IUPAC Recommendations

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Terminology of polymers in advanced lithography (IUPAC Recommendations 2020)

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Abstract: As increasingly smaller molecular materials and material structures are devised or developed for technological applications, the demands on the processes of lithography now routinely include feature sizes that are of the order of 10 nm. In reaching such a fine level of resolution, the methods of lithography have increased markedly in sophistication and brought into play 2terminology that is unfamiliar, on the one hand, to scientists tasked with the development of new lithographic materials or, on the other, to the engineers who design and operate the complex equipment that is required in modern-day processing. Publications produced by scientists need to be understood by engineers and *vice versa*, and these commonly arise from collaborative research that draws heavily on the terminology of two or more of the traditional disciplines. It is developments in polymer science and material science that lead progress in areas that cross traditional boundaries, such as microlithography. This document provides the exact definitions of a selection of unfamiliar terms that researchers and practitioners from different disciplines might encounter.

Keywords: microlithography; nanotechnology; polymers; recommendations; terminology.

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AL-1 Introduction

Nanoscience has become increasingly important as a means to tackle societal challenges and help to solve problems related to water purification, energy and energy storage, health, and information and communication technologies. Driven by the electronics revolution, today lithographic tools are available for fabricating increasingly small structures and objects. Through lithography (pattern generation), chemistry and more specifically polymer science provide many of the key capabilities needed to build objects at this very small length scale.

The growth of lithography and pattern formation across disciplines has led to a sometimes bewildering selection of terminology. Terms can be used with no consensus on their meaning, or several definitions can be applied to the same word. Considering the number of different, though not-unrelated, scientific and technological communities, it is not surprising that this can happen. As a result, in this document we have attempted to produce a list of the most important terms that are currently used within the broad study and application of lithography down to the nanoscale. It is not an exhaustive list, but it is one that should assist the reader who is unfamiliar with the concepts and serve as a guide to the use of standard terminology by those researching in these areas. The terms that we have chosen to define relate to the structures formed in lithography and to the materials and processes used to form them.

Definitions of relevant terms from other IUPAC publications have been used where they are already satisfactorily defined in the context of polymer or nanoscience. The reader should be aware that some terms might have similar, but nonetheless acceptable, alternative definitions that apply in other contexts. This document provides definitions that apply to the nanoscale and may not be applicable to larger dimensions.

Where possible, definitions of terms have been refined to achieve greater generality or improvement in consultation with experts in the relevant fields.

For simplicity, the terms are listed alphabetically and numbered sequentially. Cross-references to terms defined elsewhere in the document are denoted in italic typeface. If there are two or more terms on successive lines prior to a common definition, the later entries are accepted synonyms. In instances where two terms have similar, though not identical, meanings and it is essential that the distinction be recognized, each definition makes cross-reference to the other.

AL-2 Terminology

AL-2.1 absorbance, A, A_{10} , A_{e} , B

Logarithm of the incident radiant power divided by the transmitted radiant power through a sample.

- Note 1: Depending on the base of the logarithm, a decadic or napierian absorbance is used.
- Note 2: Absorbance as defined excludes surface effects, such as those of containment.
- Note 3: Absorbance is sometimes called extinction, but this term should properly be reserved for the sum of the effects of absorption, scattering, and luminescence.
- Note 4: The term optical density, while still in use, is obsolete and therefore not recommended.
- Note 5: Adapted to terminological format from the mathematical format of the definition given in Chapter 2 of [1].

AL-2.2 absorption

Phenomenon in which radiation transfers some or all of its energy to matter that it traverses [2].

AL-2.3 adhesion

Attachment of interfaces between phases or components that is maintained by intermolecular forces, chain entanglements, or both.

- Note 1: Interfacial adhesion is also referred to as tack.
- Note 2: Adhesive strength (recommended symbol: F_a , unit: N m⁻²) is the force required to separate one condensed phase domain from another at the interface between the two phase domains divided by the area of the interface.
- Note 3: Interfacial tension (recommended symbol: y, unit: N m⁻¹, J m⁻²) is the change in Gibbs energy per unit change in interfacial area for substances in physical contact.
- Note 4: Adapted from the definition in [3]. The more concise definition proposed here is recommended.

AL-2.4 adhesion promoter

Interfacial agent comprised of molecules possessing two or more functional groups, each of which exhibits preferential interactions with the various types of phase domains in a composite [3].

AL-2.5 aerial image

Image of a mask pattern that is projected onto the photoresist coated wafer by an optical system.

AL-2.6 annealing (in polymer science)

Thermal treatment of a solid polymer material at a fixed or changing temperature that leads to desired changes in its physical structure and properties without involving complete melting or dissolution [4].

- Note 1: Annealing of a *crystalline polymer* is usually carried out by keeping the polymer at temperatures just below its melting point.
- Note 2: Annealing may be carried out by exposure of a *crystalline polymer* to a poor solvent or to its vapors.
- Note 3: In a *crystalline polymer*, the process of annealing leads to *reorganization* and involves an increase of order in existing crystallites (Definition 5.17 in [4]), an increase in *degree of crystallinity*, and changes to more stable *polymorphs*.

AL-2.6.1 solvent vapor annealing

Annealing via the exposure of a substrate to solvent vapor.

Note: Solvent vapor annealing is most commonly used in lithography to process *block copolymer* (BCP) thin films, often leading to a more equilibrated structure.

AL-2.6.2 thermal annealing (in lithography)

Annealing in which a heating step is used to activate chemical processes in a resist that depend on diffusion.

Note: Thermal annealing is frequently employed in photolithography and in block copolymer lithography.

AL-2.7 anti-reflective coating (ARC)

Material used in *lithography* or in other technologies that is applied to a surface in order to reduce reflection.

AL-2.8 aqueous-base development

See development.

AL-2.9 aspect ratio (in lithography)

Proportional relationship between the width and height of an *image* produced by exposing a *resist*.

AL-2.10 atomic force microscopy (AFM)

scanning force microscopy (SFM)

High-resolution scanning probe microscopy that maps a surface with a demonstrated *resolution* of the order of fractions of a nanometer.

Note: Such tools for microscopy may also be used for nanoscale pattern generation of thin organic films on substrates.

AL-2.11 base quencher

Base added to a *chemical amplification resist* to neutralize low levels of acid that might diffuse into nominally unexposed regions and cause blur.

AL-2.12 block copolymer (BCP)

Copolymer that is a block polymer [5].

Note: In the constituent macromolecules of a block copolymer, adjacent blocks are constitutionally different, i.e., adjacent blocks comprise constitutional units derived from different species of monomer or from the same species of monomer but with a different composition or sequence distribution of constitutional units.

AL-2.13 block copolymer lithography

Process in which a thin film of *block copolymer* is formed into a regular nanoscale pattern.

Note: See also directed self-assembly.

AL-2.14 bottom anti-reflective coating (BARC)

Layer placed between a *photoresist* and a *substrate* to prevent reflection from the latter resulting in a reduction in photoresist pattern quality, as characterized by resolution, line edge roughness, etc.

AL-2.15 bottom-up lithography

Pattern formation using *self-assembly* processes.

AL-2.16 basting solvent

Solvent in which a resist or additional thin-film component (typically a BARC) is dissolved for the coating process.

AL-2.17 chain scission (in polymer science)

Chemical reaction resulting in the breaking of skeletal bonds [5].

AL-2.18 chemical amplification (in lithography)

Process comprising a catalyzed chain reaction used to deprotect a photopolymer to change the solubility of the polymer and create a pattern.

- Note 1: Chemical amplification can lead to a change in the structure and consequently to a change in the physical properties of a polymer.
- Note 2: The term 'chemical amplification resist' is commonly used for resists that employ a photo-acid generator or a photo-base generator.
- Note 3: An example of chemical amplification is the transformation of [(tert-butoxycarbonyl)oxylphenyl groups on polymer chains to hydroxyphenyl groups catalyzed by a photo-generated acid.

AL-2.19 chromophore

Part of a molecular entity (atom or group of atoms) in which the electronic transition responsible for a given spectral band is approximately localized [2].

- Note 1: The term arose in the dyestuff industry and referred originally to the groupings in the molecule that are responsible for the dye's color.
- Note 2: The term has been extended for use in infrared spectroscopy to designate bands that correspond to localized vibrational transitions.

AL-2.20 clearance dose, D_n^0

clearing dose dose to clear

Dose of radiation required to completely remove a positive-tone resist from a large area.

AL-2.21 contact hole

Hole in a layer of a semiconductor device enabling contact with an underlying semiconductor layer.

Note: Contact holes are usually of a diameter less than 100 nm.

AL-2.22 contrast, y

contrast ratio

Maximum of the absolute value of the gradient of a contrast curve taken as a measure of the ability of a resist to differentiate the regions that have been exposed to radiation from those that have not.

Note: For ease of determination, for positive- and negative-tone resists respectively, contrasts are usually calculated as

$$\gamma = \frac{1}{2 \log_{10} \left(D_{\text{n}}^{0.5} / D_{\text{n}}^{0} \right)} \text{ and } \gamma = \frac{1}{2 \log_{10} \left(D_{\text{p}}^{1} / D_{\text{p}}^{0.5} \right)}$$

in which $D_{\rm p}^0$, $D_{\rm p,p}^{0.5}$, and $D_{\rm p}^1$ are the incident exposure doses to light or radiation required for incipient gel formation in a negative-tone system, the dose at 50 % of the original resist thickness remaining after development for either system, and the clearance dose for a positive-tone system, respectively.

AL-2.23 contrast curve

Plot of the fraction of the original thickness that remains after the *development* of a uniformly irradiated *resist* versus the logarithm of the incident exposure dose.

AL-2.24 contrast ratio

See contrast

AL-2.25 critical dimension (CD)

Length of the smallest geometrical features that can be formed in a lithographic process.

- Note 1: The final device CD is often notably smaller than the smallest geometrical features that can be formed in a lithographic process, achieved, for example, by etch or slimming processes.
- Note 2: The critical dimension uniformity (CDU), which is a statistical measurement of the variation in length of the smallest geometrical feature, is often as low as 3 σ of 10 % of the CD.

AL-2.26 dark loss

Unwanted change in the solubility of a *resist* that takes place in the absence of exposure.

AL-2.27 defect

image defect

Imperfection introduced during pattern formation.

AL-2.28 defect-free pattern

Imaged *resist* without imperfections in pattern.

Note 1: In a *photoresist*, for example, no error is introduced by the photochemistry.

Note 2: In a DSA resist, for example, no error is introduced by the self-assembly process.

AL-2.29 deprotection

Removal of a protecting group which leads to a change in the solubility of a polymeric resist.

Note: Deprotection is a common feature in the performance of most chemical amplification resists.

AL-2.30 depth of focus

Tolerance of the placement of the image plane in relation to *image* quality.

Note: Term used in an exposed and developed photoresist.

AL-2.31 development

Process in which a developer is used to generate an *image* by removing the soluble portion of the latent pattern of an exposed resist.

Note 1: Aqueous-base development is carried out using a 0.262 M solution of tetramethylammonium hydroxide in water as developer.

Note 2: *Solvent development* is carried out using a non-polar solvent as a developer.

AL-2.32 diffusion

Irregular spreading or scattering of a gaseous or liquid material [6].

Note: Eddy diffusion in the atmosphere is the process of transport of gases due to turbulent mixing in the presence of a composition gradient. Molecular diffusion is the net transport of molecules that results from their irregular molecular motions alone in the absence of turbulent mixing; it occurs when the concentration gradient of a particular gas in a mixture differs from its equilibrium value. Eddy diffusion is the most important mixing process in the lower atmosphere, while molecular diffusion becomes significant at the lower pressures of the upper atmosphere.

AL-2.33 dip-pen nanolithography

Direct write, tipbased patterning method that uses the tip of an AFM probe to act as a pen and deposit molecules on a surface.

Note: The ink used in dip-pen nanolithography often consists of thiols that self-assemble on surfaces.

AL-2.34 directed self-assembly (DSA) (in lithography)

Process in which a thin film of block copolymer is formed into a regular nanoscale pattern on chemically or topographically *nanopatterned* surfaces (or a combination thereof).

AL-2.35 dislocation

Defect, or irregularity, within an ordered structure.

Note 1: A screw dislocation is a structure in which a helical path is traced around a linear defect (dislocation line) by the atomic planes in the crystal *lattice*.

Note 2: An edge dislocation is a defect where an extra half-plane of atoms is introduced mid-way through the crystal.

Note 3: In the context of *lithography*, a dislocation may be found in a *block copolymer* pattern.

AL-2.36 dissolution inhibitor

Compound that, when included in a resist formulation, slows the rate of dissolution.

Note 1: In lithography, the effectiveness of a dissolution inhibitor is changed after exposure to imaging radiation, which facilitates its application in resist formulations.

Note 2: A typical example of a resist based on a dissolution inhibitor comprises a diazonaphthoquinone within a phenolic resin.

AL-2.37 dissolution promoter

Compound that, when included in a resist formulation, increases the rate of dissolution.

AL-2.38 dissolution rate

Rate at which *resist* is removed during *development*.

Note: Usually reported in nm s⁻¹.

AL-2.39 doctor blading

Coating of solution or slurry drawn to uniform film by use of a knife edge or doctor blade.

Note: The term has been borrowed from printing and coating technologies. It is believed that it derives from the blades employed in letter press equipment that were used to wipe so-called ductor rolls, the term "ductor" becoming doctor over time.

AL-2.40 doping (p- and n-type)

Process that increases the thermal-equilibrium concentration of free charge carriers in a material to augment its electrical conductivity using chemical agents or additives (i.e. dopants).

Note: Typical dopants to organic polymers (compounds) are:

- a) Oxidants, giving positively charged (p-doped) polymers that act as hole conductors;
- b) Reductants, giving negatively charged (n-doped) polymers that mostly act as electron conductors.
- c) Strong Brønsted acids, which are indispensable dopants to polymers such as polyaniline.

AL-2.41 dose

exposure dose

Amount of radiation per unit area to which a *resist* is exposed.

Note: For optical lithography, exposure dose is reported in mJ cm⁻², while for electron beam lithography, exposure dose is reported in μ C cm⁻².

AL-2.42 dose to clear

See clearance dose.

AL-2.43 double exposure

Lithographic process requiring two exposures to radiation for a single resist layer to form a finished pattern.

AL-2.44 double patterning

Printing of two distinct lines at the edges of a single *resist* line pattern by means of a deposit-etch process.

AL-2.45 dry deposition

Assembly of a layer on a *substrate* by the use of a solvent-free process, such as *vapor deposition*.

AL-2.46 dry development

Process in which a portion of a latent pattern in an exposed *resist* is removed to form the *image* without the use of a liquid developer.

AL-2.47 dry-etch resistance

etch resistance

Facility of an exposed resist to withstand etching conditions, usually a plasma, determined in comparison to a reference standard.

Note: Plasma may be oxygen or halogen-based.

AL-2.48 dual-tone resist

Photoresist capable of being processed in either positive tone (aqueous base development) or negative tone (organic solvent development).

AL-2.49 edge acuity

Degree to which the edge of an image appears sharp and precise.

Note: Also known as edge sharpness.

AL-2.50 electron-beam resist

e-beam resist

See resist.

AL-2.51 embossing

Creating a pattern by pressing a master die into a malleable material.

AL-2.52 epitaxial crystallization

Growth of crystals on other crystals involving a precisely defined mutual orientation of their *lattices*.

Note: The process involves heterogeneous nucleation of the growing crystals by the *substrate* crystal faces.

AL-2.52.1 epitaxy

Deposition of a crystalline over layer on a crystalline *substrate*.

- Note 1: The over layer is called an epitaxial film or epitaxial layer.
- Note 2: An ordered spatial relationship existing between the lattices of *substrate* crystals and those grown by epitaxial crystallization on top of the substrate crystals.
- Note 3: Examples involving polymers are given under the terms homoepitaxy and heteroepitaxy, where if the crystals are of the same substance, but possibly different polymorphs, the former term applies, in contrast to the use of the latter term, which involves crystals of two different substances.
- Note 4: The term epitaxy is sometimes used for epitaxial crystallization. This use is not recommended.

AL-2.53 etch

Treatment to remove *substrate* to a requisite depth from those areas of a surface no longer protected following the exposure and development of an overlaid resist.

AL-2.53.1 dry etching

Process of removal of material, typically of a masked pattern on a semiconductor, by exposing it to a bombardment of ions.

AL-2.53.2 etch rate

Rate of material removal using either a wet or a dry-etch process.

Note: Usually reported in μ m min⁻¹.

AL-2.53.3 etch resistance

See dry-etch resistance.

AL-2.53.4 wet etching

Process of removal of material, typically of a masked pattern on a semiconductor, by exposing it to a corrosive liquid.

AL-2.54 exposure latitude

Extent to which a light- or radiation-sensitive material can be overexposed or underexposed and still achieve acceptable imaging.

AL-2.55 focused ion beam (FIB)

Technique used for the site-specific analysis, deposition, ablation, and micromachining of materials down to dimensions of 10 to 15 nm.

Note: FIB should not be confused with ion-beam lithography.

AL-2.56 glass-transition temperature, T_g

Temperature at which the viscosity of a glass is 10¹³ Pa s [7].

- Note 1: Temperature at which amorphous materials or amorphous regions within semi-crystalline materials undergo a reversible transition from a hard, rigid glassy state into a rubber-like state capable of deformation.
- Note 2: The glass transition is a second-order transition that in polymer science marks the onset of chainsegmental motion as the temperature is raised.

AL-2.57 hard bake

High temperature annealing to solidify any resist material remaining after development in order to provide a durable protective layer for etching.

AL-2.58 image (in lithography)

Pattern produced in or on a substrate during a lithographic process.

Note: The term was originally used to describe patterns produced by means of light exposure followed by development, but with the growth in the number of lithographic methods it may now refer to those produced by molding, *embossing*, or other kinds of patterning processes.

AL-2.58.1 developed image

Visible *image* produced by an effect of radiation on a *substrate* followed by subsequent lithographic development.

AL-2.58.2 latent image

Invisible image produced by an effect of radiation on a substrate, which can be rendered visible by subsequent lithographic development.

AL-2.59 image blur

Broadening during the *development* of a lithographic *image*.

Note: Image blur is measured as the distance between regions of 12 and 88 % maximum exposure.

AL-2.60 immersion fluid

High refractive index liquid medium used in *immersion lithography* that replaces the air gap between the lens and the *resist* surface in conventional *photolithography*.

AL-2.61 ion-beam resist

See resist.

AL-2.62 lift-off process

Method whereby a film, usually metallic, deposited on a patterned substrate after etch processing, is removed during resist strip, which leaves only that portion of the film that is deposited directly onto the exposed regions of the substrate.

Note: A lift-off process is commonly employed to pattern substrates when using resists that have little or no dryetch resistance.

AL-2.63 line edge roughness (LER)

Variations along one edge of a linear resist feature over an extended length.

AL-2.64 line width

Width of a linear exposed lithographic feature.

AL-2.65 line width roughness (LWR)

Variations in the width of a linear *resist* feature over an extended length.

AL-2.66 line-space patterning

Developed lithographic pattern comprising alternating lines with spaces between.

AL-2.67 lithography

Process whereby an *image* is created on an apparently planar surface.

Note: The term was originally applied within printing technology, but its usage has been extended to embrace the imaging processes of the microfabrication techniques used to make integrated circuits and microelectromechanical systems.

AL-2.67.1 direct-write lithography

Pattern created without recourse to irradiation through a *mask* of the *image*.

Note: Typical direct-write imaging systems are electron-beam lithography and ion-beam lithography.

AL-2.67.2 electron beam lithography

e-beam lithography

Lithography performed by exposing a resist to a beam of electrons.

AL-2.67.2.1 electron-beam direct-write lithography (EBDW)

Electron beam lithography whereby the pattern is written directly onto the *photoresist* without the use of a *mask*.

AL-2.67.3 extreme ultraviolet lithography (EUVL)

Photolithography performed by exposing a resist to extreme ultraviolet (13 nm) radiation.

AL-2.67.4 holographic lithography

See interference lithography.

AL-2.67.5 immersion lithography

Photolithography that provides *resolution* enhancement by immersing a *resist*-coated *substrate* in a fluid during the exposure process.

Note: See also immersion fluid.

AL-2.67.6 imprint lithography

Patterns created by mechanical deformation of an imprint *resist* and a subsequent curing process.

AL-2.67.6.1 nanoimprint lithography

Subset of *imprint lithography* that allows for the fabrication of nanometer scale patterns.

AL-2.67.7 interference lithography

holographic lithography

Technique for patterning regular arrays of fine features without the use of complex optical systems or *photomasks*.

AL-2.67.8 magnetolithography

Lithography for direct patterning of surfaces based on the application of a magnetic field to the *substrate* using paramagnetic metal *masks*.

AL-2.67.9 maskless lithography

Lithography that does not need a mask of the image to make a pattern.

Note: See also direct-write lithography.

AL-2.67.10 microlithography

Lithography or pattern formation at a resolution of the order of microns.

AL-2.67.11 nanolithography

Umbrella term that is used to describe all lithographic techniques that allow for the fabrication of nanometer scale patterns.

AL-2.67.12 nanosphere lithography

Lithography in which material is deposited into the interstices of a 2D array of nanospheres that are subsequently removed to form a pattern.

Note: *Vapor deposition* is the most commonly used deposition technique.

AL-2.67.13 photolithography

optical lithography

Lithography performed by exposing a resist to an intense parallel light beam through an image mask.

AL-2.67.14 scanning-probe lithography

Lithographic method in which a microscopic or nanoscopic stylus is moved mechanically across a surface to form a pattern.

AL-2.67.15 soft lithography

Family of techniques for fabricating or replicating structures using elastomeric stamps, molds, and conformable photomasks.

AL-2.67.16 X-ray lithography

Lithography performed by exposing a *resist* to X-radiation through an *image mask*.

AL-2.67.17 3D lithography

Lithography performed in three dimensions, typically carried out using nanoimprint patterning or 2-photon lithography.

AL-2.67.18 2-photon lithography

Photolithography within a thick photoresist film, within which the photochemically-induced solubility change results from the simultaneous absorption of 2 photons.

Note 1: Usually the imaging radiation is of near-IR wavelength.

Note 2: An instrument such as a confocal microscope can be used for 2-photon lithography.

AL-2.68 mask

Transparent substrate pre-patterned with the desired image that is inserted into the incident beam in photoand X-ray lithography.

- Note 1: A dark field mask is used with a positive tone *photoresist* and a bright field mask with a negative tone photoresist.
- Note 2: Masks are typically transparent fused silica blanks with a pattern defined in a chrome film using *direct*write lithography.

AL-2.68.1 magnetic mask

Mask with a pattern defined by a paramagnetic metal.

AL-2.69 mask error enhancement factor (MEEF)

Increase in error of pattern edge location during pattern formation when the wavelength of light used to expose a *resist* is greater than the feature size.

AL-2.70 micro, µ

SI prefix for 10^{-6} [1].

Note: The micro- prefix may be used for objects with at least one characteristic dimension in the range of 1 to 100 µm.

AL-2.71 microcontact printing

Form of soft lithography that uses micron-scale and smaller relief patterns on a master elastomer stamp to form images on the surface of a substrate through conformal contact.

Note: Stamps fabricated from polydimethylsiloxane are often used to make patterns of self-assembled monolayers on a metal, such as gold.

AL-2.72 microfabrication

Process whereby structures of micrometre scale and smaller are fabricated.

AL-2.73 microfluidics

Multi-disciplinary subject concerned with the behavior, precise control, and manipulation of fluids that are geometrically constrained within a small, typically sub-millimeter, scale channel.

AL-2.74 micromolding

Form of *soft lithography* that uses the relief patterns in a master template to make 3-dimensional structures.

Note 1: Molds are commonly fabricated from an elastomer, such as polydimethylsiloxane.

Note 2: Micromolding is used to manufacture parts of micro-objects, such as microfluidic circuits.

AL-2.75 molecular glass

Assembly of small molecules that vitrify, rather than crystallize, when cooled.

Note: Molecular glass photoresists are used in deep- and extreme-UV photolithography.

AL-2.76 molecular logic gate

Molecule that acts as a device performing a logical operation based on one or more physical or chemical inputs and a single output.

AL-2.77 molecular template

Molecular structure that transfers a pattern to or organizes another molecular scale structure.

AL-2.78 molecular wires

Molecular-scale objects that conduct electrical current.

AL-2.79 Moore's law

Empirical observation by Gordon E. Moore, co-founder of Intel, that, over the history of computing hardware, the number of transistors on integrated circuits doubles approximately every two years.

Note: Moore's law applies more fundamentally to advances in lithographic processing, particularly achievable resolution, since the inception of printed circuit boards.

AL-2.80 morphology

Shape, optical appearance, or form of phase domains in substances, such as high polymers, polymer blends, composites, and crystals [8].

Note 1: For a polymer blend or composite, the morphology describes the structures and shapes observed, often by microscopy or scattering techniques, of the different phase domains present within the mixture. Note 2: Typical shapes include spheres, cylinders, lamellae, and gyroids.

AL-2.81 nano, n

SI prefix for 10^{-9} [1].

Note: The nano- prefix may be used for objects with at least one characteristic dimension in the range of 1 and 100 nm.

AL-2.81.1 nanodevice

Device in which the manufactured size is between 1 and 100 nm.

AL-2.81.2 nanodomain morphology

Morphology consisting of phase nanodomains [8].

AL-2.81.3 nanoelectromechanical systems (NEMS)

Devices that integrate electrical and mechanical functionality at the nanoscale. A miniaturization of micro-electromechanical systems (MEMS).

AL-2.81.4 nanoelectronics

Application of nanotechnology to microelectronics.

AL-2.81.5 nanoimprint

See nanoimprint lithography.

AL-2.81.6 nanomaterial

Material comprising particles or containing features in the size range of 1 to 100 nm.

AL-2.81.7 nanoparticle

Particle of any shape with an equivalent diameter of approximately 1 to 100 nm.

Note: nanoparticle photoresists are used in deep- and extreme-UV photolithography.

AL-2.81.8 nanopattern

Patterns on a substrate with lesser dimensions of between 1 to 100 nm.

AL-2.81.9 nanophotonics

nano-optics

Study of the interaction of light with particles or substances on a scale less than the wavelength of the light.

AL-2.81.10 nanostructure

Structure or feature of size between 1 and 100 nm.

AL-2.81.11 nanotechnology

Manipulation of matter on an atomic and molecular scale.

AL-2.82 near-field scanning optical microcopy (NSOM)

Microscopy applied to the investigation of *nanostructures* that breaks the farfield *resolution* limit by exploiting the properties of evanescent waves.

Note: NSOM can be used to make nanopatterns.

AL-2.83 negative-tone development (NTD)

Process for revealing the *latent image* in a *resist* in which the exposed regions are less soluble in the developer than the unexposed regions.

AL-2.84 negative-tone resist

negative-working resist

See resist.

AL-2.85 normalized image log slope (NILS)

normalized image slope

Measure of the information content of the aerial image and represents an energy (intensity) gradient at the position of the nominal line edge.

AL-2.86 numerical aperture

Value that characterizes the range of angles over which a device can accept or emit light.

AL-2.87 optical density

See absorbance.

Note: An obsolete term and therefore not recommended.

AL-2.88 outgassing (in lithography)

Unwanted release of gas or vapor from a resist during a vacuum based patterning process.

AL-2.89 pattern collapse

Destruction of pattern during and after *development* caused by the surface tension of the development solvent.

AL-2.90 pattern transfer

Transfer of the pattern of a developed lithographic *image* to an underlying *substrate* by processes such as etching.

AL-2.91 phase separation

Process by which a single solid or liquid phase separates into two or more new phases [7].

AL-2.92 phase transition

Change in the nature of a phase or in the number of phases as a result of some variation in externally imposed conditions, such as temperature, pressure, microstructure, activity of a component, or a magnetic, electric or stress field [7].

AL-2.93 photoacid generator (PAG)

Compound that on exposure to radiation gives rise to a proton.

AL-2.94 photoactive compound (PAC)

Compound that on exposure to radiation will release an active ionic or radical species.

AL-2.95 photocrosslinking

Formation of a covalent linkage between two macromolecules or between two different parts of one macromolecule initiated by exposure to radiation.

Note: Corrected from [2] in which the definition makes no reference to the role of radiation.

AL-2.96 photomask

See mask.

AL-2.97 photonic crystal

Periodic structures consisting of a dielectric material that shows strong interaction with light.

AL-2.98 photonics

Science and technology of the production, transmission, absorption, sensing, and direction of light.

AL-2.99 photoresist

See resist.

AL-2.100 pitch

optical pitch

Repeat dimension of a line-space pattern.

AL-2.101 pitch division

Method for making a lithographic pattern smaller than that deemed possible given the wavelength of the imaging radiation.

Note: A current objective of *directed self-assembly* is to use the process with conventional *lithography* to double the pitch.

AL-2.102 planarising layer

Coating used to create a level surface during lithographic processing.

Note: This layer is often organic and may be called an organic planarizing layer (OPL).

AL-2.103 plasma

Gas that is at least partly ionized and contains particles of various types, viz. electrons, atoms, ions, and molecules [9].

Note: A plasma as a whole is an electrically neutral medium sustained in the gas phase by an applied electromagnetic field.

AL-2.104 plasma enhanced chemical vapor deposition (PECVD)

Process to deposit a solid film on a *substrate* resulting from *plasma*-induced reactions of precursor compounds, either in the gaseous state or on the film surface.

- Note 1: A RF frequency or DC discharge generated by two electrodes inducing a *plasma* from a gas occupying the space between.
- Note 2: Examples of PECVD films are SiO₂ films via PECVD of dichlorosilane or silane and oxygen precursors or tetraethoxysilane in an oxygen or oxygen-argon plasma, silicon nitride formed from silane and ammonia or nitrogen, and amorphous silicon from monosilane or tetrachlorosilane, as well as polymers from vinyl monomers.

AL-2.105 plasma etch

Plasma processing used in the fabrication of integrated circuits that generates volatile products from the elements of the material etched and the reactive species generated by the *plasma*.

Note: A variation of this method that removes a single layer of atoms is known as atomic layer etching (ALE).

AL-2.106 positive-tone development

Process for revealing the *latent image* in a *resist* in which the exposed regions are more soluble in the developer than are the unexposed regions.

Note: See also positive-tone resist.

AL-2.107 positive-tone resist

positive-working resist

See resist.

AL-2.108 post-apply bake (PAB)

Thermal *annealing* step following the coating of a *substrate* with a *resist* material.

AL-2.109 post-exposure bake (PEB)

post bake

Thermal annealing step following the exposure of a resist to imaging radiation.

AL-2.110 post-exposure delay (PED)

Pause between successive patterning steps in lithographic processing.

AL-2.111 protecting group

Non-reactive group temporarily used to transform a reactive group into one that does not react under conditions where the non-protected group reacts.

- Note 1: Trimethylsilylation is a typical transformation used to protect reactive functional groups, such as hydroxy or amino groups, from their reaction with the propagating species in an anionic polymerization.
- Note 2: In *photoresists*, protecting groups may also alter solubility (e.g., tBOC protection of hydroxy groups in chemically amplified poly(4-hydroxystyrene) resists).

AL-2.112 proximity effect

Widening of the exposure dose distribution, and hence the developed pattern, caused by the scattering of the primary beam electrons within the resist and substrate.

AL-2.113 quenching

Deactivation of an excited molecular entity [2].

- Note 1: Intermolecular deactivation may occur by interaction with an external environmental influence, such as that of a quencher.
- Note 2: Intramolecular deactivation may occur by a substituent through a non-radiative process.
- Note 3: When the external environmental influence of a quencher interferes with the behavior of the excited state after its formation, the process is referred to as dynamic quenching. Common mechanisms include energy transfer, electron transfer, etc.
- Note 4: When the environmental influence inhibits the excited state formation, the process is referred to as static quenching.

AL-2.114 raster scan

Rectangular pattern of line-by-line scanning for *image* capture used in *electron beam* and *ion beam lithography*. Note: See also vector scan.

AL-2.115 reactive ion etching (RIE)

Etching technology used in microfabrication that uses chemically reactive *plasma* to remove material from a substrate.

AL-2.116 resist

Material, usually a polymer, that when irradiated either undergoes a marked change in solubility in a given solvent or is ablated.

- Note 1: A resist polymer under irradiation either forms patterns directly or undergoes chemical reactions leading to pattern formation after subsequent processing.
- Note 2: In a positive-tone resist, also called a positive-working resist, the material in the irradiated area not covered by a *mask* is removed on *development*, which results in an *image* with a pattern identical with that on the mask. In a negative-tone resist, also called a negative-working resist, the non-irradiated area is subsequently removed, which results in an image with a pattern that is the complement of that on the mask.
- Note 3: Adapted from the definition in [10]. The more general definition proposed here is recommended.

AL-2.116.1 chemically amplified resist (CAR)

Resist that undergoes solubility change upon exposure of photoacid generator, followed by thermally activated acid catalyzed deprotection.

See also chemical amplification.

AL-2.116.2 electron beam resist

e-beam resist

Resist optimized for use under electron beam irradiation.

AL-2.116.3 ion beam resist

Resist optimized for use under ion beam irradiation.

AL-2.116.4 multi-component resist

Resist comprising more than one active component.

AL-2.116.5 photoresist

Resist optimized for use under photo illumination.

AL-2.115.6 X-ray resist

Resist optimized for use under X-ray irradiation.

AL-2.117 resist profile

Topography of a *resist* pattern in cross section.

AL-2.118 resist strip

Subsequent removal of the remaining *resist* that covers the protected regions of a *substrate* during *development* and *etch* processing.

AL-2.119 resolution

Smallest feature size achievable using a given imaging process.

AL-2.120 screw dislocation

See dislocation.

AL-2.121 self-assembly

self-organization molecular self-assembly dynamic self-assembly

Spontaneous and reversible organization of molecular entities by non-covalent interactions [11].

- Note 1: Typical non-covalent interactions are van der Waals interactions, π - π interactions, electrostatic interactions, and *hydrogen bonds*.
- Note 2: Self-assembly is a process in which a system of pre-existing components, under specific conditions, adopts a more organized structure through interactions between the components themselves.

AL-2.122 sensitivity (in lithography), $D_{n,p}^{0.5}$

Incident exposure dose required to achieve 50 % of the original thickness remaining after development of either a negative- or positive-tone resist.

AL-2.123 shot noise

Noise which originates from the discrete nature of elementary charge.

Note: Shot noise decreases the resolution of an image in e-beam lithography.

AL-2.124 silvlation

silation

Introduction of a substituted silvl group (R₃Si) to an alcohol, carboxylic acid, amine, thiol, or phosphate, commonly as a protecting group.

Note: Trimethylsilylation used to protect reactive functional groups, such as hydroxy or amino groups, from their reaction with growing anionic species in anionic polymerization.

AL-2.125 soft bake

Short, low temperature *annealing* step following the coating of a wafer with a *photoresist*.

Note: The purpose of the soft bake is to (1) drive out remaining coating solvent from the resist layer; (2) improve the adhesion of the resist to the substrate; and (3) anneal the shear stresses introduced during spin-coating.

AL-2.126 solvent development

See development.

AL-2.127 spin coating

Streaming of a solution in a volatile solvent onto the center of a flat *substrate* spun at high speed in order to deposit a uniform thin film of solute.

AL-2.128 stamp

3-dimensional template comprising the negative pattern used to leave an impression on the surface of a malleable material.

AL-2.129 substrate (in lithography)

Surface on which a lithographic process is conducted.

Note: Typical materials used as substrates include silicon and gallium arsenide, but also pre-deposited metals or a pre-existing lithographic pattern on these same materials.

AL-2.130 supramolecular assembly

supramolecular species supramolecular structure supramolecule

Molecular system comprising two or more self-assembled molecular, or molecular and ionic, entities held together by means of non-covalent intermolecular binding interactions [11].

Note 1: While a supramolecular assembly may comprise only two molecular or molecular/ionic entities, for example a DNA double helix or a host-guest complex, the term is more commonly used to denote larger constructs, typically with rod-like, sheet-like, or spherical structures.

Note 2: The dimensions of supramolecular assemblies can range from nanometers to micrometers.

Note 3: The use of the term supramolecular polymer is discouraged.

AL-2.131 surface roughness

Measure of the texture of a surface that is quantified by vertical deviations from its ideal location.

AL-2.132 surfactant

surface active agent

Substance which lowers the surface tension of a medium in which it is dissolved and/or the interfacial tension with other phases, and, accordingly, is positively adsorbed at the liquid/vapor and/or at other interfaces [12].

Note: Deposition and development processes in advanced lithography sometimes involve the addition of surfactants to resist compositions.

AL-2.133 swing curve

Sinusoidal variation in the lithographic clearance dose arising from changes in the phase difference between incoming and outgoing radiation that is induced by variations in resist thickness.

AL-2.134 topcoat

Protective layer spun directly on top of a resist.

Note: In immersion lithography, a topcoat serves as barrier for chemical diffusion between the liquid medium and the photoresist.

AL-2.135 top-down patterning

top-down processing

Pattern formation using lithographic (also embossing) methods.

AL-2.136 top-surface imaging (TSI)

Lithographic process in which the exposed region of resist is silylated and the image then formed through reactive oxygen etch.

Note 1: Usually a chemically amplified *photoresist* is used.

Note 2: Oxygen *plasma* is used to convert any silicon to SiO₂.

AL-2.137 vapor deposition

Growth of solid materials on a *substrate* by deposition from the gas phase.

AL-2.138 vector scan

Pattern formation using a directed electron beam or ion beam that skips from region to region requiring exposure but is otherwise turned off.

Note: See also raster scan.

AL-2.139 X-ray resist

See resist.

AL-3 Membership of sponsoring bodies

Membership of the IUPAC Polymer Division Committee for the period 2017–2018 is as follows:

President: G. T. Russell (New Zealand); Vice President: C. K. Luscombe (USA); Secretary: M. G. Walter (USA); Past President: M. Buback (Germany); Titular Members: C. Fellows (Australia); R. Hiorns (France); R. Hutchinson (Canada); I. Lacik, (Slovakia); J. He (China); I. Lacík (Slovakia); N. Stingelin (USA) N. Stingelin (UK); P. Topham (UK); Y. Yagci (Turkey). Associate Members: S. Beuermann (Germany); M. C.-H. Chan (Malaysia); C. dos Santos (Brazil); D. S. Lee (South Korea); G. Moad (Australia); P. Theato (Germany). National Representatives: R. Adhikari (Nepal); J. He (China); M. Hess (Germany); V. Hoven (Thailand); C.-S. Hsu (Taiwan); P. Mallon (South Africa); O. Philippova (Russia); M. Sawamoto (Japan); A. Sturcova (Czech Republic); J. van Hest (Netherlands).

Membership of the Subcommittee on Polymer Terminology (until 2005, the Subcommittee on Macromolecular Terminology) during the preparation of these Recommendations (2009–2018) was as follows:

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