PAS 135:2007

PUBLICLY AVAILABLE SPECIFICATION

Terminology for nanofabrication

ICS 01.040.71; 71.100.99

British Standards

Publishing and copyright information

ISBN 978 0 580 61320 3

Publication history

First published December 2007

Amendments issued since publication

Amd. no.	Date	Text affected

Contents

Annexes

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 17 and a back cover.

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Foreword

Publishing information

This Publicly Available Specification (PAS) has been commissioned by the UK Department for Innovation, Universities and Skills (DIUS) and developed through the British Standards Institution. It came into effect on 31 December 2007.

Acknowledgement is given to the following organizations that were involved in the development of this terminology:

- Cavendish Lab, Cambridge;
- CENAMPS;
- National Physical Laborator;
- Psi-tran Ltd;
- University of Glasgow;
- University of Southampton.

In addition, acknowledgement is given to the contributions of those that commented, including BSI Technical Committee NTI/1, *Nanotechnologies*, the working groups of ISO Technical Committee ISO/TC 229, *Nanotechnologie*s, and other organizations and experts.

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This PAS is not to be regarded as a British Standard. It will be withdrawn upon publication of its content in, or as, a British Standard.

The PAS process enables a specification to be rapidly developed in order to fulfil an immediate need in industry. A PAS may be considered for further development as a British Standard, or constitute part of the UK input into the development of a European or International Standard.

Relationship with other publications

This PAS is issued as part of a suite of nanotechnology terminology PASs:

- PAS 71, *Vocabulary – Nanoparticles;*
- PAS 131, *Terminology for medical, health and personal care applications of nanotechnologies*;
- PAS 132, *Terminology for the bio-nano interface*;
- PAS 133, *Terminology for nanoscale measurement and instrumentation*;
- PAS 134, *Terminology for carbon nanostructures*;
- PAS 135, *Terminology for nanofabrication*;
- PAS 136, *Terminology for nanomaterials*.

PAS 131 to PAS 136 include terms the definitions for which differ to those given in PAS 71:2005, which was published in June 2005. These differences are the result of further reflection and debate and reflect consensus within the PAS steering groups. Until PAS 71:2005 can be revised to incorporate these changes, it is intended that the terms in PAS 131 to PAS 136 take precedence over PAS 71:2005.

This suite of PAS acknowledges the standards development work being conducted by BSI Technical Committee NTI/1, *Nanotechnologies*, ISO TC/229, *Nanotechnologies*, IEC/TC 113, *Nanotechnology standardization for electrical and electronic products and systems*, and CEN/TC 352, *Nanotechnologies*. Attempts have been made to align the definitions in these PASs with the definitions being developed by these committees, particularly the draft ISO/TS 27687 *Terminology and definitions for nanoparticles*. However, as the work of these committees is at a development stage, complete alignment has not been possible in every instance.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a Publicly Available Specification cannot confer immunity from legal obligations.

Introduction

Many authorities predict that applications of nanotechnologies will ultimately pervade virtually every aspect of life and will enable dramatic advances to be realized in most areas of communication, health, manufacturing, materials and knowledge-based technologies. Even if this is only partially true, there is an obvious need to provide industry and research with suitable tools to assist the development, application and communication of the technologies. One essential tool in this armoury will be the harmonization of the terminology and definitions used in order to promote their common understanding and consistent usage.

This terminology includes terms that are either specific to the sector covered by the title or are used with a specific meaning in the field of nanotechnology. It is one of a series of terminology PASs covering many different aspects of nanotechnologies.

This terminology attempts not to include terms that are used in a manner consistent with a definition given in the *Oxford English Dictionary* [1], and terms that already have well established meanings and to which the addition of the prefix "nano" changes only the scale to which they apply but does not otherwise change their meaning.

The multidisciplinary nature of nanotechnologies can lead to confusion as to the precise meaning of some terms because of differences in usage between disciplines. Users are advised that, in order to support the standardization of terminology, this PAS provides single definitions wherever possible.

1 Scope

This Publicly Available Specification (PAS) lists terms and definitions used in or associated with the naming or describing of applications of nanotechnologies to the fabrication of components, devices, structures or systems with nanoscale dimensions, known throughout this document as *nanofabrication*.

The terms relate specifically to the production of structures and device elements that are typically less than 100 nm in more than 1-dimension.

It is applicable to, though is not limited to, fabrication tools and techniques for electrical, electronic, magnetic, mechanical, optical components, devices, structures and systems, and for the fabrication of larger structures, components, devices and systems from nanoscale elements.

NOTE The term nanolithography is used by some as a synonym for nanofabrication. In this document, nanolithography is regarded as one part of the process of nanofabrication.

This PAS is intended for use by technologists, regulators, non-government organizations (NGOs), consumer organizations, members of the public and others with an interest in the application or use of nanotechnologies in the subject area.

NOTE The fabrication of nanoparticles is covered in PAS 71:2005.

2 Classifiers (general terms)

2.1 nanoscale

size range from approximately 1 nm to 100 nm

NOTE 1 Properties that are not extrapolations from larger size will typically, but not exclusively, be exhibited in this size range.

NOTE 2 The lower limit in this definition (approximately 1 nm) has no physical significance but is introduced to avoid single and small groups of atoms from being designated as nano-objects or elements of ***nanostructures****, which might be implied by the absence of a lower limit.*

[ISO/TS 27687[1]]

2.2 nanostructure

nanoscale structure

2.3 nanolithography

process of defining an arbitrary pattern with minimum feature sizes of less than 100 nm

2.4 self-assembly

assembling of components to create a new level of organization without external input

2.5 directed assembly

formation of a **nanostructure** that can, in principle, have any defined pattern

2.6 top down and bottom up

<**top down**> process that progresses from larger units to smaller units

<**bottom up**> progressing from small or subordinate units to a larger and functionally richer unit

[derived from *The American Heritage Dictionary of the English Language* [2]]

2.7 resist

a radiation sensitive material

NOTE 1 Exposure to patterned radiation produces a latent image in the ***resist****, so after development a relief pattern is left in the* ***resist*** *on the substrate.*

NOTE 2 With a positive ***resist*** *the exposed material is removed by the developer, with a negative* ***resist*** *the unexposed material is removed by the action of the developer.*

2.8 additive processing

layer of new material is added, in order to leave a pattern of deposited material on the substrate

NOTE Two terms are used to describe ***additive processing*** *using* ***resist****: lift-off and stencil. In lift-off the layer of new material is applied to the whole surface, the pattern is revealed after the removal of the unexposed* ***resist*** *with the overlaid material; with a stencil the new material is only added where the surface is not protected by* ***resist*** *(as with electro-plating with a* ***resist*** *layer in place).*

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[1] In preparation.

2.9 subtractive processing
material is removed except where the surface is protected by the patterned **resist**

2.10 printing
process in which a whole pattern is transferred in one process step

2.11 direct writing – primary lithography
process in which the pattern is written into the **resist** in a serial fashion

NOTE This process can be used directly or can define a pattern that can be printed.

2.12 mask
physical embodiment of a pattern

*NOTE A dark/light field photo-mask has the pattern defined in, respectively, transparent/opaque openings in an opaque/transparent background. By extension, a masking layer in **resist** on underlying layers of material written by **primary lithography** is often described as a **mask**.*

2.13 template
physical embodiment of a pattern in relief that allows replication of the pattern (albeit inverted) that can be used to transfer the pattern

*NOTE The word **template** encompasses moulds, dies and stamps.*

2.14 natural lithography
fabrication process in which the definition of the primary pattern is by the replication of a naturally occurring pattern

*NOTE For example, the stripes that occur on collagen fibres or the pattern formed by strands of RNA. The term refers to the use of a **mask** or **template** that does not require the use of a focused beam of radiation to define the pattern.*

[*Natural lithography.* Appl.Phys. Lets 41, 377-379, 1982 [3]]

3 Bottom up

3.1 Chemical

3.1.1 chemical vapour deposition (CVD)
synthesis of a solid material by chemical reaction of a gaseous precursor or mixture of precursors, commonly initiated by heat

NOTE An example would be the growth of carbon nanotubes from methane gas with catalyst particles.

3.1.2 molecular beam epitaxy (MBE)
technique of growing single crystals in which beams of atoms or molecules are made to strike a single-crystalline substrate in a vacuum, giving rise to crystals whose crystallographic orientation is related to that of the substrate

NOTE 1 The beam is defined by allowing the vapour to escape from the evaporation zone to a high vacuum zone through a small orifice.

*NOTE 2 **Nanostructures** can be grown in this method by exploiting strain, e.g., InAs dots on GaAs substrate.*

[*McGraw-Hill Dictionary of Scientific and Technical Terms* [4]]

3.2 Solution – templated

3.2.1 hard
template whose shape remains fixed during processing

NOTE An example of this is a self-assembled array of uniformly sized glass or polymer microbeads.

3.2.2 soft
template whose shape can change during processing, while retaining the desired geometric relationship, e.g. periodicity

*NOTE An example of this is a lyotropic liquid crystal **template**.*

3.3 Solution – non-templated

3.3.1 radiation track etching
formation of a **nanostructure** by etching along the pathways formed by radiation damage in a solid

NOTE An example of this is a porous polymer in which tracks are etched using a selective solvent that only dissolves short chains.

3.3.2 anodic etching
removal of material by application of a positive electrical potential to a metal in a suitable electrolyte solution

NOTE 1 The formation of a nanostructured porous material is due to the focusing of current density at the thinnest points in a passivating oxide, which generally form a quasi-periodic array that have been created by the radiation.

NOTE 2 Examples are anodic etching of porous silicon and alumina that leaves nanosize openings in the material.

3.3.3 sol-gel processing
production process involving the conversion of a sol to a gel, which is then desiccated to produce particles or a film

*NOTE A thin layer of the sol deposited on a substrate continues to react until the degree of cross-linking transforms the sample into a solid-like gel. The latter maybe heated to remove volatile products so forming a **hard** solid film.*

[derived from PAS 71:2005, definition **6.23**]

3.3.4 electroplating
deposition of a film by application of electric current between an electrically conducting substrate and an electrolyte containing a solution of a compound that can be reduced or oxidized to form a solid film on the substrate surface

4 Top down

4.1 Mechanical

4.1.1 Primary lithography – direct writing

4.1.1.1 scanning probe microscopy (SPM)
method in which a probe is scanned over the surface of a sample, usually coupled to a feedback loop. A generic term for all devices using physical interaction between a probe tip and a sample surface for sub-micrometer imaging

NOTE 1 Amongst this family the following can be used for nanofabrication, for example, the physical probe can be used to move or place atoms on a surface, change the chemistry of a surface, or remove material from a surface in a controlled manner leaving a textured surface.

NOTE 2 Established types of ***scanning probe microscopy*** *that can be used for nanofabrication include:*

- *AFM (Atomic Force Microscopy);*
- *MFM (Magnetic Force Microscopy) ;*
- *SNOM (Scanning Near-field Optical Microscopy (or NSOM Near Field Scanning Optical Microscopy));*
- *SECM (Scanning Electrochemical Microscopy);*
- *STM (Scanning Tunneling Microscopy).*

4.1.1.2 scanning tunneling microscopy (STM)

technique for revealing the apparent electron-density-related atomic structure of surfaces, using a needle-like probe near the object under observation; a tunneling current, which is measured, is generated by altering the potential at the tip of the probe; a 3D representation of the sample surface is generated by rastering the tip over the surface of the object and mapping the distance for constant current level at various points

NOTE STMs have also been used to produce changes in the molecular composition of substances.

[PAS 71:2005, definition **10.28**]

4.1.1.3 atomic force microscopy (AFM)

technique for imaging surfaces by mechanically scanning their surface contours using a microfabricated probe, in which the deflection of a sharp tip sensing the surface forces, mounted on a **soft** cantilever, is monitored as the tip is moved across the surface

NOTE Part of the family of microscopies referred to as ***Scanning Probe Microscopy*** *(SPM).*

[PAS 71: 2005, definition **10.2**]

4.1.1.4 laser assisted ablation

method of producing features on a surface using the energy from a (typically pulsed) laser to erode material from the surface of a target material or structure

4.1.2 Deposition

4.1.2.1 scanning probe microscopy (SPM) (STM/AFM)

See **4.1.1.1**

4.1.2.2 dip-pen nanolithography

direct-write **soft lithography** technique that is used to create **nanostructures** on a substrate of interest by delivering collections of molecules via capillary transport from an AFM tip to a surface

NOTE The writing speed can be increased by using multiple 'pens' writing in parallel. Applications of this technology currently range through chemistry, materials science, and the life sciences, and include such work as biological gene nanoarrays, additive photo-mask repair.

[http://www.nano.org.uk/nano/glossary.htm#d [5]]

4.1.2.3 nano-imprint lithography (NIL)

process in which a pattern is transferred by pressing a **template** (usually called a die or stamp or mould) of the desired pattern in relief into a deformable **resist**, which is cured in one of a number of ways

NOTE 1 Types of ***nano-imprint lithography*** *are conveniently divided by the use of a particular type of* ***resist for imprinting****. With thermoplastic polymeric materials, the* ***resist*** *is heated so that it can flow when the pressure is applied to the* ***template****. With thermosetting* ***resists****, heat is applied after the initially liquid resist has been displaced by the* ***template****. Negative photo-sensitive* ***resists*** *can be set by the application of light though the (transparent in this case)* ***template****. Techniques using photo-sensitive* ***resist*** *are called, by different workers, optical imprinting, optical nano-imprinting or step and flash.*

NOTE 2 As the pattern is defined by the topography of the ***template*** *it is a* ***printing*** *process and not a* ***primary lithography****. Mechanical transfer is a synonym for nano-imprint lithography.*

4.1.2.4 resist for imprinting

polymeric materials that are deposited to form the **resist**

NOTE When the ***template*** *is pressed into the* ***resist*** *to form a pattern, the* ***resist*** *is displaced and a relief pattern is formed.*

4.1.2.5 residual layer

unwanted thin layer of **resist** remaining on the substrate after imprint stage

NOTE The ***residual layer*** *is removed by an anisotropic* ***dry etching*** *step (in for example oxygen).*

4.1.2.6 soft lithography

mechanical **printing** techniques in which an elastomeric (or ***soft***) **template** is used to transfer the pattern

NOTE ***Soft lithography*** *is a term introduced by Xia and Whiteside.*

[derived from XIA, Y.N., G.M. WHITESIDES, *Soft lithography* [6]]

4.1.2.7 micro contact printing

form of **soft lithography** in which a **soft** mould is dipped into an ink and the pattern transferred to a substrate by pressing

NOTE The fidelity of the transfer is strongly dependent on the local surface characteristics of the substrate for the particular material used as an ink.

4.1.2.8 nano embossing (including 3D patterning)

transfer of a pattern using a **template** into bulk material rather than into a thin film.

NOTE In embossing the flow of material displaced by the ***template*** *is not constrained. The embossed artefact is normally the end product while in imprinting the patterned* ***resist*** *is used in subsequent processing.*

4.1.3 Etching

4.1.3.1 dry etching

process that makes use of partially ionized gases, produced by a low pressure discharge, where ions, electrons and activated neutrals are produced from relatively inert molecular gases, to remove material from a substrate

NOTE ***Dry etching*** *can be a physical process in which inert gases like argon are used to erode the surface, or it can be a combination of physical and chemical material removal when used with fluorine-, chlorine-, or bromine-containing gases. In* ***plasma etching*** *the substrate is in direct contact with the plasma, exposed at the same pressure level (as opposed to ion beam etching). A key to the naming of etching machines is in Annex A.*

4.1.3.2 plasma etching

process that takes place in a plasma consisting of ions and electrons formed by an electrical discharge to remove material from a substrate

NOTE 1 The term ***plasma etching*** *machine is usually restricted to a machine with two capacitive electrodes in which the material to be etched is immersed in the plasma*

NOTE 2 As the ionization of the gas is rarely complete, there are also neutral species, some in an excited state (radicals) that can participate in the etching.

NOTE 3 The term ***plasma etching*** *machine is usually restricted to a machine with two capacitive electrodes in which the material to be etched is immersed in the plasma (see Annex A (e)).*

4.1.3.3 chemical etching

process of using acids, bases or other chemicals to dissolve away unwanted materials from a substrate

NOTE The products of a chemical etch are either soluble in the etch solution (as in ***wet etching****) or volatile at low pressures (as in* ***dry etching****).*

4.1.3.4 physical (sputter) etching

process of etching through physical interactions (momentum transfer) between accelerated chemically inert ions (e.g. argon) and etched solid

NOTE The process is anisotropic, and non-selective.

4.1.3.5 wet etching

chemical etching process with a liquid etchant, as opposed to a plasma etch

4.1.3.6 dry ashing

form of **chemical etching** in which surface material is spontaneously etched by the neutral or activated gas and forms volatile etch products

NOTE For example photoresist ***mask*** *removal in an oxygen plasma ambient.*

4.1.3.7 ion beam etching (milling)

<in ion beam etching> a plasma source produces a (neutral) beam that is transported to the substrate to remove material from a substrate

NOTE 1 The substrate is held at a low pressure and the plasma is formed in a separate ion source. A decoupled plasma is also called a remote plasma, and the equipment needed is called a triode setup. The plasma source can be an RF discharge or a dc source (Penning source). In a typical triode setup control of the energy and flux of ions to the substrate in the substrate chamber happens independently. The sample being etched can be made neutral by extracting low-energy electrons from an auxiliary thermionic cathode, thus making this usable for sputtering insulators as well as conductors.

NOTE 2 ***Chemically assisted ion beam etching*** *(CAIBE) uses an injected reactive gas in the vicinity of substrate.*

4.1.3.8 **reactive ion etching (RIE)**

form of **plasma etching** in which the wafer is placed on an RF driven electrode and the counter electrode has a larger area than the driven electrode

NOTE The plasma beam is generated under low pressure by an electromagnetic field. High energy ions, predominantly bombarding the surface normally create a local abundance of radicals that react with the surface. RIE can produce very anisotropic profiles as compared with isotropic profiles produced with wet ***chemical etching****.*

4.1.3.9 **light-assisted etching**

processes where light is used to influence or control the etching process

NOTE ***Light-assisted etching*** *is based on the photosensitivity of* ***chemical etching*** *under certain conditions. A desired lateral structure can be produced, depending on the illumination pattern, which is defined by optical imaging during the etching process. This technique has been used to prepare laterally structured luminescent porous silicon for example.*

4.1.3.10 **focused ion beam (FIB)**

beam of ions (usually gallium) focused through a set of electrostatic lenses to create a small spot on the substrate

NOTE 1 The beam removes material from the substrate through ***physical sputtering****. The beam spot can be scanned across the surface to create a pattern. Nanometer scale resolution can be obtained in this process.*

NOTE 2 Also know as FIB milling.

4.1.3.11 **chemically assisted ion beam**

reactive gases are introduced during etching via needles or gas rings above the substrate

4.1.3.12 **high density plasma**

plasma etching which uses a high density (typically 10^{11} to 10^{12} ions/cm^3) ion beam as created by electron cyclotron resonance, **helicon**, **magnetron** or inductive methods

NOTE Plasma can be used for either etching or deposition depending on the location of the substrate.

4.1.3.13 **electron cyclotron resonance (ECR)**

ionized plasma produced by superimposing a static magnetic field and a high-frequency electromagnetic field at the **electron cyclotron resonance** frequency

NOTE A large number of multiply charged ions can be efficiently created and used for ***plasma etching****.*

4.1.3.14 **magnetron**

process in which plasma is confined by a magnetic field, ionization efficiency is increased leading to higher density of ions

4.1.3.15 **helicon**

method by which a **high density plasma** is generated using a helical antenna

4.1.3.16 **inductive coupled plasma (ICP)**

method by which energy is magnetically coupled into the plasma by a current carrying loop around the chamber

4.1.3.17 **isotropic etch**
process (usually wet) in which etch rate in the horizontal and vertical directions are identical

4.1.3.18 **anisotropic etch**
process in which etch rate in the direction normal to the surface is much higher than in direction parallel to the surface

NOTE No undercutting, i.e. lateral distortion of pattern is minimized, is needed to define very tight geometries with high aspect ratios.

4.1.3.19 **selective etching**
process in which one material is etched rapidly while the other is etched very slowly or not etched at all

NOTE For example, HF water solution etches SiO_2 *very rapidly while not etching silicon.*

4.1.3.20 **crystallographic etch**
process in which the etch rates are different for different crystallographic directions

4.1.3.21 **ion damage (semiconductors)**
any deterioration in the electrical or optical properties of the semiconductor after exposure to ions

NOTE In Si, the major concern is static charge introduced into the gate insulator, in III-V ***semiconductors*** *ion assisted diffusion of dopant species.*

4.1.3.22 **deep reactive ion etching (DRIE)**
highly **anisotropic etch** process used to create high aspect ratio structures

NOTE 1 For example steep sided holes and trenches.

NOTE 2 There are two main technologies for DRIE: cryogenic and Bosch.

4.1.3.22.1 **Bosch process (pulsed or time-multiplexed etching)**
alternates repeatedly between two modes to achieve nearly vertical structures

NOTE 1 In one mode a standard, nearly isotropic plasma etch, is applied and in the second mode a chemically inert passivation layer is deposited. The passivation layer protects the entire substrate from further ***chemical etching****.*

NOTE 2 During the etching phase, the directional ions that bombard the substrate attack the passivation layer at the bottom of the trench (but not along the sides), they collide with it and sputter it off, exposing the substrate to the chemical etch.

4.1.3.22.2 **cryogenic process**
substrate cooled to approximately 163K

NOTE The low temperature slows down the chemical reaction that produces ***isotropic etching****. Ions continue to bombard upward-facing surfaces and etch them away producing steep side walls.*

4.1.4 Deposition

4.1.4.1 focused ion
ion beam induced deposition used to deposit material

NOTE FIB-assisted chemical vapour deposition occurs when a gas, such as tungsten carbonyl ($W(CO)_6$) is introduced to the vacuum chamber and allowed to chemisorb onto the sample. By scanning an area with the beam, the precursor gas will be decomposed into volatile and non-volatile components; the non-volatile component, such as tungsten, remains on the surface as a deposit. This is useful, as the deposited metal can be used as a sacrificial layer, to protect the underlying sample from the destructive sputtering of the beam. Other materials such as platinum can also be deposited.

4.1.4.2 focused electron
deposition of material using a **focused electron** beam

NOTE As in focused beam ion deposition a precursor gas is used.

4.1.4.3 charged beam writing machine
machine that uses a focused beam of charged particles (ions or electrons) to expose a **resist** in a deliberate pattern

*NOTE A deflection system under computer control, a beam blanker and a **stage** form parts of this system.*

4.1.4.4 picture element
<in a focused beam pattern generation machine it is the> area between the nearest neighbour points in the **address grid**

4.1.4.5 pixel
shortened form of **picture element**

4.1.4.6 pixel rate
number of **pixels** addressed per unit time (inversely proportional to the dwell time per **pixel**)

4.1.4.7 direct writing
process in which a primary pattern in **resist** is defined by a **charged beam writing machine**

4.1.4.8 Gaussian beam
electron beam, focused to a single circular spot, in which the cross-sectional current density has a 2-dimensional Gaussian distribution

4.1.4.9 shaped beam
an electron beam focused to a specific fixed shape in which the **areal current density** is uniformly distributed throughout the shape

4.1.4.10 variable shaped beam
differs from a **shaped beam** in that the shape may be dynamically modified at high speed by changes to the optics

4.1.4.11 projection beam
shaped beam that contains a multiplicity of fixed shapes

4.1.4.12 raster scan
writing strategy in which all **address grid** points within a field are sequentially scanned by the beam but the beam is blanked where there are no pattern elements to be written

NOTE The scanning sequence is usually by row, always scanned in the same direction with a "beam flyback" taking place after the end of each row.

4.1.4.13 vector scan
writing strategy in which the beam is only scanned over the **address grid** points contained within individual elements of the pattern

4.1.4.14 serpentine (boustrophedan) scan
writing strategy for individual pattern elements where **pixels** are exposed in rows (or columns) in alternate directions

4.1.4.15 areal current density
measure of the intensity of the beam given by the number of particles (ions or electrons) charge per unit area per second times the charge carried by each particle

4.1.4.16 areal dose
charge density delivered to the substrate when scanning a 2-dimensional pattern element

4.1.4.17 line dose
charge delivered to the substrate during a single pass line scan, normally defined in terms of Coulombs per cm

4.1.4.18 gamma
measure of the contrast of a photographic process

*NOTE It is normally defined for a positive **resist** as the maximum value of slope of a plot of the remaining thickness versus the logarithm to base 10 of the dose.*

4.1.4.19 spot size
for a **Gaussian beam** the diameter, which contains between 12% and 88% of the integrated current of the beam

4.1.4.20 blankers
device that is between the charge source and the **stage** that allows or disallows the charged particles to continue to the **stage**

4.1.4.21 step size
distance between two adjacent points in the **address grid**

4.1.4.22 stage
table carrying the sample (wafer) that can be moved to allow **field stitching** and **alignment**

4.1.4.23 field stitching
ability to accurately join small scanned areas together side by side in order to pattern a larger area

4.1.4.24 address grid
2-dimensional array of points in the plane of the substrate plane onto which the final focused beam can be positioned

4.1.4.25 main field
portion of the above grid which is addressable directly with the main field deflector system

NOTE Usually at slow speed but high accuracy.

4.1.4.26 sub field
small subsets of the main field which are addressable by the sub field deflector (usually at high speed)

*NOTE When used together, the main and **sub field** deflectors can address a large area at high speed.*

4.1.4.27 alignment
ability to position a layer of lithography to markers previously defined on the substrate

4.1.4.28 alignment marks
patterns previously formed or written onto a substrate, from which subsequent lithography processes can determine the exact positioning of the sample/wafer and hence allow the location of subsequent patterns to high tolerance

4.1.4.29 overlay accuracy
accuracy to which features in a subsequent layer of lithography are aligned to those in a previous layer

4.1.4.30 proximity correction
charged particles striking the sample give raise to secondary particles of limited range that also expose the **resist**, thus the developed pattern is not a true representation of the intended pattern

*NOTE Correction is done by modifying of the dosage in each **pixel** so that the desired pattern in **resist** is obtained.*

4.1.4.31 printing using charged beams
process in which the pattern is printed rather than directly written

4.1.4.32 stencil mask
mask consisting of holes in a material that does not allow transmission of the charged beam

4.1.4.33 electron or ion projection printing
process in which a **stencil mask** to use to transfer the pattern in the **mask** by spatial modulation of the distribution of charged particles to **resist** on the sample

4.2 Electro-magnetic radiation

4.2.1 Etch

4.2.1.1 photochemical-etching
See **4.1.3.9**

4.2.2 Print

4.2.2.1 x-ray lithography
process that uses x-ray radiation to expose the **resist**

*NOTE As x-rays are difficult to focus to a nanometrically sized beam (but see **extreme ultra violet lithography**), **x-ray lithography** is used to refer to a **printing** process, using a **mask** that has a pattern that consists of regions opaque and transparent to x-rays. The **mask** typically consists of a membrane of a material that has low x-ray absorption, with a pattern of highly absorbing material (e.g. a metal).*

4.2.2.2 extreme ultra violet (EUV) lithography

reduction **printing** is used to produce an image in **resist** using radiation of wavelength in the 10 to 100 nm range

*NOTE Usually reflective optics are used to focus the radiation (see **4.2.2.5**, Note 2).*

4.2.2.3 deep ultra violet (DUV) lithography

wavelength of the radiation used to produce an image in resist is in 100 to 200 nm range

4.2.2.4 immersion optics

technique of immersing the wafer coated photoresist in a suitable liquid that is used to reduce the effective wavelength employed to transfer the image to the resist

NOTE The effective wavelength is decreased by the refractive index of the liquid.

4.2.2.5 optical lithography

process in which electromagnetic radiation of greater than 100 nm is used to produce an image in the **resist**

*NOTE 1 This distinguishes **optical lithography** from x-ray or **EUV lithography** in which shorter wavelengths are used*

*NOTE 2 For **optical lithography** to achieve the resolution required for the sub 100 nm regime of interest in nano-fabrication requires the use of particular techniques, for example immersion and **assist features** in the **mask**. At the time of writing, primary **optical lithography** in which a focused beam of light is scanned in order to write an arbitrary pattern has not been demonstrated in the sub 100 nm regime. Optical **printing** using a **mask** prepared by electron beam lithography has demonstrated sub 100 nm resolution. In such **optical lithography**, pattern defined in the **mask**, then called a **reticle**, is reduced in size by the optical lenses in this optical reduction printer.*

4.2.2.6 optical proximity correction

denotes the correction of the original pattern so as to ensure that the aerial image recorded in the photoresist is as good an approximation as possible to the desired final pattern

*NOTE This is done by the addition of **assist features** to the pattern in the original **mask** or **reticle**.*

4.2.2.7 assist features

patterned layer of material, usually transparent, that is present on the **mask** or **reticle**, in addition to the pattern of light absorbing material

NOTE Its purpose is to adjust the phase of the transmitted light.

4.2.2.8 projection optical printing tool

tool in which an image of the **mask** is projected onto the **resist** on the wafer

*NOTE Usually such tools that are capable of sub 100 nm resolution use reduction optics – that is a reduced image of the original **mask** is project onto the **resist**. In this case the **mask** is usually called a **reticle**.*

4.2.2.9 reticle

mask that is a magnified version of the pattern, used in reduction projection **printing**

NOTE Also spelt as reticule.

5 Abbreviations

AFM	Atomic Force Microscopy
CVD	Chemical Vapour Deposition
DUV	Deep Ultra Violet (often taken as wavelength > 100 nm)
ECR	Electron Cyclotron Resonance
EUV	Extreme Ultra Violet (often taken as wavelength < 100 nm)
FIB	Focused Ion Beam
ICP	Inductive Coupled Plasma
MBE	Molecular Beam Epitaxy
NEMS	Nano Electro-Mechanical Systems
NIL	Nano Imprint Lithography
RIE	Reactive Ion Etching
SNOM	Scanning Near-Field Optical Microscopy
STM	Scanning Tunelling Microscopy

Annex A (informative) Etching machines

A.1 Identification of different types of etching

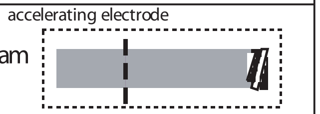
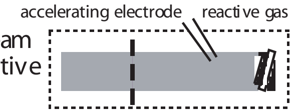
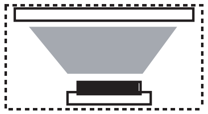
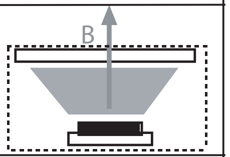
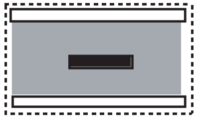
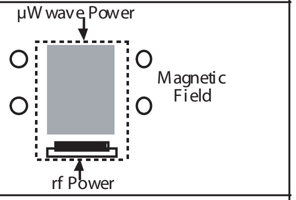
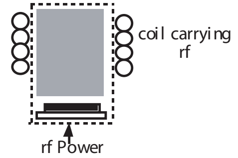
The are three main varieties of such machines:

a) ion beam machines ((a) and (b));

b) machines that have RF driven capacitive electrodes ((c), (d) and (e)); and,

c) machines that produce high ion density plasma (in the range of 10^{11} ions/cm^3), ((f) and (g)).

In the machine that have capacitive electrodes, the energy of the ions bombarding the sample and the ion density vary with the power of the single external power source; in the high density and ion beam machines, the generation of the plasma and the ion extraction (and so ion energy) are controlled separately by different power sources.

	Ions generated by:	Ions extracted by:	Gas selected to be:	Usual Name	Diagram and distinguishing features
a)	hot wire (dc) or plasma gun	dc fields	not reactive	Ion Beam Etching IBE	Noble gas ion beam 
b)	hot wire (dc) or plasma gun	dc fields	reactive	Chemically Assisted Ion Beam Etching CAIBE	Noble gas ion beam with injected reactive gas 
c)	rf discharge	same rf field	reactive	Reactive ion etching RIE	pressure typically less than 50 mT driven electrode smaller 
d)	rf discharge	same rf field	reactive	Magnetron reactive	Axial Magnetic Field to increase ion density pressure typically less than 50 mT driven electrode smaller 
e)	rf discharge	same rf field	reactive	Plasma Etching PE	Relatively high pressure around 1 T 
f)	microwave field with magnetic field	separate rf field	reactive	Electron Cyclotron Resonance-Reactive Ion Etching ECR-RIE	high ion density Pressure 1-5 mT typically 
g)	rf field induced by a driven loop	separate rf or lf field	reactive	Inductively Coupled Plasma Etching ICP Etching	high ion density Pressure 1-5 mT typically 

Key to Etching machines

⬚	vacuum envelope	▬	wafer for etching	▭	electrode	▨	plasma

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