NaDa Taxonomy: a common vocabulary for FAIR Nanofabrication Data management

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Introduction

Nanotechnologies are greatly interested in FAIR data management and dedicated ontologies, since developing materials and devices, understanding new materials and supporting applications in health, environment and other key and challenging areas require long times, huge resources, both infrastructure and materials and energy, and skilled staff, which are probably today the most rare resources.

In the field of nanotechnologies, the research areas of materials/nanomaterials development, (including modelling and simulations), and materials characterization are experiencing well- developed studies aimed at establishing structured methodologies for describing and archiving experiments. We cite Characterization Data (ChaDa) [1,2], dedicated to data management of material characterization experiments, and Modelling Data (MoDa)[3,4], which keep evolving and are for sure important references for both ontology and FAIR data management in the mentioned fields.

In this paper, we introduce *Nanofabrication Data (NaDa)* Taxonomy, a shared vocabulary tailored specifically for the nanofabrication ecosystem. We have start working on FAIR data management for a speific research area part of nanotechnologies: the nanofabrication. By aligning with the FAIR Data Principles, NaDa Taxonomy sets out to unify descriptive and procedural terms, creating a consistent foundation for data documentation and management across different labs, instruments, and projects. The goal is to allow researchers not only to locate and retrieve valuable datasets readily, but also to interpret and integrate them seamlessly into new or ongoing experiments. As nanofabrication accelerates toward increasingly intricate devices and processes, adopting a standardized taxonomy is essential for collaborative research, knowledge transfer, and, ultimately, the development of next-generation technologies

To better understand the scope and the needs of this work, it is worthwhile introducing EuroNanoLab (ENL). ENL is a distributed research infrastructure consisting of over 40 state-of-the-art academic nanofabrication centers across Europe, most of which having semiconductor cleanrooms.

Since its very beginning, in 2016, ENL has defined the data management as one of the pillars of its activity, dedicating one of its “Expert groups” to this topic, and initiating the development of a FAIR model for nanofabrication by joining the GO FAIR initiative[5]. ENL elaborated the GO NANOFAB manifesto[6], which contains the main features of nanofabrication and cleanroom process flows, to underline the value of paradigms and tools allowing to save time and resources and avoiding to

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[1] https://zenodo.org/records/2636609
[2] https://www.cencenelec.eu/media/CEN-CENELEC/CWAs/RI/2025/cwa17815_2025.pdf
[3] https://emmc.eu/moda
[4] https://www.cencenelec.eu/media/CEN-CENELEC/CWAs/RI/cwa17284_2018.pdf
[5] https://www.go-fair.org/go-fair-initiative/
[6] https://www.go-fair.org/implementation-networks/overview/go-nanofab/

"reinvent the wheel". Here we simply highlight that cleanroom tools can cost anywhere from some tens of thousands to some million euros, even in R&D configurations, and that the setup of new processes could require one year to achieve a first controlled "silicon loop"[7].

Accordingly, we consider it relevant and useful to develop NaDa, a standardized vocabulary dedicated to nanofabrication of sensors and devices in cleanrooms, in order to improve data management in this research field and to support a FAIR nanofabrication data system.

The present work illustrates the first release of the NaDa taxonomy, verified on the technology available in three Italian cleanrooms, (MNF@FBK[8], Cleanroom ISNM@CNR[9], PiQuET@INRIM-PoliTO[10]), and on the research results of previous studies and projects, presented in the following section.

Available taxonomies connected to nanofabrication

An examination of the international panorama of public research cleanrooms at the European level, reveals a great variety in the vocabularies used to describe technologies, cleanroom equipment and cleanroom fabrication process steps.

A preliminary survey of existing studies on taxonomies for cleanroom nanofabrication, identified several references that can be considered as starting points:

- project NanoFabNet[11], which partially built its results on ISO-TS 80004-8:2020
- PAS 135:2007, published by the British Standard Institution in 2007[12]
- ISO-TS 80004-8:2020[13] (with updates in the ISO 80004-1:2023[14]), and ISO standard dedicated to nanomanufacturing
- NNCI tools, the National Nanotechnology Coordinated Infrastructure, collecting tool information from several American research centers[15].

NanoFabNet taxonomy

NanoFabNet examined the cleanrooms of the EuroNanoLab and some cleanrooms in the USA, collecting information from 66 cleanrooms in total. A huge analysis work has been done to define logical consistence of groups and sub-groups, with great effort dedicated to interview to cleanroom staff and experts to converge to common definitions.

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[7] J. A. Liddle et al., «So, You Want to Have a Nanofab? Shared Use Nanofabrication and Characterization Facilities: Cost-of-Ownership, Toolset, Utilization, and Lessons Learned,» Journal of Research of the National Insitute of Standards and Technology, vol. 125, p. 125009, 2020.
[8] http:// https://sd.fbk.eu/en/infrastructure/
[9] http:// https://www.bo.imm.cnr.it
[10] https://www.inrim.it/it/ricerca/infrastrutture/piemonte-quantum-enabling-technology-piquet
[11] https://www.nanofabnet.net/
[12] https://it.scribd.com/doc/300313330/PAS-00135-2007
[13] https://www.iso.org/standard/74666.html
[14] https://www.iso.org/obp/ui/en/#iso:std:iso:80004:-1:ed-1:v1:en
[15] https://nnci.net/search/tools

The work developed in NanoFabNet produced the first classification of all the fabrication tools available in the ENL cleanrooms, and for sure can be considered the main reference also for the NaDa project. The technologies and tools have been organized according to a three-levels structure:

- Top level: *Main Category*. It refers to 5 high level technologies: *lithography, etching, deposition, packanging, other*; proposing for the first three ones a connection with the ISO/TS 80004-8:2020 definitions: “Nanopatterning lithography”, “Etching processes”, “Deposition processes”.
- Secon level: *Subcategory.*
- Third level: *Generic Tool*.

More than 3000 tools have been processed in this project. The final map consists of 5 categories, 21 subcategories and 55 generic instrument names.

PAS 135:2007 - Publicly Available Specifications: Terminology for Nanofabrication

This work, dated 2007, developed by the British Standards Institution, proposes a series of terms referred to nanofabrication organized in three main sections: Classifiers, dedicated to base terms like nanostructure, nanoparticle, nanolithography, and Bottom Up and Top Down sections with focus both on some of the technologies, like DRIE, CVD, NIL, and to detail terms like reticle, stage, proximity correction.

ISO nanomanufacturing vocabulary

The ISO/TS 80004-1:2020 standard is based on a rigorous methodology, and documentation includes clear definition of basic building block, like nanostructure, nanotechnology,… and rely on the experience of ISO in several other contexts. It includes several tens of definitions and, as said, is one of the sources used by NanoFabNet. It is really interesting also for the details proposed for some of the categories, like nanopatterning and material synthesis, which are of particular relevance in nanofabrication.

NNCI

This third reference is interesting for the high number of tools managed across several research institutions. It offers the possibility to easily search tools, though at the moment, it does not propose a general, rigorous classification, acting more as a global database.

NaDa taxonomy rev. 0

The main aim of the NaDa project is to contribute to the development of a taxonomy that supports the definition of FAIR data management for cleanroom nanofabrication, useful per se, to enable faster and easier information exchanges and serving as the basis for a dedicated ontology.

According to the FAIR paradigm, we worked to create a vocabulary structured to manage current nanofabrication technologies and opened to updates.

The first step was to define nanofabrication at a very high and general level. The fabrication of a device using cleanroom technology can be simplified as a sequence of thin layers of materials being added on a starting substrate, typically a semiconductor wafer (or a piece of it). The final structure is obtained by selectively removing part of these layers in defined areas, through patterning and etching steps, according to the device design. The materials could remain as deposited, or grown, or they may undergo transformation during processing, e.g., through thermal steps that densify their structure.

This highly simplified definition of nanofabrication can of course be further detailed, however the important point is that it allows us to classify all process steps in three main categories:

- ADD: whatever fabrication step “adding something” on the top of the processed item (e.g. the wafer), or inside it
- REMOVE: action operating to remove (etch) materials from the processed item
- TRANSFORM: actions which don’t really add or remove materials, but change properties of the materials and/or the substrate.

Below this top-level classification, referred to as “super class”, we defined the “classes”, that describe groups of technologies, partially corresponding to the NanoFabNet “Main Categories”. As an example, the ADD super class includes the following “classes”:

- synthesis: the placing of a substance on a substrate
- Integration: process by which two materials adhere to each other ensuring a mechanically stable interconnection; connecting different components.

Moreover, ADD can host technologies like wafer-to-wafer integration and wafer-level-integration, opening the classification to recent evolution of micro-nanofabrication of devices.

Specific nanofabrication technologies are listed in the third level of the classification, referred to as “class instances”. As an example, synthesis includes:

- Atomic Layer Deposition ALD
- catalytic chemical vapour deposition CCVD
- Chemical Vapour Deposition CVD
- dip coating
- Electrodeposition, electroplating
- Electroless deposition
- electro-spray
- evaporation
- focused electron-beam deposition
- focused ion-beam deposition FIB deposition
- Molecular beam epitaxy MBE
- Physical Vapour Deposition PVD
- sputter deposition
- polyelectrolyte layer-by-layer LbL
- Thermal spray
- Spin coating
- spray deposition
- surface polymerization.

Although it is obvious how challenging it is to identify appropriate definitions, we believe that meeting FAIR requirements necessitates the clear and unambiguous identification of “things”. According to this, we decided to avoid using groups labelled as “other”.

According to ISO Technical Specifications and NanoFabNet documentation, we identified two critical technologies that were missing: thermal processing and certain doping techniques. Furthermore, as previously mentioned, integration and packaging are now considered part of the fabrication process, and for this reason we decided to include them in the main classification.

Material characterization and device testing are crucial for the development of new devices and processes. However, due to the availability of CHADA, we decided to limit our work to nanofabrication technologies, that is to technologies that impact device development, refering to CHADA for its measurement and characterization.

The work was further complemented by a first classification of generic tools, inspired by NanoFabNet. These tools should not be considered a “fourth level” of the classification, but rather a complementary component for building the ontology in the field of nanotechnology. Indeed, tools are essential for the implementation of technologies, but they are distict entities. They are characterized by specific attributes that need to be managed, such as recipes, operating parameters, handling constraints and more.

Appendix I reports the draft of the rev.0 of the NaDa taxonomy.

Acknowledgment

This work has been initially inspired by the EuroNanoLab and its continuous attention to the topic of scientific data management and the importance of sharing the know-how, and making it available outside the research infrastructure, to maximize its impact at large. It has been further developed thanks to two strategic projects, iEntrance and NFFA-DI, both part of the Italian Recovery and Resilience Plan (PNRR). Both iEntrance and NFFA-DI include specific effort on digital empowerment of nanotechnologies and favoured discussions bringing to this document.

Appendix I

NaDa rev. 0 – April 2025

Top level categories: main nanofabrication types

process superclass	***group process steps determining the same type of effect on the item which is undergoing the fabrication. Types are ADD, REMOVE, TRANSFORM***
ADD	nanofabrication process class including elementary nanofabrication processes determining the integration of a layer of material on the surface of the item undergoing the fabrication using chemical or physical effects
REMOVE	nanofabrication process class including elementary nanofabrication processes determining the removal of material from the surface of the item or directly part of the item undergoing the fabrication usign chemical or physical effects
TRANSFORM	nanofabrication process class including elementary nanofabrication processes determining a chemical or physical change in the item or in the material layers present on the surface of the item

Second level: technologies groups

process super class	***process class***	***Definition***
transform	lithography	Process in which a pattern is transferred from a CAD based set of information and data into a resist or directly into a substrate. These or the complementary parts are then later removed
remove	etching	A process used in micro- and nanofabrication to chemically or mechanically remove layers from the surface of a item undergoing fabrication (wafer, but not only) during fabrication/ manufacturing. Comment: Etching is a critically important process module in nanofabrication, and every wafer undergoes many etching steps before it is complete.
add	synthesis	the placing of a substance on a substrate Comment: This might be individual atoms or the forming of a layer of a substance
add	integration	process by which two materials adhere to each other ensuring a mechanically stable interconnection; connecting different components; packaging could be a subcategory
transform	doping	adding elements to the materials under fabrication in order to modify electrical properties like conductivity. Comment: main doping are by ion implantation, diffusion from solid or liquid sources, gas injection
transform	thermal processing	The use of heating associated or not to gas or vapours mixtures, to modify the item (wafer, piece of wafer). Semiconductor thermal processes can reach 1400 oC. They are performed in tools called furnaces, or tubes. Main gas or vapours are: oxygen, hydrogen, nitrogen, argon, vaporized water, chlorine acid
transform	dicing	method to cut a wafer or any other sample to individual dies by mechanical sawing or laser cutting

Third level: technologies

superclass	***class***	***class instance - technologies***	***generic tools***
transform	lithography	3D lithography	laser lithography system that enables the fabrication of true three-dimensional nanostructures using commercially available photoresists
transform	lithography	Additive processing	3D printer
transform	lithography	block copolymer lithography	laser lithography system that enables the fabrication of true three-dimensional nanostructures using commercially available photoresists
transform	lithography	colloidal crystal template lithography	
transform	lithography	dip-pen nanolithography	
transform	lithography	ebeam lithography - electron beam lithography	ebeam, SEM ebeam tool
transform	lithography	photolithography/optolithography	stepper, mask aligner, direct laser writer
transform	lithography	Nano-imprint lithography	nanoimprinting tool
transform	lithography	Focused ionbeam lithography	FIB
transform	lithography	ion induced deposition	FIB with GIS tool
transform	lithography	ion induced etching	FIB
transform	lithography	ion projection lithography	
transform	lithography	micro-contact printing	nanoimprinting tool
transform	lithography	microfluidic deposition	
transform	lithography	nanoembossing	nanoimprinting tool
transform	lithography	natural lithography	
transform	lithography	plasmonic lithography	
transform	lithography	scanning force probe writing	SPM
transform	lithography	scanning tunnelling microscope chemical vapour deposition STM SVD	STM
transform	lithography	soft lithography	nanoimprinting tool
transform	lithography	X-ray lithography	synchrotron facilities

superclass	*class*	*class instance - technologies*	*generic tools*
remove	etching	DRIE Bosch etching	DRIE
remove	etching	DRIE Cryogenic etching	DRIE
remove	etching	dry ashing	plasma or RF or microwave asher
remove	etching	Focus Ion Beam assisted etching/milling	FIB
remove	etching	Inductively coupled plasma etching ICP RIE	ICP RIE
remove	etching	ion beam etching/milling	IBE/CIBE
remove	etching	Laser ablation	laser tools
remove	etching	laser assisted etching/photochemical etching	laser tools
remove	etching	radiation track etching	
remove	etching	RIE	RIE
remove	etching	wet etching	chemical bench
add	synthesis	Adsorption	
add	synthesis	Atomic Layer Deposition ALD	ALD
add	synthesis	catalytic chemical vapour deposition CCVD	CCVD
add	synthesis	Chemical Vapour Deposition CVD	CVD, LPCVD, ALCVD, PECVD
add	synthesis	dip coating	chemical bench
add	synthesis	Electrodeposition, electroplating	chemical bench
add	synthesis	Electroless deposition	chemical bench
add	synthesis	electro-spray	spray nozzle tool
add	synthesis	evaporation	evaporator

superclass	***class***	***class instance - technologies***	***generic tools***
add	synthesis	focused electron-beam deposition	
add	synthesis	focused ion-beam deposition FIB deposition	FIB
add	synthesis	Molecular beam epitaxy MBE	MBE
add	synthesis	Physical Vapour Deposition PVD	PVD, Sputter, Magnetonsputter
add	synthesis	sputter deposition	PVD, Sputter, Magnetonsputter
add	synthesis	polyelectrolyte layer-by-layer LbL	
add	synthesis	Thermal spray	
add	synthesis	Spin coating	spin coater, track
add	synthesis	spray deposition	spry coater
add	synthesis	surface polymerization	
add	bonding	direct bonding	bonder
add	bonding	anodic bonding	bonder
add	bonding	thermalcompression bonding	bonder
transform	dicing	diamond blade dicing	diamond blade
transform	dicing	laser dicing	laser dicer
transform	thermal processing	Silicon dry oxidation	furnace
transform	thermal processing	Silicon wet oxidation	furnace
transform	thermal processing	Sintering	furnace
transform	thermal processing	Anneling	furnace
transform	thermal processing	Drive in	furnace
transform	thermal processing	Baking	baking furnace, furnace
transform	doping	ion implantation	ion implanter
transform	doping	doping by diffusion from solid source	furnace
transform	solution modificatior	resist development	track, becker, wet bench, spin coater

class instance - technologies	***technolgoy definition***
3D lithography	process in which patterns or structuring can be achieved with nanoscale dimensions in all three dimensions
Additive processing	process in which the addition of a layer of new material is used to create a pattern of deposited material on the substrate
block copolymer lithography	process in which microphase separation in diblock copolymers is used to create polymer templates with nanoscale patterns
colloidal crystal template lithography	process in which crystallized colloidal particles are used to create a 2D or 3D framework for subsequent deposition or etching
dip-pen nanolithography	method in which a scanning tip is used to transfer specific material onto a substrate surface, via a solvent meniscus, for patterning a substrate at length scales below 100 nm. "Dip Pen Nanolithography" was the trade name of a product supplied by NanoInk, Inc. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results. [SOURCE:ISO 18115-2:2013, 5.40]
ebeam lithography - electron beam lithography	direct write patterning process that uses a focused, concentrated stream of electrons to modify the solubility of a resist layer
photolithography/optolithography	process in which electromagnetic radiation is used to transfer a mask through a reticle to create a pattern (not in ISO: also direct wite technique is considered)
Nano-imprint lithography	process in which a pattern is transferred by pressing a nanoscale template (usually called a die, stamp, mask or mould) of the desired pattern in relief into a deformable resist, which is then cured thermally or with light
Focused ionbeam lithography	direct write patterning process that uses a focused ion beam to modify the solubility of a resist layer
ion induced deposition	use of a focused, concentrated stream of ions to bring about or give rise to the localized reaction of an adsorbed molecule to deposit material
ion induced etching	use of a focused ion beam to induce the localized reaction of an adsorbed molecule to etch the substrate material
ion projection lithography	use of accelerated ions in conjunction with a mask to create nanoscale exposure patterns in resist
micro-contact printing	form of soft lithography in which a soft mould is dipped into an ink and the pattern transferred to a substate by pressing
microfluidic deposition	use of micrometre scale or nanoscale channels in a solid manifold to facilitate the transfer of material from a liquid or solution state into a solid state onto a substrate surface
nanoembossing	transfer of a pattern using a template into bulk material rather than into a thin film
natural lithography	process in which the primary pattern is defined by the replication of a pattern that occurs in nature 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.
plasmonic lithography	use of nanoscale metallic patterns to guide near-field optical radiation to create nanoscale photolithographic exposure patterns in resist
scanning force probe writing	use of a scanning probe microscope (SPM) tip to mark, ink or otherwise locally modify the surface of a substrate
scanning tunnelling microscope chemical vapour deposition STM SVD	application of a voltage to an STM tip to facilitate nanoscale CVD in the proximity of the tip onto a substrate
soft lithography	mechanical printing processes in which an elastomeric (or soft) template is used to transfer the pattern

class instance - technologies	***technolgoy definition***
X-ray lithography	process that uses X-ray radiation to expose a mask to create a lithographic pattern Note 1 to entry: As X-rays are difficult to focus on a nanoscale-sized beam [(but see extreme ultraviolet lithography (EUV)], 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). Usually, a resist material is used to make the mask.
DRIE Bosch etching	process that alternates repeatedly between an etching mode and a passivation mode to achieve the etching of nearly vertical structures
DRIE Cryogenic etching	process in which the substrate is cooled to approximately 163 K to produce nearly vertical etched sidewall structures
dry ashing	form of chemical etching in which surface material is spontaneously etched by a neutral or activated gas and forms volatile etch products
Focus Ion Beam assisted etching/milling	beam of ions (usually gallium) focused through a set of electrostatic lenses to create a small spot on the substrate. The beam removes material from the substrate through physical sputtering. The beam spot can be scanned across the surface to create a pattern. Nanoscale resolution can be obtained in this process.
Inductively coupled plasma etching ICP RIE	method by which energy is magnetically coupled into the plasma by a current carrying loop around the chamber, using etching based on ions reacting with substrate surface and hitting it
ion beam etching/milling	use of a plasma source to produce an ion beam to remove material from a substrate. varieation of RIE and ICP-RIE; the ions are not attracted to the substrate thanks to electrode configuration, but directly accelerated and shot to the substrate surface, where both physical and chemical reactions determine the material removal
Laser ablation	process using the energy from a pulsed laser to erode material from the surface of a target. It is a method of producing nanoscale features on a surface
laser assisted etching/photochemical etching	processes in which light is used to influence or control the etching process. 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 process has been used to prepare laterally structured luminescent porous silicon, for example.
radiation track etching	formation of a structure by etching along the pathways formed by radiation damage in a solid. EXAMPLE:Porous polymer in which tracks are etched using a selective solvent that only dissolves short chains.
RIE	form of plasma etching in which the wafer is placed on a radio-frequency-driven electrode and the counter electrode has a larger area than the driven electrode. Uses both physical and chemical mechanisms to achieve high levels of resolutions. The process is one of the most diverse and most widely used processes. Since the process combines both physical and chemical interactions, the process is fast. The high energy collision from the ionization helps to dissociate the etchant molecules into more reactive species. In the RIE process, cations are produced from reactive gases which are accelerated with high energy to the substrate and chemically react with the item surface. Factors such as applied coil or electrode power, reactant gas flow rates, duty cycles and chamber presures were considered as main process parameters. 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 etching
wet etching	chemical removal of a surface material with a liquid etchant. chemical removal of a surface material with a liquid etchant; Wet etching is a material removal process that uses liquid chemicals or etchants to remove materials from a wafer. The specific patters are defined by masks on the wafer. Materials that are not protected by the masks are etched away by liquid chemicals. A wet etching process involves multiple chemical reactions that consume the original reactants and produce new reactants. The wet etch process can be described by three basic steps. (1) Diffusion of the liquid etchant to the structure that is to be removed. (2) The reaction between the liquid etchant and the material being etched away. A reduction-oxidation (redox) reaction usually occurs. This reaction entails the oxidation of the material then dissolving the oxidized material. (3) Diffusion of the byproducts in the reaction from the reacted surface
Adsorption	retention, by physical or chemical forces, of gas molecules, dissolved substances or liquids by the surfaces of solids or liquids with which they are in contact
Atomic Layer Deposition ALD	process of fabricating uniform conformal films through the cyclic deposition of material through self-terminating surface reactions that enable thickness control at the atomic scale
catalytic chemical vapour deposition CCVD	chemical vapour deposition based on the decomposition of gaseous molecules in the presence of a catalyst
Chemical Vapour Deposition CVD	deposition of a solid material onto a substrate by chemical reaction of a gaseous precursor or mixture of precursors, commonly initiated by heat
dip coating	creation of a thin film by dipping a substrate into a solution containing the material of interest
Electrodeposition, electroplating	deposition of material onto an electrode surface from ions in solution by electrochemical reduction
Electroless deposition	autocatalytic deposition of material onto a solid surface from ions in solution in the presence of a soluble reducing agent
electro-spray	deposition of material onto a surface by pressurization through a nozzle held at an applied voltage
evaporation	process in which a material is vaporized by heating in high or ultra-high vacuum conditions for subsequent deposition onto a substrate

class instance - technologies	***technolgoy definition***
focused electron-beam deposition	chemical vapour deposition using a focused, concentrated stream of electrons to induce localized reactions of molecules from a precursor gas onto a surface
focused ion-beam deposition FIB deposition	ion induced formation and transfer of a material onto the surface of a substrate. FIB-assisted chemical vapour deposition occurs when a gas, such as tungsten hexacarbonyl (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
Molecular beam epitaxy MBE	process of growing single crystals in which beams of atoms or molecules are deposited on a single-crystal substrate in vacuum, giving rise to crystals whose crystallographic orientation is in registry with that of the substrate. The beam is defined by allowing the vapour to escape from the evaporation zone to a high vacuum zone through a small orifice
Physical Vapour Deposition PVD	process of depositing a coating by vaporizing and subsequently condensing an element or compound, usually in a high vacuum
sputter deposition	physical vapour deposition process employing energetic particles to transfer atoms from a target material to a substrate
polyelectrolyte layer-by-layer LbL	repeated alternate deposition of oppositely charged polymers onto a surface
Thermal spray	deposition of nanoparticles to form a solid film from a plasma-based or combustion-based nanoparticle source
Spin coating	creation of a thin film by deposition of a material in solution onto a rotating substrate by utilizing centrifugal force
spray deposition	process to deposit material onto the outside or uppermost layer of substrate by pressurization of a liquid through a nozzle to create droplets or aerosols
surface polymerization	creation of a polymer film on a surface from a vapour phase or liquid phase monomer
direct bonding	Bonding substrates, typically silicon wafers, without any interposer, applying thermal budget. It requires highly clean and smooth surfaces. It is based on chemical bonds between the surfaces
anodic bonding	Mostly used for connecting silicon/glass and metal/glass through electric fields
thermalcompression bonding	Two metals are brought into atomic contact applying force and heat simultaneously.The diffusion requires atomic contact between the surfaces due to the atomic motion. The atoms migrate from one crystal lattice to the other one based on crystal lattice vibration.This atomic interaction sticks the interface together.
diamond blade dicing	process by which items are cut with diamond blade systems, with movement driven by computer loading the dicing layout
laser dicing	process by which items are cut with lasers, with movement driven by computer loading the dicing layout
Silicon dry oxidation	the wafer or other silicon item are inserted into an hermetically sealed furnace chamber where a mixture of O2 and N2 are injected once the internal chamber temperature has reached the target. The O2 reacts with surface Si generating SiO2
Silicon wet oxidation	the wafer or other silicon item are inserted into a hermetically sealed furnace chamber where a mixture of O2, H2 (together forming the wet oxidizing thanks to the formation of H2O vapour) and N2 are injected once the internal chamber temperature has reached the target. The vapour reacts with surface Si generating SiO2
Sintering	the wafer or other item are inserted into a hermetically sealed furnace chamber where specific mixture of N2, H2, Ar are injected once the process temperature has reached the target. This process is aimed at improving the quality of the metal/semiconductor, and in turn on the contact quality and resistance
Anneling	the wafer or other item are inserted into a hermetically sealed furnace chamber where N2 is injected and the temperature rose until the target. Main aim of this process is recovering of damages induced by previous process steps, mainly ion implantation
Drive in	the wafer or other item are inserted into a hermetically sealed furnace chamber where N2 is injected and the temperature rose until the target. Main aim of this process is giving energy to implanted or diffused doping atoms in order to allow their integration in the silicon (or other semiconductor) reticle and activate them from the electrical point of view.
Baking	thermal processing aimed at transforming one or more material layers present on the top of the wafer. Examples are: resist backing, to strengthen it before etching o ion implantation.
ion implantation	use of incident flux high energy ions to modify the surface material by damage and recrystallization; use of incident flux high energy ions to add atoms to the semiconductor bulk in order to modify its electrical properties, like conductivity
doping by diffusion from solid source	solid source substrates, extremely highly doped, are placed close the item undergoing the fabrication, in a furnace, and according to temperature and time it is possibile to regulate the dopant reaching the item itself
resist development	