EMN for Advanced Manufacturing

Key Industry Sector Topics

DRAFT

Draft Strategic Research Agenda

December 2022

The content of this preliminary version may change due to ongoing consideration of stakeholder feedback

Key Industry Sectors (KIS) – Overview

1. Metrology equipment & service

overarching KIS relevant for the other KISs

2. Machine tools & robotics
3. Digitalized & integrated manufacturing systems
4. Energy generation, transmission & storage
5. Advanced materials & processing
6. Nano- & microelectronics
7. Nano- & microtechnology
8. Optics & photonics
9. Land & sea-based mobility
10. Aerospace
11. Complex infrastructure & civil engineering
12. Life science technology
13. Defense & security

Metrology equipment & services

1

Metrology equipment & service

includes all equipment and services necessary for reliable quality control in manufacturing: Measurement systems industry, accredited measurement labs, NMI's, organisations with a focus on measurements and quality infrastructure, including publishers.

"Strengthen trust in metrology for advanced manufacturing"

Mission by EMN Stakeholder Council Convenor Dietrich Imkamp, Zeiss, DE

"Tomorrow's instruments will yield the complete measurement results, consisting of values and corresponding uncertainties. It will become common practice to use measuring equipment including its digital twin for uncertainty estimation."

Vision by EMN Vice-Chair Alessandro Balsamo, INRIM, IT

Metrology equipment & services

ADVANCED MANUFACTURING
EURAMET

1 Metrology equipment & service

includes all equipment and services necessary for reliable quality control in manufacturing: Measurement systems industry, accredited measurement labs, NMI's, organisations with a focus on measurements and quality infrastructure, including publishers.

1) **Validating and "calibrating" Artificial Intelligence** (AI) algorithms for uncertainty determination (e.g. identification of change points for self-validating thermometers)
2) Establishing **traceable measurement methods** for new industrial applications and new industry sectors (e.g. Computed Tomography (CT) for Additive Manufacturing (AM))
3) Traceability and standardisation of determination of **internal structures** (e.g. Ultrasound, CT); error estimation assisted by simulation and AI tools
4) Further develop reference software for **software validation** in manufacturing QC (e.g. tracim.ptb.de)
5) **Extending** data evaluation **software validation** to complex geometrical surfaces and components
6) Calibration of **complex artefacts** (e.g. freeform objects) for advanced manufacturing in the required uncertainty levels
7) Establishing complex **multi-sensor systems** (hybrid metrology) to tackle challenging features & surfaces
8) Improving **form & surface roughness measurement** standards and measurements, incl. deflectometry
9) **Defining and validating standards for integration of metrology** into **digital production** (e.g. Digital Calibration Certificate (DCC))
10) **Fully exploit potential** of revised SI (e.g. using Si lattice, redefined Kelvin) and new methods (e.g. stabilized light sources, Johnson noise thermometer, photonic thermometers, non-contact acoustic thermometer for large volume high speed air temperature and humidity measurement)

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Machine Tools & Robotics

2

Machine tools & robotics includes all machines and tools used for manufacturing of components and products: Machine tools, including tools for additive manufacturing, hybrid tools, laser- and charged particle-based machining tools, etc.; robotics for machining and handling of components.

1) **Quality Management Systems (QMS) bottom-up approach** to deliver part and process quality
   ⇨ Defining enhanced measuring and monitoring key performance indicators (KPIs) beyond throughput times or error rates, with **one single digital thread** from design process planning through execution and to final part and process validation
   ⇨ Customer driven product expectation & legislation reduces life cycles and requires **flexibility of metrology systems** to accommodate design changes
2) **Standard interface for AI applications** for vision control, monitoring and prediction in robotics
   ⇨ Developing software and hardware harmonisation standards and protocols
   ⇨ Providing easier connectivity and data transfer between shopfloor eco-systems
3) **Real-time evaluation algorithms of high frequency data and Machine Learning (ML) for integrated machine tool sensors**
   ⇨ Providing real-time high frequency data enabling self-adapting & correction of manufacturing processes
   ⇨ Predicting and preventing imminent process issues and avert quality or productivity losses
   ⇨ Predicting tool wear
   ⇨ Location and pose determination in point cloud registration

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4) **Improving shopfloor metrology** towards **flexible, robust low-cost process** and quality control
   - ⇨ Responsive, agile manufacturing requires robust hardware and software in challenging environment
   - ⇨ Developing **mobile metrology platforms** suitable for deploying measuring systems in shopfloor environment
   - ⇨ **Multi-feature calibration objects** for integrated machine tool sensors for performance checks

5) **Metrology for dynamic machining systems**
   - ⇨ Improving volumetric error models ⇨ demanding dynamic positioning applications of robotic systems
   - ⇨ Harmonisation of definitions (terminology, reference coordinate systems, model equations,…) used in error models
   - ⇨ Developing best practice guidelines for application of error models
   - ⇨ Improving standard for robot performance incl. accuracy (e.g. ISO 9283)

6) **Metrology for Additive Manufacturing (AM)**
   - ⇨ Developing reliable defect detection and characterisation in AM parts
   - ⇨ Developing methods for reliable determination of link between process parameters & product quality
   - ⇨ Developing application specific process control for AM machine tools and metrology for post processing
   - ⇨ Developing new traceable surface temperature measurement (thermographic phosphors/quantitative imaging)
   - ⇨ Developing methods to investigate correlations of in-process tool metrology to surface roughness/topography, microstructure, residual stress for digital twin of process and workpiece and use of AI to predict impact on product function

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Digitalized and integrated manufacturing systems

3

Digitalized & integrated manufacturing systems include all equipment, communication, control and services: Industry 4.0, smart manufacturing, automation of factories, enabled by digitalization (including the KETs artificial intelligence, digital security and connectivity).

Traceability

1) Ensuring for quality of **fast and reliable machine-to-machine communication** of metrological data
   ⇨ Seamless flow of measurement data for process and quality control through the whole supply chain
2) Enabling **data fusion methods** through different measurement sources / sensor networks
3) Developing the basis for a **Digital SI** integration of metrology and process control into digital processes
4) Developing and disseminating the **Digital Calibration Certificate**

Sustainability

5) Developing **Digital Metrological Twins** updated with metrological data for prediction of maintenance, product lifetime and reuse options
6) Waste reduction in production processes with respect to lower consumption of raw material
7) **Right first time**: Less rework and in-line corrective action related environmental footprint, production time and costs

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Flexibility

8) **Teleoperated manufacturing** processes supported by e.g., **remote vision control** and validated AI-based **monitoring and prediction algorithms**

9) Improving **sensors for manufacturing systems** with integrated online error compensation methods e.g., measuring sound spectra of cutting tools for tool wear estimation enables corresponding positioning compensation

10) **Improving overall process tolerances** and thus product quality without the need to tighten individual tolerances of single parts and components

Overall benefit of digitalized and integrated manufacturing systems:

Improved yield and product quality through enhanced reliability of production processes by full data integration

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Energy generation, transmission & storage

4

Energy generation, transmission & storage includes all components and systems for an energy system to support the EU Green Deal: Photovoltaics, wind energy systems (on & off-shore), hydropower, batteries and other energy storage systems, from chip-scale devices for harvesting energy to large infrastructures such as ITER.

1) Application specific metrology for operation of manufacturing systems under **harsh shopfloor conditions**
2) Automatic recipe downloads in machine tools
   ⇨ Integration of **metrological evaluation tools for decision making into manufacturing execution systems** and automatic dispatching systems
3) Metrology for enhanced reliability in wind energy systems (e.g. predictive maintenance for improving lifetime, characterisation of power loss, assessment of performance,…)
4) Improving equipment efficiency by **fab automation** for increased product conformance (**reliable wafer-to-wafer and lot-to-lot process control systems**, …)
5) **In-line process control** in photovoltaic solar cell and module production
   ⇨ Automated optical inspection and in-line monitoring systems
6) **Saving product raw material** (Si and non-Si) and **machining material**
   ⇨ Improved machining processes **based on metrological data** (e.g. more precise machine processes enable reduction of lubricants through less reworking, reduction of kerf width in diamond wire sawing from 60 µm to 50 µm, …)

Energy generation, transmission & storage

ADVANCED MANUFACTURING EURAMET

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7) New manufacturing systems for **larger PV wafer sizes** M10 (182.0 x 182.0 mm) at frontend production
8) **Developing digital twins based on metrological data**
⇨ Redesign of energy generating systems, e.g., 10 MW wind turbines to reduce gearbox weight and size about more than 10% , reduction of photovoltaic cell thickness to 120 µm for Silicon heterojunction cells and approximately 145 µm for half cells, …
9) Reducing thickness and total thickness variation of PV wafers from 10 µm to sub-µm supported by **reliable capacitive sensor systems** for part conformance
10) **Transition from defect detection towards defect characterisation** (visual defect characterisation methods (30 nm to 10 nm) and models for prediction of wafer health, 3D inspection and damage quantification (kind of damage, extent, and position) of wind energy system components)
11) **Surface characterisation** to assess quality and performance of thermal barrier coatings and surface treatments to enhance solar adsorption, anti-erosion, anti-ice and anticorrosion protection for renewable and low-GHG-emission energy production technologies (solar PV, CSP, wind...)
12) **Metrology** for heat transfer fluids (e.g. nanofluid, ionic melts), porous and high energy density materials

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Advanced Materials & Processing

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Advanced materials & processing includes all materials to be processed as semi-finished goods for advanced manufacturing and the manufacturing of advanced materials: Advanced materials include nano-enhanced materials, meta-materials, bio-inspired, lightweight or composite materials, smart and functional materials and coatings. They can be processed from different raw materials in different industries including chemical.

1) **Develop multi-scale, multi-technique and high performance/high throughput characterisation** approaches (Materials 2030 Roadmap): compositional, structural, mechanical and functional properties
2) **Documenting data and knowledge**: develop and disseminate a common (standardised) language (ontology) for data exchange and knowledge management (establish meaningful descriptors/measurands, CHADA data structure), support Digital Product Pass of Advanced Materials with metrology information
3) Measuring **powder material distribution** to improve quality of additive manufacturing processes
4) Quality and contamination control of **pre-used powder** for additive manufacturing
5) Characterization of **interior material structures** down to nanoscale
6) Improved and new metrology methods needed to characterise different types of advanced materials such as: active materials, composites, structural materials, nanomaterials, and biobased-materials
7) Characterisation of slurry feedstock for Layer-wise slurry Deposition (LSD) or Layer-wise induced slip casting (LIS) (properties of slurries/suspensions regarding e.g. rheology/viscosity/solids content/stability)

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8) Characterisation of optical properties of slurries for AM processes based on light curing
9) Methods for determination of materials properties in complex environments (e.g. real word, harsh, rapidly changing conditions)
10) Methods for assessment of materials' quality
11) Advanced data analysis methods for hybrid metrology approaches
12) Development of relevant reference materials
13) High quality datasets to validate virtual testing and materials informatic approaches

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Nano- & microelectronics

6

Nano- & microelectronics

includes all components and systems for manufacturing of advanced electronic devices: Covers semiconductor manufacturing of nanoscale 2D and 3D structures in integrated circuits including its supply chain, pick & place machines for PCB, MEMS (electrical part).

The metrology challenges for Nano- & Microelectronics were discussed in an **Open Consultation**, organised by EURAMET and the EMN on July 8, 2022 with contributions from major European companies addressing their metrology needs. Additional input is from other sources, such as the Key Digital Technology Partnership (**KDT**) and the **IRDS**

Manufacturing systems (lithographic scanner, ebeam writer, etching systems, …):

1) Metrology support for introduction of **high NA EUV lithography** in high volume manufact. expected in 2025, incl. @wavelength metrology and high precision 2D position metrology
2) Larger components in lithography machines may cause drift issues, for drift compensation **near ideal raw materials** and accurate methods for **material property qualification** are needed
3) **Improved overlay control** in lithographic processes requires a combination of global (optical) and local (e.g. e-beam) metrology methods, both need to be precise, fast and traceable
4) **Fast methods for metrology on complex features** are needed, e.g. on Nanowire/Nanosheet Gate-all-around FETs with Si/ SiGe stacks, the Ge-recess after etching needs to measured
5) Defect identification, uniformity and critical dimension of patterned features on masks and wafers

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Technology and device development (CMOS, 3D FET structures, Beyond CMOS, 2D materials, ...):

6) Full and fast characterization of **functional 3D nanostructures** (dimension, materials / composition, dopants, strain, optical and electrical properties) for new device technologies (compound semiconductors, vertical-cavity surface-emitting lasers, microLED, sensors, and power electronics)
7) **In-line capabilities** of metrology methods are needed, e.g. to measure carrier mobility
8) Traceable nanometrology methods on **3D device structures** are needed, e.g. using AFM, e-beam and opt. methods incl. synchrotron radiation
9) Development of **hybrid metrology**: combining results of different methods on well-defined measurands

Systems and fab integration (standards, traceability, comparability, robustness, ...):

10) **Fully integrate metrology tools** in the semiconductor manufacturing lines (Industry 4.0)
11) Modelling of the measurement signal(s) of metrology tools for all different samples/devices
12) **Industrial calibration standards** should be easy to use, stable over time and should cover the whole parameter ranges of instruments and measurement objects
13) Use of **AI-based methods** to support metrology; however, AI methods need to be trusted

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Nano & microtechnology

7 Nano- & microtechnology µ

includes all components for manufacturing of complex devices in Nano- and Microtechnology (Mechanical Engineering): Microsystems, MEMS (mechanical part), sensors (incl. those integrated in smart clothing) and actuators (incl. those integrated in machine tools for modification of functional surfaces (up to macroscale)); Nanostructures as functional elements (nanowires, -apertures); multi-axes nano positioning devices.

1) **Dynamic** characterization of **miniaturized actuators and sensors**
2) Use of different metrology methods (**hybrid metrology**) for nano- and microstructure characterization with small uncertainty
3) Further develop traceable **3D nanometrology** including calibration methods and artefacts
4) Development of **Machine Learning** for nanoparticle metrology and metrology based on point cloud data
5) **Modification of existing standards** such as ISO 2768 or ISO 286 to **include more diversified dimensions below 1 mm** in general types of instruments used are typically surface characterization instruments, and these standards are not dimensional in the same way as e.g. ISO 286
6) Fully exploit potential of revised SI, e.g. using atomically flat surfaces in nanometrology
7) Alignment with roadmapping analysis of the **NanoFabNet** project/hub: www.nanofabnet.net

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Optics & photonics

8

Optics & photonics includes all components and systems for manufacturing of functional optical elements and photonic devices: This covers ultraprecision machining (e.g. for asphere and freeform optics) and silicon-related technologies (e.g. nano-LED), both targeting to use light - over a broad spectrum range - for advanced applications.

1) Metrology of **mass produced complex optical components** (aspheric and freeform)
2) Multi-scale characterization of **structured optical surfaces**
3) **Characterization of light sources and detectors** e.g. LED arrays, imaging sensors
4) Support manufacturing of **large optical surfaces** used in big research structures (telescopes, synchrotron)
5) Progress on establishing inter-comparability / traceability of all sensor principles for **3D/3D^{+}-metrology** on all relevant spatial wavelengths
6) Adapt to trend from “feature based classical metrology” to “**ML / inference based metrology**” for process control rather than part qualification
7) Establish standards for connectivity / **algorithm certification**
8) Appreciative of **SME significance** and addressing their special needs
9) Establish overarching metrology strategy synchronized with European Industrial Strategy

Optics & photonics

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10) Traceable sphericity measurements of **spherical artefacts** with uncertainties below 10 nm
11) Traceable, absolute form measurement of aspherical & freeform artefacts with uncertainties of some 10 nm
12) Development and provision of **aspherical and freeform reference standards** & optical flatness standards
13) **Radius measurement of optical lenses** with uncertainties below 100 nm
14) **Traceable measurements of:** optical wavefronts with uncertainties below 10 nm, the modulation transfer function of lenses with uncertainties below 0.01, properties of diffractive optical elements, properties of hybrid optics (refractive/diffractive) micro-optics
15) **Miniaturised system components** such as electro-optical circuits through suitable types of integration (monolithic, heterogeneous, hybrid)
16) **Metrology for manufacturing integrated optical elements**, defractive/refractive, such as lenses (e.g. wafer-level optics, WLO), filters, polarizers, antennas, multiplexers, amplifiers, but also non-linear, such as frequency converters, (pulsed) lasers, etc.

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17) **Intelligent design** (e.g. through AI support) and **(partially) automated production** of the above structures, especially from the point of view of cost efficiency
18) **Improved interfaces to macro-optics/electronics**, such as fiber couplers or wireless communication as well as robust connection technologies & housings against environm. influences; standardisation concepts
19) **Silicon photonics** and new material systems for other wavelength ranges, including the associated manufacturing processes
20) **Intelligent sensor data evaluation**, as close to the process as possible and with low latency, for example through analogue, optical data pre-processing and/or through intelligent algorithms
21) **Cross-system concepts** from the field of plasmonics and organic semiconductor technology

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Metrology is to support the following expected developments in optics & photonics:

Real-time process control; On-line non-destructive testing of laser manufactured parts; Process optimisation bases on novel in-line/on-line photonic measurement and multi-modal metrology; Big data correlation, meta-modelling and quality prediction; Data analytical techniques / mathematical methods to optimise information obtained from available measurements; Novel optical fibres for use at wavelengths higher than the UV (and beyond 2µm); Non-mechanical high-speed beam scanning systems; Re-configurable and programmable beam shaping systems (tailored light); Rapid monitoring and quantitative feedback systems; Focusing and imaging optics facing the Abbe limit for highest spatial resolution of energy; Multibeam guiding and switching; Miniaturised interchangeable optical processing systems; Material, coatings and components for high power/high-intensity beams; High energy and highly agile ultra-short pulse lasers; High brilliance diode lasers (CW and pulsed) with different wavelengths; Lasers for the generation of coherent X-rays; High power mid-infrared lasers with wavelengths greater than 1 µm; Multibeam lasers; …

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Land & sea-based mobility

9 Land & sea-based mobility includes all components and tools to manufacture vehicles (car, lorry, train, tractor) and ships to transport people or goods: Covers new or improved drive technologies based e.g. on electric power, hydrogen or synthetic fuels to support the EU Green Deal. Also includes evaluation of distributed sensor signals needed for integrated mobility concepts, autonomous driving, etc.

1) Manufacture and calibration of **low-cost real-time sensors** for reliable autonomous driving
2) **Characterization of optical sensors** for manufacturing control and in autonomous driving
3) **Optical systems** for intelligent autonomous cars and other vehicles
4) Reference data sets for validation of autonomous car systems, especially operation under harsh conditions
5) Cryogenic and ultra-high temperature **light-weight materials characterisation**
6) **Augmented GNSS**, positioning validation, trustworthy sharing of measurement data
7) Increased requirements on **drive train components in electrical cars ⇨ noise reduction**
8) Increased mechanical rigidity due to **weight of batteries ⇨ safety aspects**
9) Smart manufacture and assembly of **electrical engine components**
10) Long and reliable **fatigue life of welds in lightweight structures** by better geom. control of misalignments
11) Materials datasets under operational conditions, e.g. magnetic materials required to validate models used in design and manufacture of high-performance electric motors[1]

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Aerospace

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Aerospace includes all components and systems needed to be manufactured for transportation of people and goods in air and astronauts and instrumentation in space: The aerospace sector is characterized by stringent safety requirements for application in challenging and changing environments with associated special manufacturing requirements.

1) (Automated) metrology for **manufacturing of larger components** (up to 100 m) **in harsh environments**
2) Reliable metrology for components and systems under challenging **dynamic boundary conditions**
   ⇨ Sensing in-situ for on test or in-service application for high temperature/vibration/pressure or electrically/radiologically harsh environments
   ⇨ Stable references are needed for moving objects characterized by highly varying speed and accelerations
3) **Metrology of systems in flight** (e.g. for large deployable reflectors) ⇨ In-service sensing of pressure/ temperature/vibration/flow/chemistry – e.g. emissions or incoming pollutants
4) **Development of refractive index compensating 3D interferometry**
5) **Metrology for alignment fixtures** used in mounting/adjustment of Head Up Display Units (HUDs) of aircrafts
6) Metrology for **2-3 axis gimbal systems**
7) Measurement of vibration, torque, temperature, radiation etc. including in-service and in-manufacture
8) **Standards for quantification of environmental impact**, e.g. embedded CO_2 and energy consumption[1]
9) Metrology for **magnetic properties** under realistic conditions: Measurement of magnetic performance under representative stress and temperature

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10) Manufacturing and **in-service health monitoring** including **insulation and infiltration quality and monitoring**: Electrical, thermal and mechanical properties in-service and in-manufacture. Include energy storage systems. **Insulation system health monitoring** is a key requirement for electrical machines – includes tapes and filled resins etc.
11) Metrology for complex geometries and **multi-material assemblies**, e.g. ALM structures, electrical coils, and stacks
12) Inspection and metrology of **composite materials** ⇨ lightweight products ⇨ particle strength / fibre / dispersion of added functional material ⇨ characterisation
13) Metrology for **close-loop manufacture** of composite materials
14) Non-destructive in-situ metrology to support high precision assembly of electromagnetically low contrast parts
15) Metrology to monitor heat treatment of high value parts, e.g. single crystal nickel alloy turbine blades: Self-validating thermocouples, new methods for in-situ calibration drift detection, e.g. based on sensor networks
16) Metrology for structural and dimensional quantities of hydrogen fueld systems at high pressure and cryo temperatures

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Complex Infrastructure & Civil Engineering

ADVANCED MANUFACTURING

EURAMET

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Complex infrastructure & civil engineering includes all components and tools needed to realize larger complex infrastructures in civil engineering and big science: Covers major building and infrastructure projects e.g. complex bridges and tunnels for challenging mobility projects as well as more unique facilities with extreme engineering requirements e.g. the Future Circular Collider (FCC) at CERN. This also includes manufacturing of products “in the field” e.g. agritech.

1) Reliable large-distance metrology needs link of GPS position info with **geodetic length instrumentation**
2) Extreme demands on **long-term stability of sensors** for monitoring purposes
3) Characterisation of **lightweight composite foams** or non-structural **foam concrete** (porosity, mechanical properties...)
4) High-performance **aerogel insulation materials** characterisation (very low thermal conductivity meas.)
5) Metrology systems capable of functioning in harsh environments
6) **Refractive index compensating long-range multi-wavelength interferometry**
7) New instrumentation & methods for surveying and geodetic measurements with increased real time accuracy
8) **Reference software for geo information systems** and infrastructure optimisation tools
9) High accuracy determination of **geodetic referential frames** (geoid, quasi-geoid)
10) Metrology and inspections techniques for 3D printing of concrete (e.g. ultrasonic/vibration/radiographic)
11) Methods for the estimation of accuracy/precision/uncertainty of drone inspections
12) Metrology for ITER fusion source (e.g. digital twin for alignment of sections including distortion during welding process)

Key Industry Sectors (KIS) – Overview

ADVANCED MANUFACTURING
EURAMET

1 Metrology equipment & service

overarching KIS relevant for the other KISs

2 Machine tools & robotics

3 Digitalized & integrated manufacturing systems

4 Energy generation, transmission & storage

5 Advanced materials & processing

6 Nano- & microelectronics

7 Nano- & microtechnology

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8 Optics & photonics

9 Land & sea-based mobility

10 Aerospace

11 Complex infrastructure & civil engineering

12 Life science technology

13 Defense & security

Life Science Technologies

12

Life science technology includes all components needed to realize reliable manufacturing processes in medical engineering, biotechnology, pharmaceuticals and food industry: Covers medical engineering (implants, prosthetics, medical robotics, injection systems, medical imaging instruments, …) and manufacturing aspects in biotech, pharmaceutical, cosmetics and food industry including related sterilization, packaging and personalized dosing technologies.

1) Metrology for **production of medical devices**, e.g. insulin injection systems and (personalised) implants (FDA requirements)
2) Metrology challenges in production for medicines (**personalized dosing**)
3) Metrology for surface characterization: **nanotexturing** or chemical surface functionalization to achieve antibacterial properties for example
4) Metrology for **drug delivery elements in functionally graded implants** (either chemically or structural or porosity graded) or in micro- or nanoscale devices
5) Quantitative method to characterise the ratio of several types of **surface functionalisation** (multifunctional materials)
6) Metrology for quality control of life science products and **product packaging**
7) Metrology for further investigate effects of environmental changes (temperature and humidity) on feedstock material for AM powder-based processes (powder quality and its flowability)
8) Metrology to control binder jetting processes for e.g. for bioceramics, that are used to tailor the final part porosity by controlling the ingrowth of tissue
9) Metrology for assessment of influence of storage conditions/humidity on bioresorbable materials
10) Metrology for determination of material behaviour after post-processing (investigation of residual binding liquids used in additive manufacturing of ceramics after heat treatment

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Defense & Security

13

Defense & security includes all components and systems to realize reliable manufacturing processes in non-military defence and security industry: Covers all manufacturing aspects for products, technologies, and systems to protect the citizens and manufacturing infrastructure of Europe.

1) **Resilience** of a future digitalised European metrology infrastructure and knowledge base
2) Manufacturing systems may require **monitoring and protection from naturally occurring external events** (e.g. solar radiation, seismic events, local weather, air quality,…)
3) Resilience of the **Digital SI** to cyber attacks
4) Assure **provenance** and **trustworthiness** of metrology data
5) **Integrate metrology data** in open digital platforms and secure data flow (Made in Europe, 2019)
6) Protection of manufacturing/metrology systems in **dark factories** from malicious actors
7) Awareness for the risk of **virtual attacks**
   ⇨ Ensure resilience of standards