TERMINOLOGY OF POLYMERS IN ADVANCED LITHOGRAPHY

Journal:	*Pure and Applied Chemistry*
Manuscript ID	PAC-REC-18-12-15.R2
Manuscript Type:	Recommendation
Date Submitted by the Author:	24-Dec-2019
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Keywords:	polymers, nanotechnology, microlithography, terminology, recommendations
Author-Supplied Keywords:	

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TERMINOLOGY OF POLYMERS IN ADVANCED LITHOGRAPHY

(IUPAC Provisional Recommendations 2020)*

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Abstract: As decreasingly smaller molecular materials and material structures are devised or developed for technological applications, the demands on the processes of lithography have been such that feature sizes routinely generated in 2017 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 terminology that is unfamiliar on the one hand to scientists tasked with development of new lithographic materials or on the other to engineers who design and operate the complex equipment that is required in modern-day processing. Publications produced by scientists need to be understood by the engineers and *vice versa*, and commonly arise from collaborative research which 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 a ready reference to the exact definitions of a comprehensive selection of unfamiliar terms that researchers and practitioners from the different disciplines might encounter.

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§ co-project leaders

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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, information and communication technologies. Driven by the electronics revolution, today we have lithographic tools for fabricating decreasingly small structures and objects. Through lithography (pattern generation), chemistry and more specifically polymer science provide many of the key capabilities needed to build up 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 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 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 of or all its energy to matter which 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: γ, 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 vapours.
Note 3: In a *crystalline polymer,* the process of annealing leads to *reorganization* and involves increase of order in existing crystallites (Definition 5.17 in [4]), increase of *degree of crystallinity*, and changes to more stable *polymorphs*.

AL-2.6.1 **solvent vapor annealing**
Annealing in which exposure of a *substrate* to solvent vapor enables the formation of an 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*.

AL-2.7 **anti-reflective coating (ARC)**
Material used in *lithography* or in other technologies that is applied to a surface to reduce reflection.

AL-2.8 **aqueous-base development**
See development.

AL-2.9 **aspect ratio** (in lithography)
Proportional relationship between 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 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*.

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AL-2.11 base quencher
Base added to a *chemical amplification resist* to neutralize low levels of acid present that might diffuse into nominally unexposed regions and cause blur.

AL-2.12 block copolymer
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 casting solvent
Solvent in which a *resist* 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 catalysed 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)oxy]phenyl 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_p^1
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 semiconductor surface enabling contact to the underlying semiconductor *substrate*.
Note: Contact holes are usually of a diameter less than 100 nm.

AL-2.22 **contrast**, γ

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

$$\gamma = \frac{1}{2\log_{10}\left(D_n^{0.5}/D_n^0\right)} \quad \text{and} \quad \gamma = \frac{1}{2\log_{10}\left(D_p^{1}/D_p^{0.5}\right)}$$

in which D_n^0, $D_{n,p}^{0.5}$and D_p^1 are respectively 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.

AL-2.23 **contrast curve**

Plot of the fraction of the original thickness that remains after *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.

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 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, tip based 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 *nanopatterned* surfaces.

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 thereby 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)**
Oxidation or reduction of an original material through the use of a small amount of a molecular or atomic additive.
Note: Doping leads to an increase in electrical conductivity.

AL-2.41 **dose**
exposure dose
Amount of radiation per unit area to which a *resist* is exposed.
Note: For optical *lithography* exposure dose reported in mJ cm^{-2} and for *electron beam lithography* exposure dose reported in μC cm^{-2}

AL-2.42 **dose to clear**
See clearance dose.

AL-2.43 **double exposure**
Lithographic process requiring two exposures to radiation of a single *resist* layer to form finished pattern.

AL-2.44 **double patterning**
Double exposure process requiring *development* or *dry-etching* of an upper *resist* layer before an underlying layer is exposed to radiation.

AL-2.45 **dry deposition**
Assembly of a layer on a *substrate* by 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 reference standard.
Note: *Plasma* may be oxygen or halogen-based.

AL-2.48 **dual-tone resist**
Photoresist that allows the printing of two distinct lines at the edges of a single *resist* line pattern by means of a deposit-etch process.

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 wherein 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 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 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 μm 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 site-specific analysis, deposition, ablation and micromachining of materials down to dimensions of 10–15 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 10^{13} 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 chain-segmental 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 *developmen*t 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 thereby 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 *dry-etch* resistance.

AL-2.63 line edge roughness (LER)
Variations along one edge of a linear *resist* feature over its entire 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 its entire length.

AL-2.66 line-space patterning
Developed lithographic pattern comprising alternate lines of *resist* 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 latterly 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 of 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.

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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 photo- and *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 µm and 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, the precise control and the 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 gyroid.

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 nm and 100 nm.

AL-2.81.1 nanodevice
Device in which the manufactured size is between 1 nm 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 microelectromechanical 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 nm to 100 nm.

AL-2.81.7 nanoparticle
Particle of any shape with an equivalent diameter of approximately 1 nm 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 nm and 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 nm to 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.

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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* and *doping*

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.

AL-2.103 **plasma**

Gas which 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 SiO_2 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, 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*.

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., *t*BOC 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 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.

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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 electronic charge.

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

AL-2.124 **silylation**
silation
Introduction of a substituted silyl group (R_3Si) 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 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 can include 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 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 SiO_2.

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*.

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AL-4 INDEX OF TERMS

AL-5 ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to Dr. Edward (Ted) S. Wilks for his scrupulous proof-reading of the final draft of this manuscript. Though no manuscript can be without fault, in this instance we can rest assured that the grammar, punctuation and English expression are as near to perfection as can be humanly achieved.

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