SUSNANOFAB
Grant Agreement No. 882506

Report on the existing relevant services and infrastructures

Document Details

Deliverable Number:	D2.3
Due date of Deliverable:	M9
Lead Beneficiary:	INL
Contributors:	TUW, IDONIAL, TECNALIA, RINA-C, NIA, CEA, TYNDALL, IPC
Dissemination Level (*):	PUBLIC

Project Contractual Details

Project Title:	Integrated EU Strategy, Services and International Coordination Activities for the Promotion of Competitive and Sustainable Nanofabrication Industry
Project Acronym:	SUSNANOFAB
Contract No.:	882506
Project Start Date:	01-03-2020
Duration:	36 months

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement Nº 882506.

Document History

Version	Date	Description
V.0	21st September 2020	First draft
V.1	30th November 2020	Final Version
V.2	23rd June 2021	Inclusion of abbreviations table

Abbreviations and Acronyms

Acronym	Description
2D	Two dimensional
3D	Three dimensional
AFM	Atomic Force Microscopy
ALD	Atomic Layers Deposition
CAIBE	Chemically Assisted Ion Beam Etching
CVD	Chemical Vapour Deposition
DC	Direct Current
DIH	Digital Innovation Hubs
EDX	Energy Dispersive X-Ray
EPPN	European Pilot Production Network
FIB	Focused Ion Beam
FTIR	Fourier Transform Infra-Red
ICP	Inductively Coupled Plasma
KETs	Key Enabling Technologies
LPCVD	Low Pressure Chemical Vapour Deposition
MBE	Molecular Beam Epitaxy
MOCVD	Metal Organic Chemical Vapour Deposition
MOVPE	Metalorganic Vapour Phase Epitaxy

PECVD	Plasma Enhanced Chemical Vapor Deposition
PLD	Pulsed Laser Deposition
PVD	Physical Vapour Deposition
RBS	Rutherford Backscattering Spectrometry
RF	Radio Frequency
RIE	Reactive Ion Etching
SEM	Scanning Electron Microscope
STM	Scanning Tunnelling Microscope
UHV-CVD	Ultra-High Vacuum Chemical Vapour Deposition
UV	Ultra-Violet
WP	Work Package
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence

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Contents

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Executive Summary

This document is a deliverable of the SUSNANOFAB project – a coordination and support action to promote a competitive and sustainable nanofabrication industry - funded by the European Union's Horizon 2020 Programme, under Grant Agreement #882506.

SUSNANOFAB is a concerted sustainable action that will establish a robust network on nanofabrication to tackle the missing links between policies, infrastructure, expertise, and industry requirements. The SUSNANOFAB project proposes an integrated strategy at a European level that articulates the whole value-chain, aiming at the promotion of a competitive and sustainable nanofabrication industry.

At a strategic level, the project is committed to delivering an EU-wide Strategic Roadmap on Nanofabrication. This roadmap among other will cover nanofabrication aspects from design to manufacturing upscaling, environmental sustainability, health & ethics matters, as well as future skills & capabilities. At an operational and end-user level, the project will develop an Open Access Digital Platform that interoperates with current platforms, projects and other initiatives at the European level.

This deliverable is developed within WP2 – nanofabrication ecosystem linking all relevant initiatives. This work package aims at providing a comprehensive landscape of the nanofabrication ecosystem by assessing the key drivers and challenges, as well as providing an extensive map of initiatives, projects, stakeholders, as well as infrastructures and services.

The report on existing services and infrastructures frame the current landscape that composes the European nanofabrication ecosystem, and will aid in completing the appraisal of the current EU situation during the roadmap development (WP3). It will also be the starting point to plan and deploy brokerage services foreseen in the WP4.

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1 Introduction

This document is the Deliverable D2.3 "Report on the existing relevant services and infrastructures", henceforth referred as to D2.3, of the SUSNANOFAB project. The main objective of this report is to map the current landscape of services and infrastructures that compose the European nanofabrication arena.

Data resulting from this exercise will support the SUSNANOFAB project towards its objectives of increasing awareness regarding existing services and infrastructures among the stakeholders, as well as promoting the establishment of sustainable links between existing infrastructures, and ultimately contributing to create a continuous growing network to cover all the nanomanufacturing value-chain.

The mapping of the existing offer of relevant services and infrastructures in the nanofabrication ecosystem will serve as basis for the development of two complementary tasks within the project: Task 3.3 – Roadmap for EU wide strategy on nanofabrication; and Task 4.4 - Planning and deployment of brokerage services.

This report will also be the starting point for the enhancement of the SUSNANOFAB Digital Platform, by providing the data categories and taxonomies for the services, technologies and tools. Data gathered in D2.3 will be the first stage for a comprehensive database of services and infrastructures in the nanomanufacturing value-chain, to be available in the SUSNANOFAB Open Access Digital Platform.

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2 Methodology

To ensure a comprehensive mapping of the available and relevant services and infrastructures in the nanofabrication ecosystem, the methodology adopted for task 2.3 was organized in two phases:

The first phase was the definition of the categorization and taxonomy for the nanofabrication services to be adopted. Seven categories were adopted, each of them includes different technologies and tools. The details of the categorization adopted will be further described in chapter 3.

After a deep desk base research on the taxonomies to be adopted for the categorization of nanofabrication services, and after analysing the technical structure of the nanofabrication and nanomanufacturing offer in the European landscape, the SUSNANOFAB consortium opted to adapt the consistent categorization scheme developed by the EuroNanoLab Consortium[1] with their authorization.

Following the definition of the classification to be adopted by the SUSNANOFAB to map the services and infrastructures in the nanofabrication field, an online survey target to nanofabrication facilities was launched. The survey was launched on October 15th 2020, and collected a total of 34 replies from nanofabrication facilities.

The survey was disseminated through the SUSNANOFAB partners' social media channels, and direct mailing to specific stakeholders from partners' networks. The key stakeholders targeted for participating in the online survey were compiled by the project partners' networks, capitalising also on partners' direct involvement in ongoing related initiatives, as EPPN, DIHs Catalogue, and KETs Centres Database.

The survey will remain open and available at SUSNAOFAB website for collecting information on services, technologies and tools provided by the nanofabrication facilities for including further stakeholders at the SUSNANOFAB network and platform aiming to create a comprehensive database for the development of the Roadmap for EU wide strategy on nanofabrication, as well as for the planning and deployment of brokerage services.

[1] EuroNanoLab is a distributed research infrastructure consisting of over 40 state-of-the-art academic nanofabrication centers across Europe. Its main vision is to accelerate research in the micro- and nanotechnology sector by enabling the transformation of a fragmented landscape of nanofabrication facilities into an integrated knowledge base supporting scientific excellence and providing researchers a fast-track to results. Available at: http://euronanolab.eu/

3 List of services and infrastructures adopted

The classification of services and infrastructures adopted for the mapping exercise has been adapted from the scheme developed by the EuroNanoLab Consortium. It comprehends 6 categories: Material Modification, Lithography, Material Deposition, Dry & Wet Etching, Characterization & Testing, and Preparation of Sample & Integration.

3.1 Materials Modification

The Materials Modification category includes the following technology/tools:

- Ion Implantation | Ion Implanters
- Furnaces | Oxidation
- Furnaces | Diffusion
- Lamp heaters | Rapid Thermal Processing/Annealing
- Vacuum Ovens | Thermal processes without air contamination

3.2 Lithography

In the Lithography category, facilities owners could select the following technology/tools:

- Optical insolation | Mask aligners, Steppers, UV & deep UV insolation
- e-beam insolation | Small size or full-water insolation
- Resist coating | Spinners, Spray coating
- Direct writing systems | Laser writing
- Wet benches for lithography | Development/baking of resist

3.3 Materials Deposition

In the Materials Deposition category, facilities owners could select the following technology/tools:

- Epitaxy | MBE, MOCVD, MOVPE
- Atomic Layers Deposition (ALD) | Monolayer by monolayer growth machines
- UHV-CVD | Ultra-Hugh Vacuum CVD
- Evaporation | DC, RF, Magnetron, Plasma
- CVD | LPCVD, PECVD
- Specialized tool clusters | Sequences of layer depositions without breaking vacuum
- Electroplating | wet electroplating, chemical deposition
- Dip coating | Dip-coating tool
- Carbon coating | Carbon evaporator
- Pulsed Laser Deposition | PLD deposition chambers

- Liquids/pastes direct deposition | inkjet, serigraphy

3.4 Dry & Wet Etching

In the Dry & Wet Etching category, facilities owners could select the following technology/tools:

- Wet chemical etching | Wet benches KOH, HF, Metal Etching, etc. (Si, III/V materials, dielectrics, metals)
- Dry Etching tools | Ion beam etching, Reactive Ion Etching, ICP Etching, Cryo RIE, CAIBE, Plasma Cleaners (Si, III/V materials, metals, organics)
- Focused Ion Beam systems | FIB, nanoFIB systems
- Related tools | Critical point dryers

3.5 Characterization & Testing

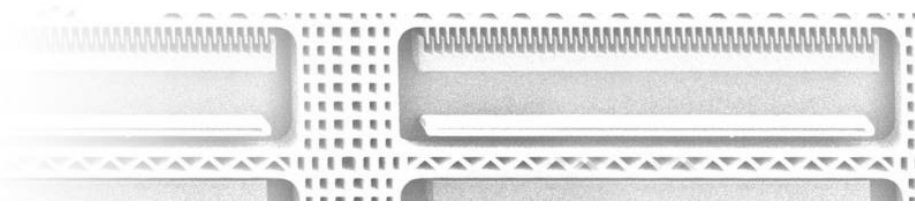
In the Characterization & Testing category, facilities owners could select the following technology/tools:

- Electrical testing | Four points probers, RF probers / parameter analysers, Impedance measurements, Hall characterizations, STM
- Material characterization | X-Ray characterization (EDX, XRD, XRF, etc.)
- Material characterization | Photo-spectrometers, Spectrofluorimeters, Micro-Raman / fluorescence spectroscopy, FTIR
- Material characterization | RBS, Gas chromatographs, Acoustic characterization
- Geometry characterization | Optical microscopes
- Geometry characterization | Profilers, Interferometers, AFM, Ellipsometers
- Geometry characterization | SEM
- Mechanical stress testing | Stress testers

3.6 Preparation of Samples & Integration

In the Preparation of Samples & Integration category, facilities owners could select the following technology/tools:

- Cleaning | Plasma cleaning, Ozone Cleaning
- Cleaning | RCA & Piranha cleaning
- Cleaning | Ultrasonic cleaning, Megasonic cleaning
- Milling, polishing, grinding | Grinding, Abrasive Polishing
- Milling, polishing, grinding | Ion milling, cross-section polishing
- Milling, polishing, grinding | Chemical Mechanical Polishing
- Chips separation | Dicing precision saws, scribers, wafer expanders, laser cutting



- Pick & place | Positioning of chips on a board
- Wafer bonding | Wafer bonding machines (anodic bonding, Si-Si bonding, thermocompression bonding, etc.)
- Assembly & electrical connections | Ball bonding, Flip-chip bonding, Wire bonding
- Packaging | 3D printers, vacuum welder

4 Survey Analysis

This section comprehends the analysis of the data collected in the online survey to map the relevant services and infrastructures in the nanofabrication value chain from October 15th to November 30th 2020, which includes a total of 34 replies from nanofabrication facilities owners, from 16 different countries.

4.1 Stakeholders

The stakeholders targeted for the online survey aiming to map the available and relevant services and infrastructures in the nanofabrication ecosystem are very specific, comprehending only nanofabrication facilities managers/owners.

Besides the EPPN Network, the DIHs Catalogue, and the KETs Centres Database, the survey was addressed to the EuroNanoLab Consortium.

Below is the list of stakeholders, composed by nanofabrication facilities, which took part on the survey for mapping the existing services and infrastructures to frame the current landscape that compose the European nanofabrication ecosystem.

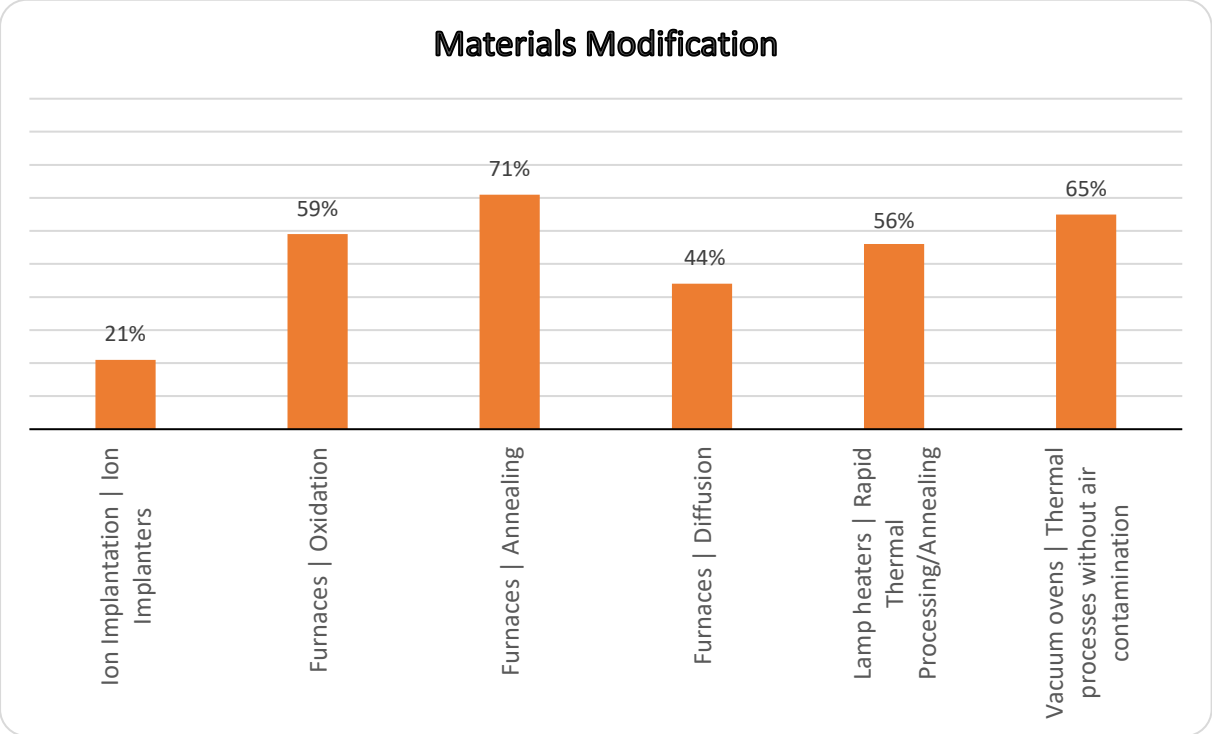
Nanofabrication Facility	Country
IMH - Institute of Modelling and High-Performance Computing, Hochschule Niederrhein University of Applied Sciences	Germany
Kaunas University of Technology	Lithuania
TU Wien	Austria
Institute of Solid State Physics, University of Latvia	Latvia
AMBER (Advanced Materials and BioEngineering Research) Centre	Ireland
CROMOMED SA	Spain
Georgia Tech - Institute for Electronics and Nanotechnology	USA
Duke University Shared Materials Instrumentation Facility	USA
Nanoscale Characterization and Fabrication Laboratory, Virginia Tech	USA
Clemson University	USA
NTNU NanoLab	Norway
SINTEF MiNaLab	Norway
IMT MINAFAB	Romania
C2N	France

National Institute of Materials Physics Romania	Romania
NanoLab@TU/e	Netherlands
USN MST lab Norway	Norway
UiO MiNaLab - NorFab	Norway
IEMN	France
TU Ilmenau - Institute of Micro- and Nanotechnologies MacroNano®	Germany
Renatech-LAAS	France
ITIM-SMARTFAB	Romania
OtaNano	Finland
MESA+NanoLab University Twente	Netherlands
NIRDTP Iasi	Romania
MIMENTO Technology Center	France
Else Kooi Laboratory	Netherlands
Kavli NanoLab Delft Technical University	Netherlands
AMOLF	Netherlands
CEITEC Nano	Czech Republic
Laboratory of Nanostructures and Nanomaterials @ CzechNanoLab	Czech Republic
INESC MN	Portugal
International Iberian Nanotechnology Laboratory (INL)	Portugal
Montana Microfabrication Facility	USA

4.2 Materials Modification

Regarding Material Modification, the results obtained from the survey were the following:

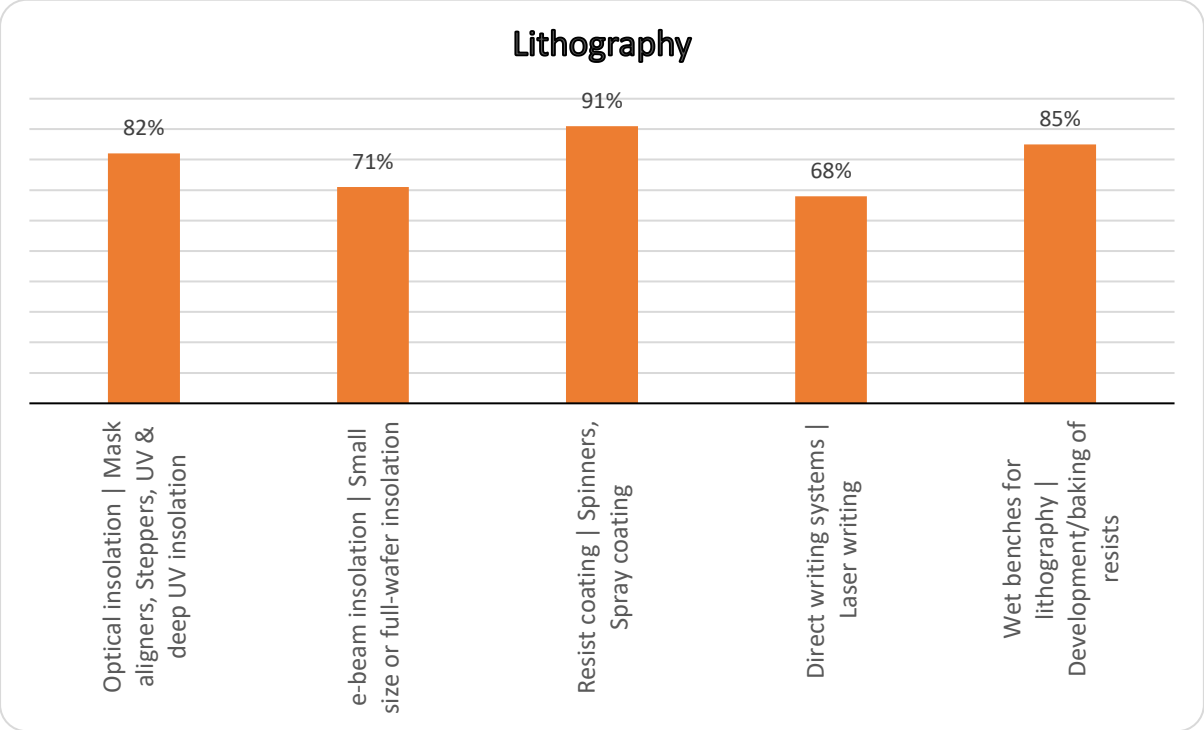
- 7 of the 34 facilities offer ion implantation or ion implanters technologies, characterizing 21% of the facilities represented in the survey.
- 20 of the 34 facilities offer furnaces oxidation technologies, representing 59% of the facilities represented in the survey.
- 24 of the 34 facilities offer furnaces annealing technologies, representing 71% of the facilities.
- 15 of the 34 facilities offer furnaces diffusion technologies, characterizing 44% of the facilities.
- 19 of the 34 facilities offer lamp heaters or rapid thermal processing/annealing technologies, which represents 56% of the facilities that took the survey.
- 22 of 34 facilities offer vacuum ovens for thermal processes without air contamination, characterizing 65% of the facilities.



4.3 Lithography

Regarding Lithography, the results obtained from the survey were the following:

- 28 of the 34 facilities offer optical insolation and mask aligners, steppers, UV & deep UV insolation technologies, characterizing 82% of the facilities represented in the survey.
- 24 of the 34 facilities offer e-beam insolation and small size or full-wafer insolation technologies, 71% of the facilities represented in the survey.
- 31 of the 34 facilities offer resist coating, spinners and spray coating technologies, characterizing 91% of the facilities.
- 23 of the 34 facilities offer direct writing systems and laser writing technologies, characterizing 68% of the facilities.
- 29 of the 34 facilities offer wet benches for lithography and development/baking of resists, which represents 85% of the facilities that took the survey.

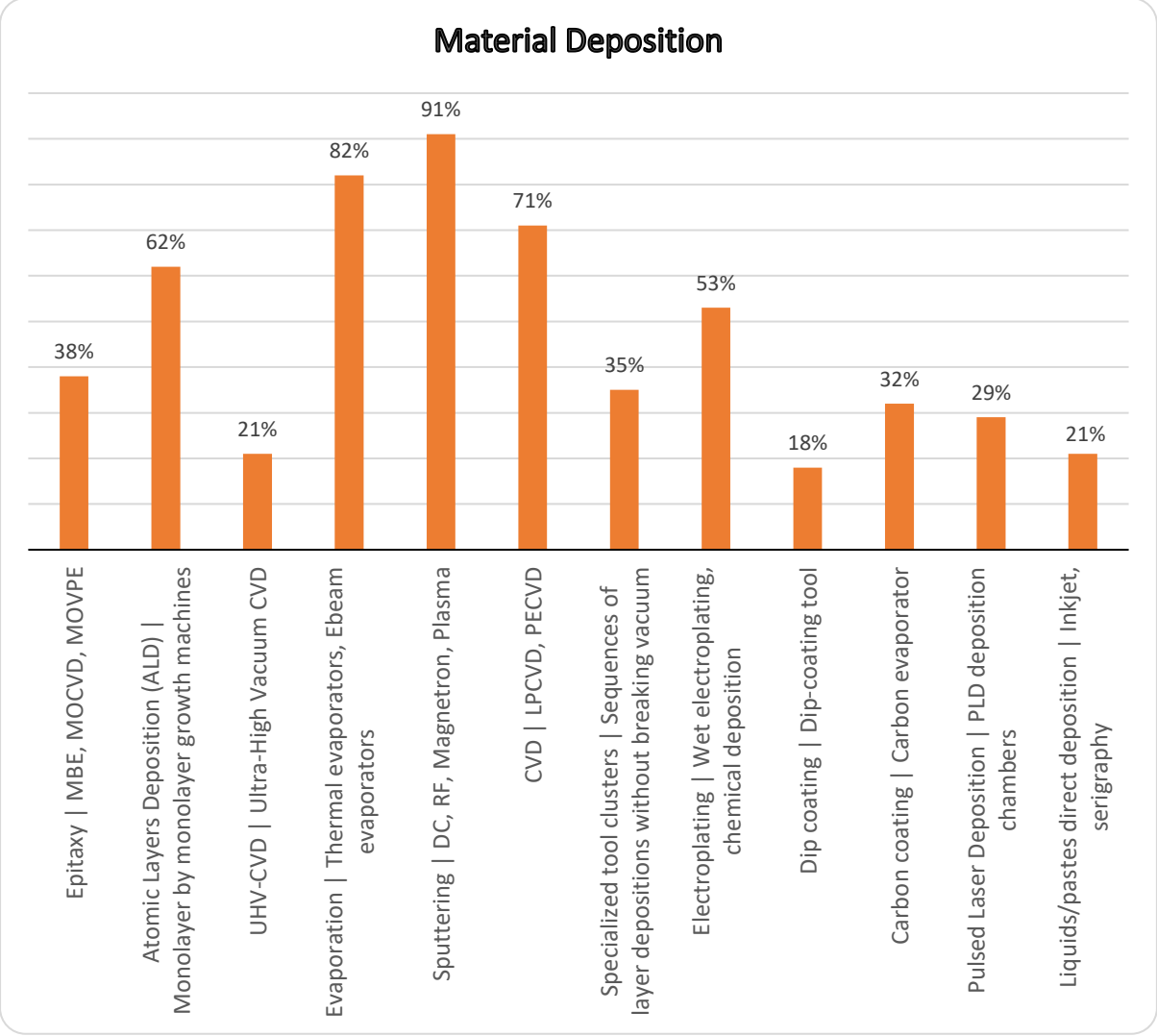


4.4 Materials Deposition

Regarding Material Deposition, the results obtained from the survey were the following:

- 13 of the 34 facilities offer Epitaxy or MBE, MOCVD, MOVPE technologies, characterizing 38% of the facilities represented in the survey.
- 21 of the 34 facilities offer Atomic Layers Deposition (ALD) or Monolayer by monolayer growth machines technologies, representing 62% of the facilities represented in the survey.
- 7 of the 34 facilities offer UHV-CVD and Ultra-High Vacuum CVD technologies, representing 21% of the facilities.
- 28 of the 34 facilities offer evaporation technologies as thermal evaporators, and e-beam evaporators, characterizing 82% of the facilities.
- 31 of the 34 facilities offer sputtering technologies as DC, RF, Magnetron, and Plasma, which represents 91% of the facilities that took the survey.
- 24 of 34 facilities offer CVD, LPCVD and PECVD technologies, characterizing 71% of the facilities.
- 12 of 34 facilities offer specialized tool clusters for sequences of layer depositions without breaking vacuum technologies, characterizing 35% of the facilities.
- 18 of 34 facilities offer Electroplating, wet electroplating, or chemical deposition technologies, characterizing 53% of the facilities.

- 6 of the 34 facilities offer dip-coating tools, representing 18% of the facilities represented in the survey.
- 11 of the 34 facilities offer Carbon coating and Carbon evaporator technologies, characterizing 32% of the facilities represented in the survey.
- 10 of the 34 facilities offer Pulsed Laser Deposition and PLD deposition chambers, representing 29% of the facilities.
- 7 of the 34 facilities offer Liquids/pastes direct deposition through Inkjet and serigraphy technologies, representing 21% of the facilities represented in the survey.



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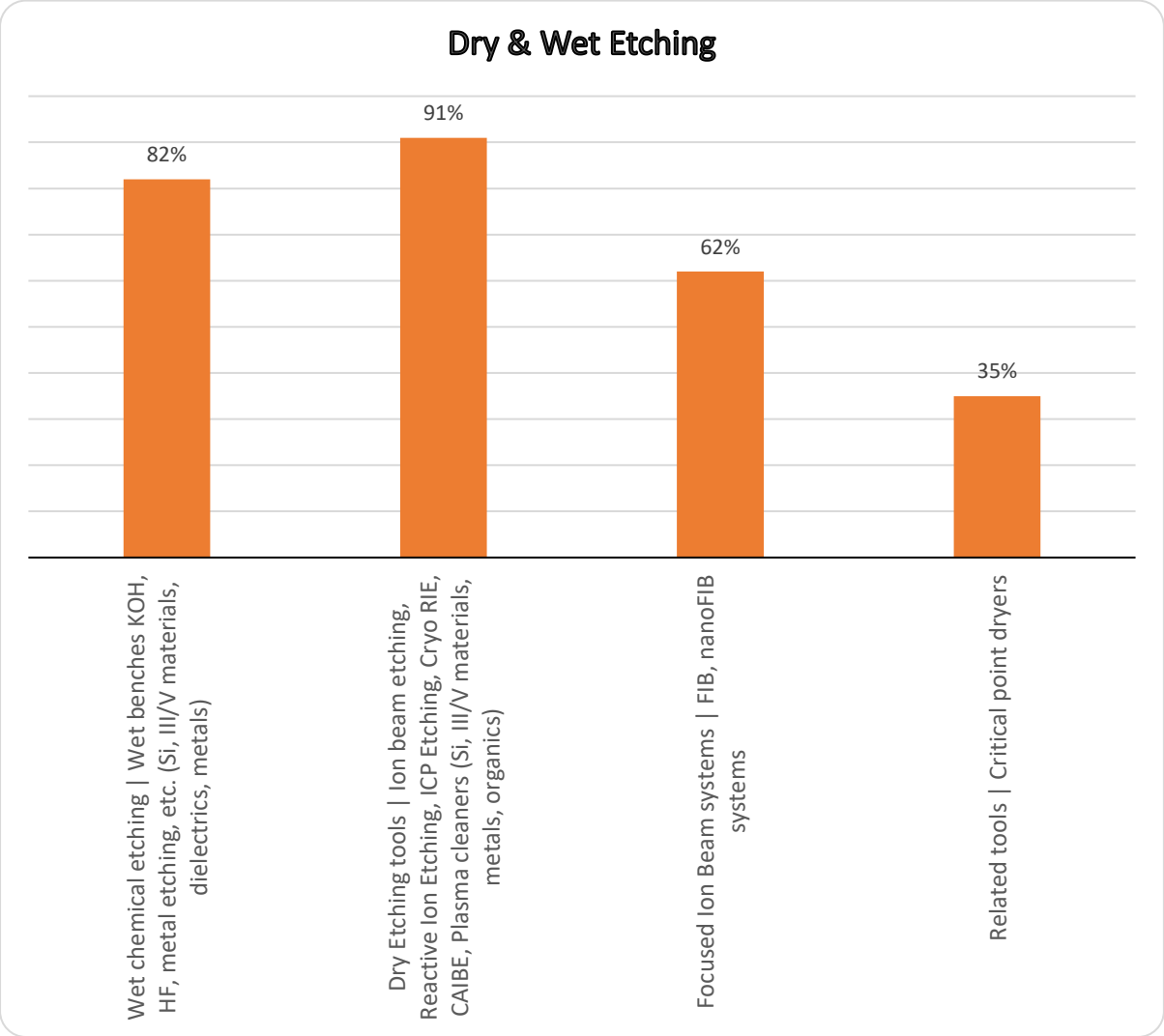
4.5 Dry & Wet Etching

Regarding Dry & Wet Etching, the results obtained from the survey were the following:

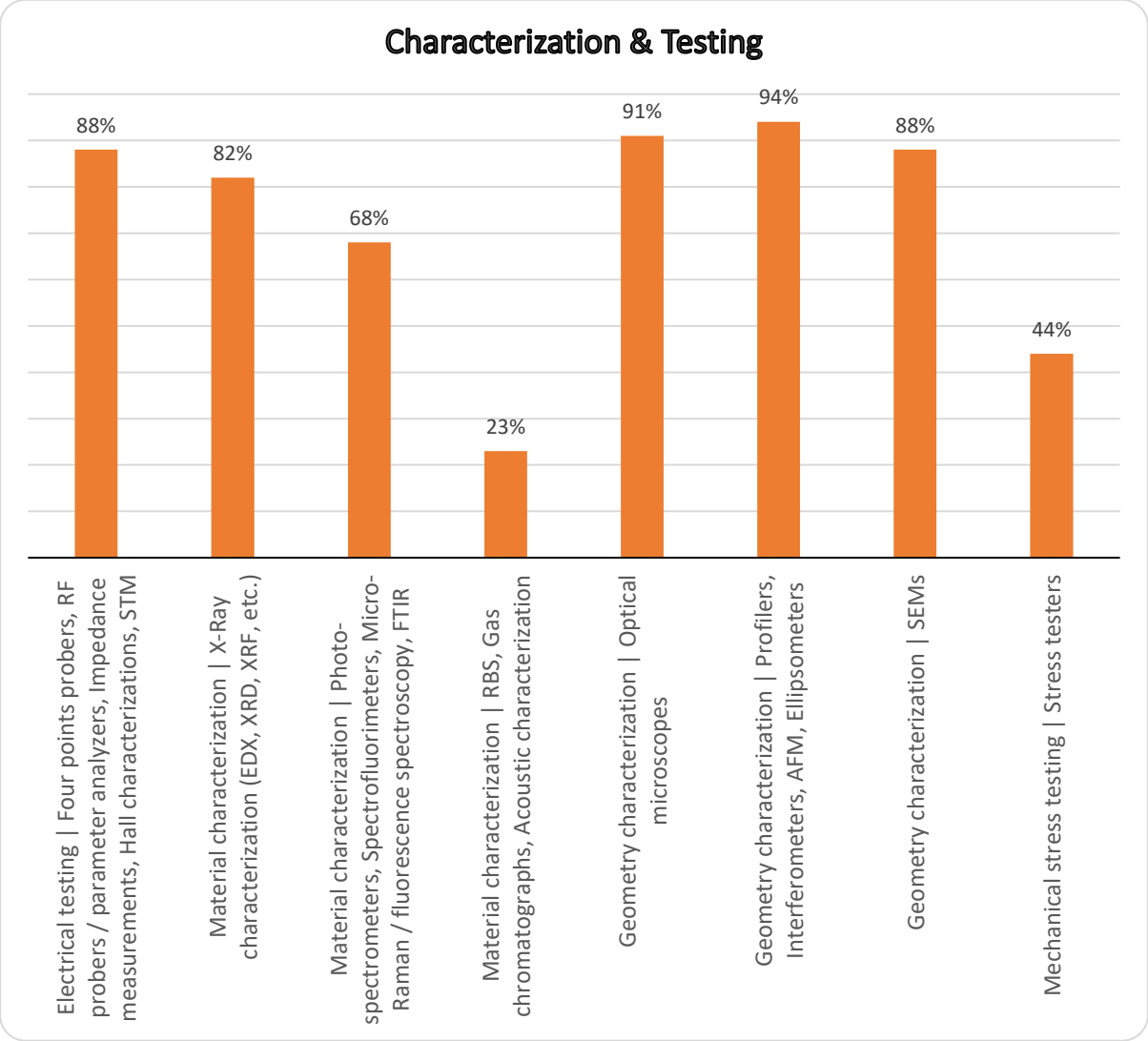
- 28 of the 34 facilities provide wet chemical etching technologies, as wet benches KOH, HF, metal etching, etc. (Si, III/V materials, dielectrics, metals), characterizing 82% of the facilities represented in the survey.
- 31 of the 34 facilities provide Dry Etching tools, as Ion beam etching, Reactive Ion Etching, ICP Etching, Cryo RIE, CAIBE, Plasma cleaners (Si, III/V materials, metals, organics), representing 91% of the facilities represented in the survey.
- 21 of the 34 facilities offer Focused Ion Beam systems | FIB, nanoFIB systems, representing 62% of the facilities.
- 12 of the 34 facilities offer Dry & Wet Etching Related tools, as critical point dryers, characterizing 35% of the facilities.



4.6 Characterization & Testing

Regarding Characterization & Testing, the results obtained from the survey were the following:

- 30 of the 34 facilities provide Electrical testing, as four points probers, RF probers/parameter analyzers, Impedance measurements, Hall characterizations, and STM tools, characterizing 88% of the facilities represented in the survey.
- 28 of the 34 facilities provide material characterization technologies as X-Ray characterization (EDX, XRD, XRF, etc.), representing 82% of the facilities represented in the survey.
- 23 of the 34 facilities offer material characterization technologies as Photo-spectrometers, Spectrofluorimeters, Micro-Raman/ fluorescence spectroscopy, and FTIR, representing 68% of the facilities.
- 8 of the 34 facilities offer material characterization technologies as RBS, Gas chromatographs, and Acoustic characterization, characterizing 23% of the facilities.
- 31 of the 34 facilities provide Geometry characterization with Optical microscopes, characterizing 91% of the facilities represented in the survey.
- 32 of the 34 facilities provide Geometry characterization with Profilers, Interferometers, AFM, and Ellipsometers, representing 94% of the facilities represented in the survey.
- 30 of the 34 facilities offer Geometry characterization with SEMs, representing 88% of the facilities.
- 15 of the 34 facilities offer Mechanical stress testing, characterizing 44% of the facilities.



4.7 Preparation of Samples & Integration

Regarding Preparation of Samples & Integration, the results obtained from the survey were the following:

- 30 of the 34 facilities offer Cleaning technologies as Plasma and Ozone Cleaning, characterizing 88% of the facilities represented in the survey.
- 25 of the 34 facilities offer cleaning technologies as RCA & Piranha cleaning, representing 73% of the facilities represented in the survey.
- 28 of the 34 facilities provide cleaning technologies as ultrasonic and megasonic cleaning, representing 82% of the facilities.
- 14 of the 34 facilities offer milling, polishing, grinding technologies, as grinding and abrasive Polishing, characterizing 41% of the facilities.

- 13 of the 34 facilities offer milling, polishing, grinding technologies, as Ion milling, and cross-section polishing, which represents 38% of the facilities that took the survey.
- 15 of 34 facilities offer milling, polishing, grinding technologies, as Chemical Mechanical Polishing characterizing 44% of the facilities.
- 24 of 34 facilities offer Chips separation technologies with Dicing precision saws, scribers, wafer expanders, and laser cutting, characterizing 71% of the facilities.
- 8 of 34 facilities offer Pick & place technologies as positioning of chips on a board, characterizing 23% of the facilities.
- 18 of the 34 facilities offer Wafer bonding machines (anodic bonding, Si-Si bonding, thermocompression bonding, etc.), representing 53% of the facilities represented in the survey.
- 21 of the 34 facilities offer Assembly & electrical connections technologies, as Ball bonding, Flip-chip bonding, and Wire bonding, characterizing 62% of the facilities represented in the survey.
- 13 of the 34 facilities offer Packaging technologies as 3D printers, and vacuum welder, representing 38% of the facilities.

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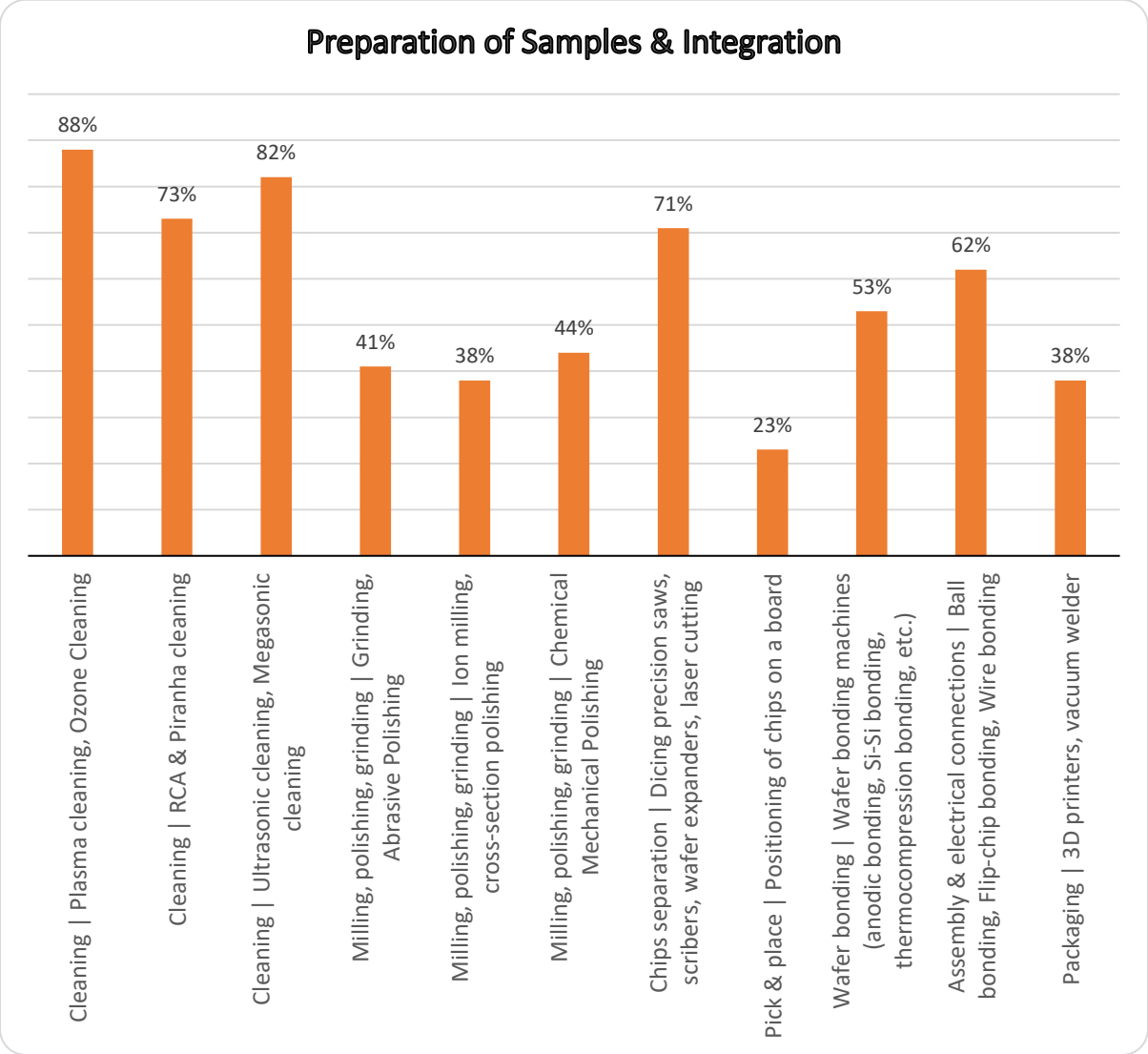

5 Conclusions

The report on the existing relevant services and infrastructures have collected data from October 15th to November 30th 2020. Summing a total of 34 replies from 16 different countries, these results will support the SUSNANOFAB project on increasing the awareness regarding the existing offer of services and infrastructures in the nanofabrication value-chain. This mapping exercise will be one of the foundations for the development of the roadmap for EU wide strategy on nanofabrication; as well as for the planning and deployment of brokerage services activities.

The definition of the categories and taxonomies of the nanofabrication services, technologies and tools is of great importance and will be adopted in other cross-cutting activities of the project, as the SUSNANOFAB Digital Platform.

The survey will remain open at SUSNANOFAB website to collect information of other nanofabrication facilities during the project duration.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 882506 (SUSNANOFAB). The content of publication is the sole responsibility of the author(s). The European Commission or its services cannot be held responsible for any use that may be made of the information it contains. Project website: http://susnanofab.eu/.