is minimised.

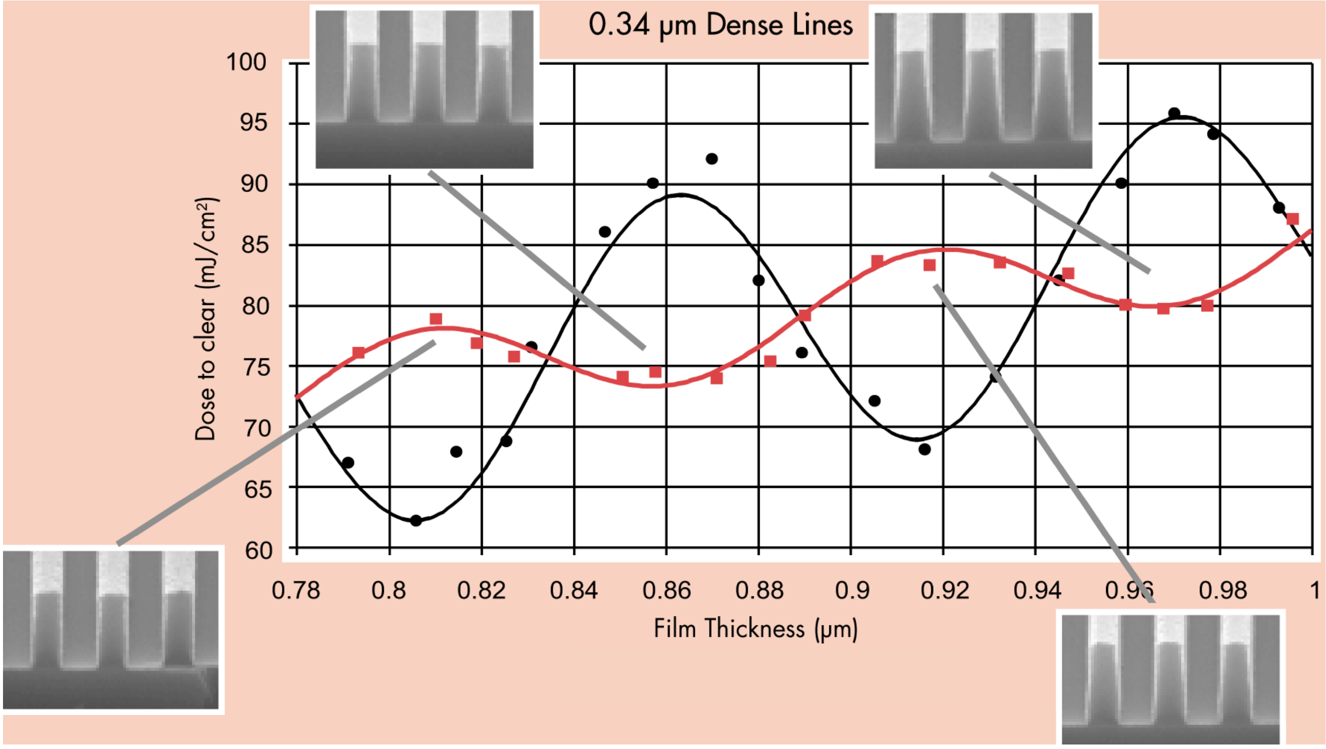


Fig. 78: The so-called swing curve represents the measured (points) and theoretical (lines) relationship between the resist film thickness and the light dose required for a development without (black) and with (red) an anti-reflective coating on the resist film. At the maxima of the graphs, the resist film thickness causes a maximum constructive interference of the light reflected at the air/photoresist and photoresist/substrate interface and the minima have a destructive interference. The anti-reflective coating minimises this interference effect thus smoothing the curve. Source: AZ® Aquatar Product Data Sheet by the manufacturer

tomatically removed through its water solubility during development.

Despite the ease of use of this TARC, it should be weighed for each lithography process and if necessary, evaluated via a comparative experiment as to whether the use of a TARC is actually necessary and will bring about the desired improvement.

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.

Fig. 80 shows this relationship on the basis of a numerical modelling for a resist film with a thickness comparable to depth of penetration of the exposure wavelength. While the intensity distribution at a substrate reflectivity of 0% is defined exclusively by the diffraction pattern at the “single slit” of the photo mask, the $\sin^2$ distribution along the direction of the exposure wavelength dominates with increasing substrate reflectivity.

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.

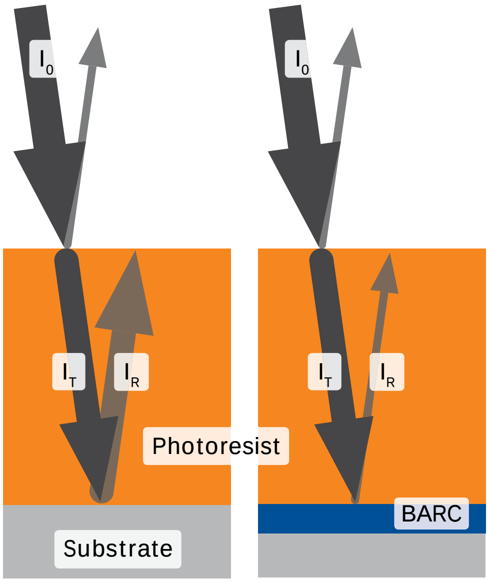


Fig. 79: The (I_T) running in the resist film to the substrate and the (I_R) light reflected on the substrate can interfere with each other, the more equally the intensities of which (left). Right: Using an anti-reflective coating (BARC, shown in blue) on the substrate, I_R and thus the interfering effect between I_T and I_R is minimised.

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 sin² 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 sin² distribution of the received light intensity.

While in the case of a broadband exposure, the different periods of the sin² 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 sin² 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 sin² 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.

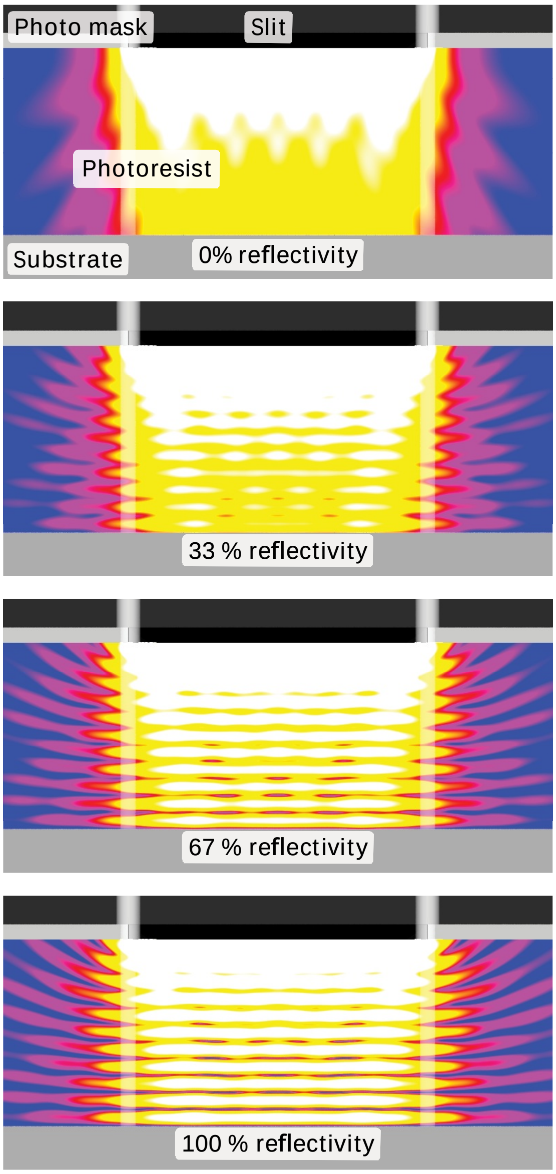


Fig. 80: A numerical simulation of the intensity distribution (from blue to white increasingly) in an exposed resist film shows how the interference-induced periodic pattern becomes ever more pronounced with increasing substrate reflectivity.

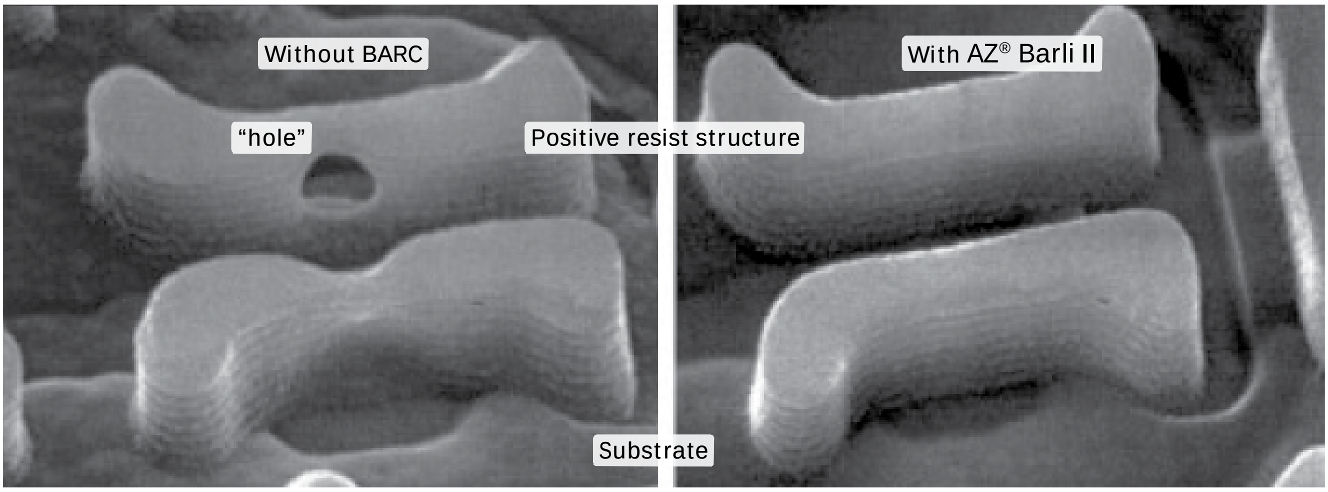


Fig. 81: The use of an anti-reflective coating on the substrate reduces on the one hand interference-related artefacts such as the periodic groove structures on the resist sidewalls as well as an unwanted exposure and subsequent development of nominally unexposed areas by reflections on substrate textures. Source: AZ® Barli Product Data Sheet by the manufacturer.

Our Photoresists: Application Areas and Compatibilities

	Recommended Applications [1]	Resist Family	Photoresists	Resist Film Thickness [2]	Recommended Developers [3]	Recommended Removers [4]
Positive	Improved adhesion for wet etching, no focus on steep resist sidewalls	AZ® 1500	AZ® 1505	≈ 0.5 µm	AZ® 351B, AZ® 326 MIF, AZ® 726 MIF, AZ® Developer	AZ® 100 Remover, TechniStrip® P1316 TechniStrip® P1331
			AZ® 1512 HS	≈ 1.0 - 1.5 µm		
			AZ® 1514 H	≈ 1.2 - 2.0 µm		
			AZ® 1518	≈ 1.5 - 2.5 µm		
		AZ® 4500	AZ® 4533	≈ 3 - 5 µm	AZ® 400K, AZ® 326 MIF, AZ® 726 MIF, AZ® 826 MIF	
			AZ® 4562	≈ 5 - 10 µm		
		AZ® P4000	AZ® P4110	≈ 1 - 2 µm	AZ® 400K, AZ® 326 MIF, AZ® 726 MIF, AZ® 826 MIF	
			AZ® P4330	≈ 3 - 5 µm		
			AZ® P4620	≈ 6 - 20 µm		
			AZ® P4903	≈ 10 - 30 µm		
		AZ® PL 177	AZ® PL 177	≈ 3 - 8 µm	AZ® 351B, AZ® 400K, AZ® 326 MIF, AZ® 726 MIF, AZ® 826 MIF	
	Spray coating	AZ® 4999		≈ 1 - 15 µm	AZ® 400K, AZ® 326 MIF, AZ® 726 MIF, AZ® 826 MIF	
	Dip coating	MC Dip Coating Resist		≈ 2 - 15 µm	AZ® 351B, AZ® 400K, AZ® 326 MIF, AZ® 726 MIF, AZ® 826 MIF	
	Steep resist sidewalls, high resolution and aspect ratio for e. g. dry etching or plating	AZ® ECI 3000	AZ® ECI 3007	≈ 0.7 µm	AZ® 351B, AZ® 326 MIF, AZ® 726 MIF, AZ® Developer	
			AZ® ECI 3012	≈ 1.0 - 1.5 µm		
			AZ® ECI 3027	≈ 2 - 4 µm		
		AZ® 9200	AZ® 9245	≈ 3 - 6 µm	AZ® 400K, AZ® 326 MIF, AZ® 726 MIF	
			AZ® 9260	≈ 5 - 20 µm		
	Elevated thermal softening point and high resolution for e. g. dry etching	AZ® 701 MiR	AZ® 701 MiR (14 cPs)	≈ 0.8 µm	AZ® 351B, AZ® 326 MIF, AZ® 726 MIF, AZ® Developer	
			AZ® 701 MiR (29 cPs)	≈ 2 - 3 µm		
Positive (chem. amplified)	Steep resist sidewalls, high resolution and aspect ratio for e. g. dry etching or plating	AZ® XT	AZ® 12 XT-20PL-05	≈ 3 - 5 µm	AZ® 400K, AZ® 326 MIF, AZ® 726 MIF	AZ® 100 Remover, TechniStrip® P1316 TechniStrip® P1331
			AZ® 12 XT-20PL-10	≈ 6 - 10 µm		
			AZ® 12 XT-20PL-20	≈ 10 - 30 µm		
			AZ® 40 XT	≈ 15 - 50 µm		
		AZ® IPS 6050		≈ 20 - 100 µm		
Image Re-versal	Elevated thermal softening point and undercut for lift-off applications	AZ® 5200	AZ® 5209	≈ 1 µm	AZ® 351B, AZ® 326 MIF, AZ® 726 MIF	TechniStrip® Micro D2 TechniStrip® P1316 TechniStrip® P1331
			AZ® 5214	≈ 1 - 2 µm		
		TI	TI 35ESX	≈ 3 - 4 µm		
			TI xLift-X	≈ 4 - 8 µm		
Negative (Cross-linking)	Negative resist sidewalls in combination with no thermal softening for lift-off application	AZ® nLOF 2000	AZ® nLOF 2020	≈ 1.5 - 3 µm	AZ® 326 MIF, AZ® 726 MIF, AZ® 826 MIF	TechniStrip® NI555 TechniStrip® NF52 TechniStrip® MLO 07
			AZ® nLOF 2035	≈ 3 - 5 µm		
			AZ® nLOF 2070	≈ 6 - 15 µm		
		AZ® nLOF 5500	AZ® nLOF 5510	≈ 0.7 - 1.5 µm		
	Improved adhesion, steep resist side-walls and high aspect ratios for e. g. dry etching or plating	AZ® nXT	AZ® 15 nXT (115 cPs)	≈ 2 - 3 µm	AZ® 326 MIF, AZ® 726 MIF, AZ® 826 MIF	
			AZ® 15 nXT (450 cPs)	≈ 5 - 20 µm		
			AZ® 125 nXT	≈ 20 - 100 µm	AZ® 326 MIF, AZ® 726 MIF, AZ® 826 MIF	TechniStrip® P1316 TechniStrip® P1331 TechniStrip® NF52 TechniStrip® MLO 07

Our Developers: Application Areas and Compatibilities

Inorganic Developers

(typical demand under standard conditions approx. 20 L developer per L photoresist)

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

(typical demand under standard conditions approx. 5 - 10 L developer concentrate per L photoresist)

AZ® 326 MIF is 2.38 % TMAH- (TetraMethylAmmoniumHydroxide) in water.

[1] In general, almost all resists can be used for almost any application. However, the special properties of each resist family makes them specially suited for certain fields of application.

[2] Resist film thickness achievable and processable with standard equipment under standard conditions. Some resists can be diluted for lower film thicknesses; with additional effort also thicker resist films can be achieved and processed.

[3] Metal ion free (MIF) developers are significantly more expensive, and reasonable if metal ion free development is required.

AZ® 726 MIF is 2.38 % TMAH- (TetraMethylAmmoniumHydroxide) in water, with additional surfactants for rapid and uniform wetting of the substrate (e. g. for puddle development)

AZ® 826 MIF is 2.38 % TMAH- (TetraMethylAmmoniumHydroxide) in water, with additional surfactants for rapid and uniform wetting of the substrate (e. g. for puddle development) and other additives for the removal of poorly soluble resist components (residues with specific resist families), however at the expense of a slightly higher dark erosion.

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 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® P1331 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® NI555 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® NI555 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® NI555 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™ NF52 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 photoresist remover used for IR, III/V, MEMS, Photonic, 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 ≈ 280 - 2000 nm wavelength, the more expensive JGS1 wafers at ≈ 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: è www.microchemicals.com/products/wafers/waferlist.html

Further Products from our Portfolio

Plating

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

Solvents (MOS, VLSI, ULSI)

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

Acids and Bases (MOS, VLSI, ULSI)

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

Etching Mixtures

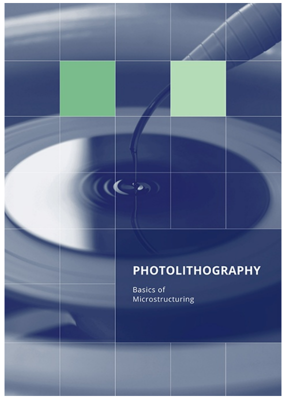
for e. g. chromium, gold, silicon, copper, titanium, ... è www.microchemicals.com/products/etching_mixtures.html

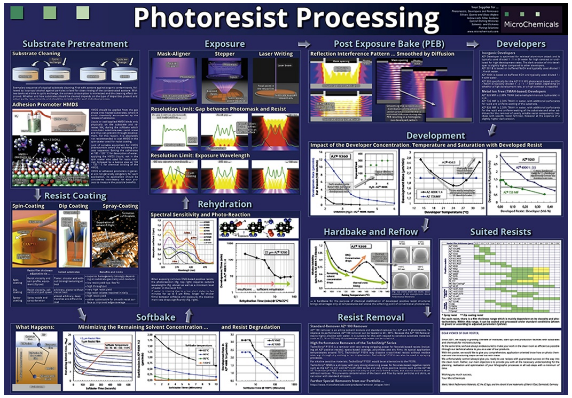
Further Information

Technical Data Sheets: www.microchemicals.com/downloads/product_data_sheets/photoresists.html

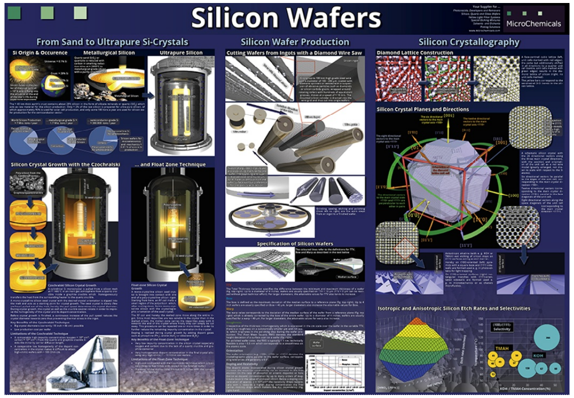
Material Safety Data Sheets (MSDS): www.microchemicals.com/downloads/safety_data_sheets/msds_links.html

Our Photolithography Book and -Posters





Photoresist Processing



Silicon Wafers

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