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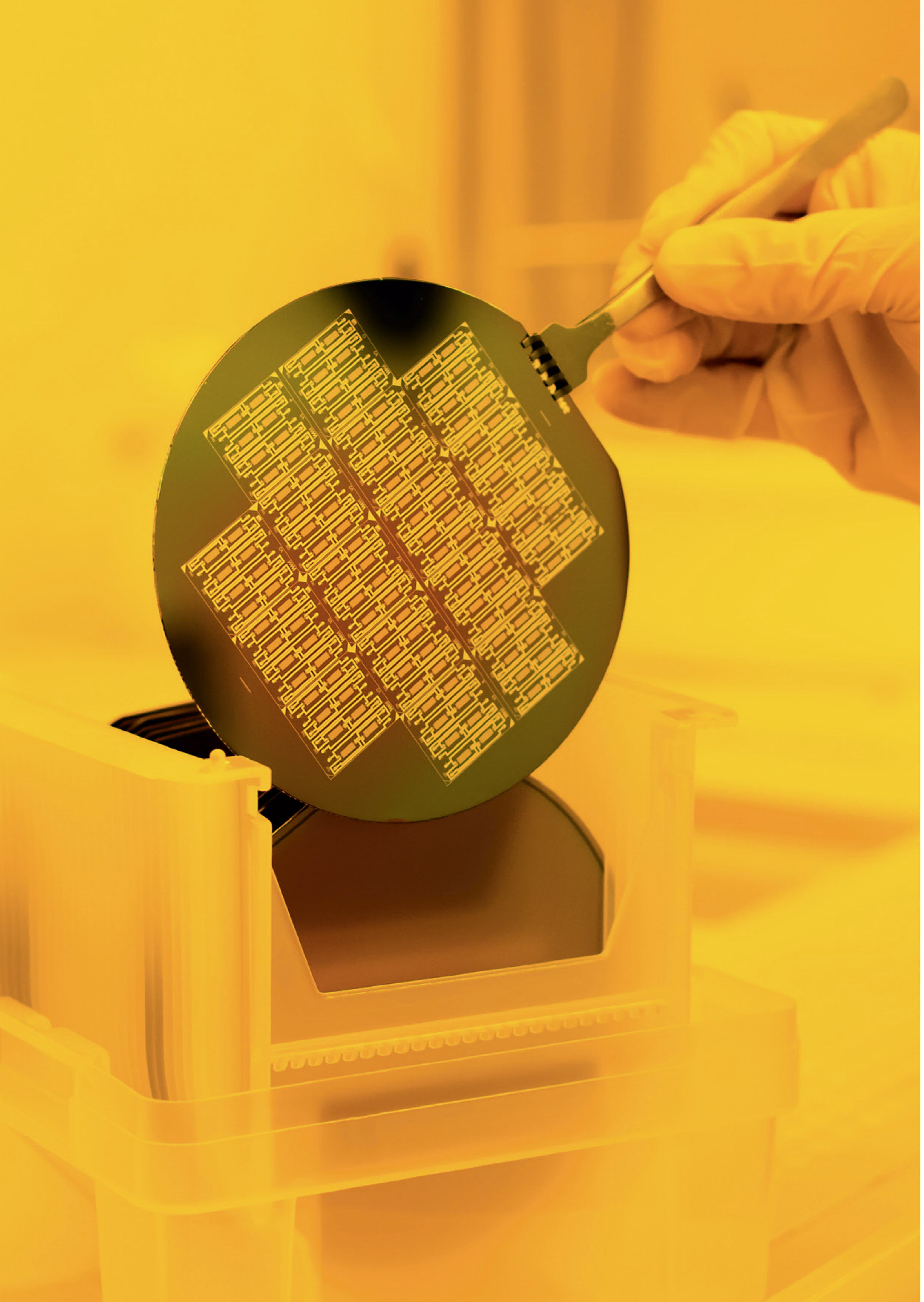
Fraunhofer IMM

FRAUNHOFER INSTITUTE FOR MICROENGINEERING AND MICROSYSTEMS IMM

MICRO- & NANOFABRICATION



UNLOCK THE FUTURE

Complex, multifunctional but easy to handle – that's the product development challenge often faced today. Complete, intelligent systems require components made using various materials and technologies. But how can an idea be transformed into a manufacturable solution? And how do we get stable fabrication processes with optimum production technologies for the best possible price?

The Fraunhofer IMM in Mainz provides research and development services – always at the cutting edge of technological progress.

Innovative ideas and approaches for Decentralized and Mobile Energy Technology, Continuous Chemical Process Engineering (Flow Chemistry), Microfluidic Analysis Systems, Medical Sensors, Technical Sensor Systems and Nanoparticle Technologies are our strength.

The combination of cutting-edge manufacturing processes and established machining equipment are our technological backbone.

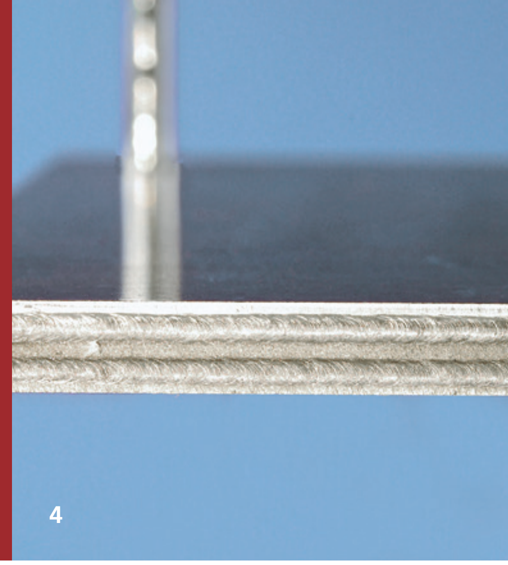
Our experienced, interdisciplinary staff members are the key to success.

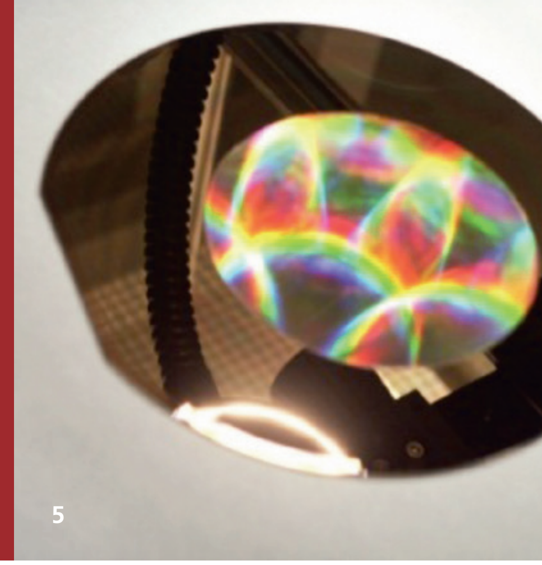
We won't stop looking for the optimum technologies to resolve your issues until you are satisfied.

Beyond commercially available standards

By merging R&D and manufacturing competencies under one roof, Fraunhofer IMM offers its partners customer-specific, micro system technology-based solutions above and beyond commercially available standards. Combining procedures and processes from various technological fields enables us to break new ground in application development. Reliability, practicability and economic viability are our guiding principles.

1 Laser welding & cutting machine
2 Picosecond-Laser machine
3 Interdigital mixer inlay machined by laser
4 Precision laser welding
5 Nano-structured photo resist on Si-wafer





LASER MICRO- & NANOSTRUCTURING

Technology expertise

Fraunhofer IMM has many years of experience in laser micro- and nano-machining, providing individual solutions for manufacturing micro- and nanostructures as well as for processing development. This includes the performance of pilot studies, rapid prototyping as well as laser machine setup.

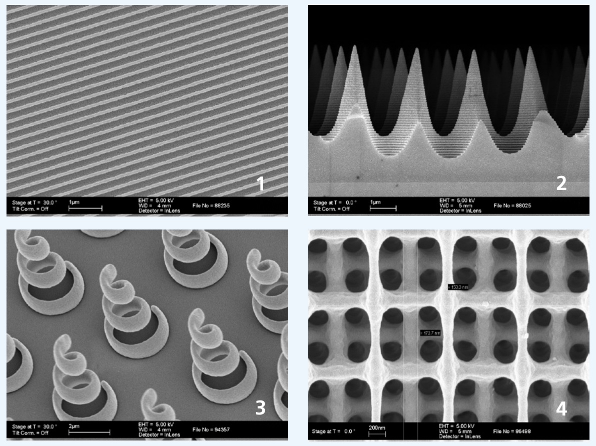
Laser sources

Fraunhofer IMM's state-of-the-art laser sources open up novel and individual processing options for a large number of industrial and research sectors:

Laser sources	Laser parameters: wavelength	pulse length	pulse frequency	max. power
Excimer laser	193 nm	7 ns	300 Hz	3 W
Solid-state lasers	1064 nm 1030 nm 532 nm	100 ns 5 ps 20 ns	0-100 kHz 6-600 kHz 1-30 kHz	50 W 25 W 18 W
CO_2 laser	10.6 µm	0.1-1 ms	1000 Hz	30 W
Ti: Sapphire-oscillator	800 nm	10 fs	76 MHz	800 mW
Diode lasers	976 nm 405 nm	cw cw	cw cw	30 W 50 mW
HeCd laser	325 nm	cw	cw	30 mW

Technical equipment

Fraunhofer IMM's laser beam sources are usually integrated into commercially available machines that have precise xy-tables or scanner optics. Some of the machines are built or optimized by IMM to achieve optimum performance. Laser-generated structures can be characterized by a wide variety of measuring equipment, such as microscopy, interferometry, laser scanning or scanning electron microscopy (SEM).
Via special clamping systems, laser-based processes can also be combined with other microstructuring technologies at IMM, such as milling or electric discharge machining (EDM).



1 Optical grating | 2 Superhydrophobic surface | 3 Nano-antennas | 4 3D photonic crystal

Processes

IMM's laser beam sources are used in a wide variety of processes:

- Fine cutting (melt and sublimation cutting): masks, inlays, sealings
- Precision drilling: pore filters, microfluidic connectings
- Milling and ablation: rapid prototyping of microfluidic structures, rapid tooling
- Welding (metals & polymers): connecting of reformers & microreactors, covering of polymer chips
- Marking: product protection, decoration
- Interference lithography: superhydrophobic surfaces, Surface Enhanced Raman Scattering (SERS) surfaces, diffractive gratings
- Two-photon polymerization: 3D photonic crystals, plasmonic structures, diffractive optical elements (DOEs)

Applications

Microstructuring by laser ablation

During ablation, material is removed by either laser direct write or mask projection techniques.

Typical applications are:
- Microfluidic mixer or evaporator inlays
- Microchannels in polymer chips for Lab-on-a-Chip systems
- Functionalization of sealings

Interconnection by laser welding

Laser welding is achieved either by focussing a pulsed or cw YAG-Laser beam on metal surfaces for seam welding or by heating up polymer interfaces during transmission welding.

Typical applications are:
- Interconnection of reformer stacks
- Tubing of microreactors, reformers and heat exchangers
- Covering polymer chips for life science technology

Nanostructuring by laser photo-polymerisation

Nanostructures with dimensions on the scale of the laser wavelength can be generated either by interference of coherent laser beams or by laser direct writing in photo resist (two-photon absorption, also with subsequent metallization):

- Superhydrophobic surfaces
- Diffractive optical elements, gratings, SERS surfaces
- 3D photonic crystals, plasmonic structures, nanoantennas

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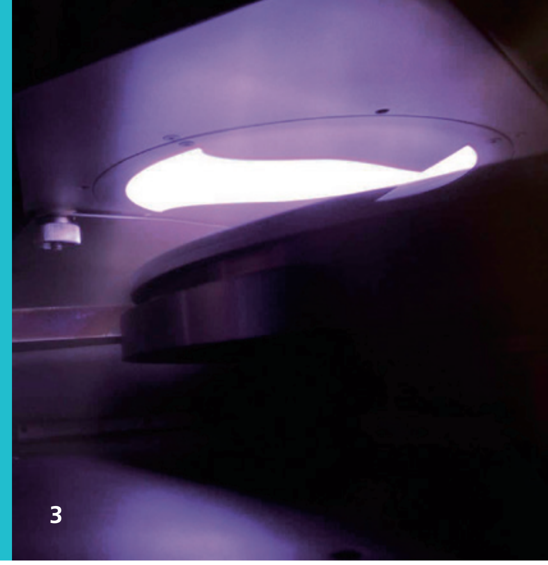
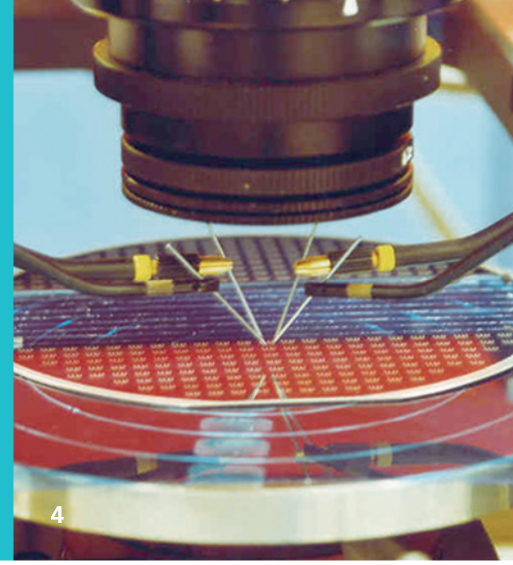




1 Wet etching benches
2 750 sqm cleanroom ISO4 to ISO7
3 Sputtering plasma
4 Waferprober

CLEANROOM FACILITIES

Development of custom MEMS devices and small-scale manufacturing are performed in our 750 sqm cleanroom area. State-of-the-art manufacturing equipment is used to run highly advanced lithography, deposition and etching processes to realize innovative product applications according to our customers' requests.
We also have numerous analytical tools for structure inspection and quality assurance. Process documentation according to DIN EN ISO 9001 ensures the high repeatability and reliability of even very complex process flows involving many dozens of single manufacturing steps.

Photolithography

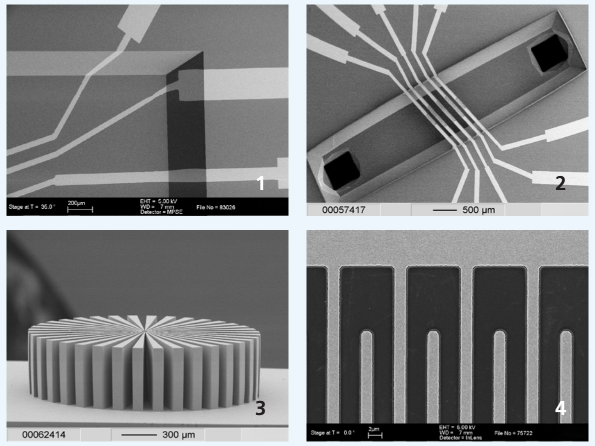
Spin and spray coating processes are available for various resist materials to realize photosensitive and non-photosensitive films. The installed mask aligners offer double-sided lithography on 4-, 5- and 6-inch substrates with resolutions down to 1 micron making them ideally suited for the realization of SOI-based MEMS applications. In addition to dedicated resists for dry etching masks and electroplating in highly acidic media, the following lithography processes are established:

- AZ (positive and negative) from 0.5 to 100 microns
- Polyimide (PI) up to 40 microns
- SU-8 from 0.5 to 500 microns

Deposition

The established deposition processes allow a dedicated variation of film properties such as conductivity, TCR or intrinsic stress. Reactive deposition of oxides, nitrides and carbides is available. Thick metal layers, some up to several mm in height, can be deposited by electroplating.

Process	Film
Thermal Oxidation	SiO_2
CVD (PECVD, LPCVD)	Si_3N_4, Si, SiO_2, SiC
PVD	Metals (Al, Au, Ag, Cr, Ti, Pd, Pt, Ni ...) metal oxides (reactive sputtered or evaporated)
Electroplating	Ag, Au, Pt, Cu, Ni



1 Conductive tracks on wet-etched silicon topology | 2 Self-supporting Si_3N_4 micro-bridges with Pt-resistors | 3 500 µm high SU-8 resist structure | 4 Noble metal interdigitated electrodes

Etching

In order to realize functional elements with complex 3D geometries we apply wet etching techniques to structure e.g. diverse thin films of metals, oxides or polymers or to etch deep into silicon along its crystalline axis, but also a Reactive Ion Etching (RIE) and a deep Reactive Ion Etching process (Bosch, ASE). Plasma stripping processes are also available for removal of polymer films.

Machinery	Operation parameters
Wet etching	Isotropic: metals, metal alloys, polymers, oxides Anisotropic: silicon (KOH or TMAH)
Advanced Silicon Etching (ASE) / Bosch Process	Si: anisotropic Feature sizes > 0.5 µm Aspect ratio up to 12
Reactive Ion Etching (RIE)	SiO_2, Si_3N_4, SiC
Ashing / stripping	Polymers

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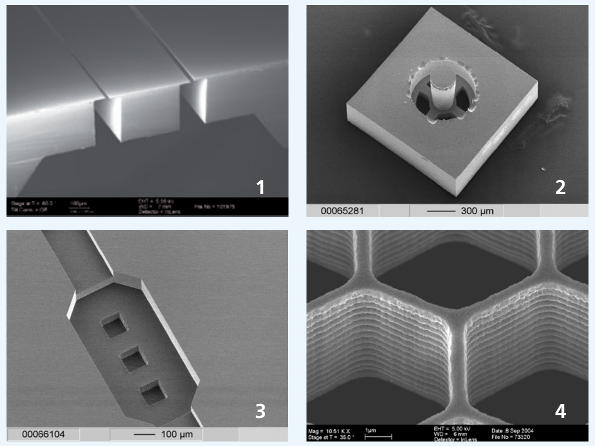
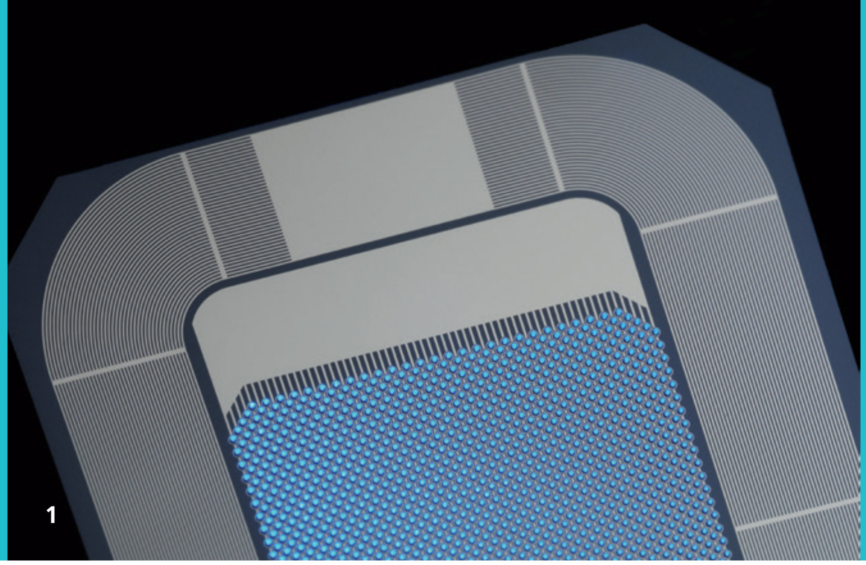
Micro metrology

Realized structures need to be qualified in many different aspects. Besides inspection microscopy, IMM's measurement capabilities include:

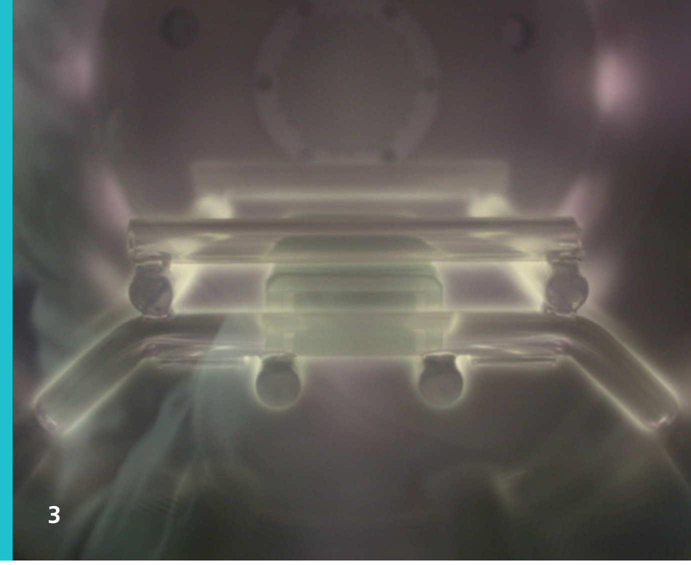
- Scanning Electron Microsocopy (SEM) with Energy-dispersive X-ray Spectroscopy (EDX) analysis
- Tactile and laser scanning profilometers
- Atomic Force Microscopy (AFM)
- Coordinate measuring machine
- White-light interferometry
- Ellipsometry and reflectometry
- Optical spectroscopy
- Wafer prober



1 Optical slit by anisotropic wet etching and ASE | 2 ASE structured three-axial force sensor | 3 Four-level micofluidic ASE structure | 4 Electron-optical silicon grid, mesh width 6 µm



1 *Helium-selective quartz membrane chip*
2 *Micromachined optical double-slit precision-assembled on dedicated glas prism*
3 *Oxygen cleaning plasma*

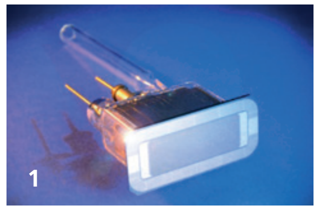


Applications

Helium-selective quartz membrane chip

Core element of the helium sensing system of the Inficon Protec P3000 sniffer leakage detector and the Inficon T-Guard leak detection sensor

- Combines highest selectivity and high pressure stability up to 2 bar due to silicon support
- Integrated heater for operation at elevated temperature
- Developed in cooperation with Inficon, Cologne, Germany

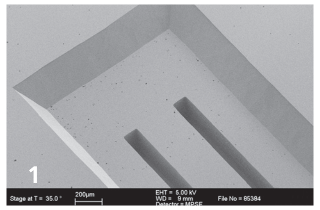


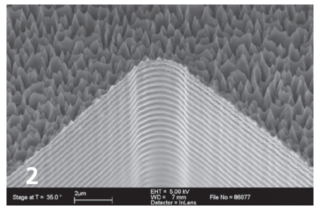
1 Helium detector of the Inficon Protec P3000 | 2 Inficon Protec P3000 sniffer leakage detector

Ultra-precision optical double-slit assembly

Monolithic silicon double-slit for the EnMap hyperspectral satellite spectrometer

- Extreme geometry: 24 mm length and 24 µm width, sub-micron precision
- Mounting of double-slit chip on mirror element by active positioning procedures
- Black Silicon surface on either side feasible
- Developed in cooperation with Kayser-Threde, Munich, Germany



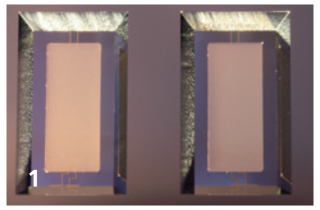


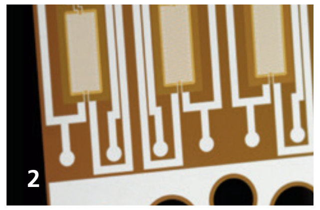
1 Silicon double-slit mounted on mirror element | 2 Anti-reflective Black Silicon surface

Radiation-resistant bolometer array

Bolometer for measuring photon flux in fusion research, dedicated development for use on the international nuclear fusion reactor ITER

- 12.5 µm platinum absorber on 2 µm SiNx membrane
- Close-tolerance platinum thermal sensing resistors
- Developed in cooperation with IPP, Garching, Germany



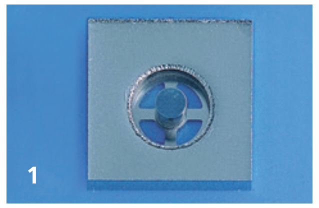


1 SiNx membrane windows with electroplated Pt absorbers | 2 Sensor chip with Pt-resistors connected up to a Wheatstone arrangement

Three-axial tactile sensor

Piezo-electric force transducer e.g. for use in medical and robotic applications

- Sensitive to compressive and shear forces as well
- Designed for small forces up to 2.5 N
- Small footprint 1.5 x 1.5 mm²
- Ion-implanted piezo resistors
- Developed in co-operation with SSSA, Pisa, Italy

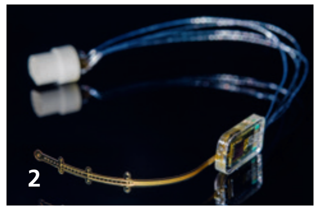


1 Piezo-resistive three-axial force transducer | 2 Sensor backside with piezo resistors and bond pads

Microelectrode probes for neural recording and stimulation

Highly flexible, chronically implantable electrode probes for neuro-science research

- Base material: photo structurable polyimide
- Low resistivity due to reinforcement of the leads by electroplating
- Highly reliable contact interface, hermetically embedded in silicone
- Can be equipped with commercial standard connectors

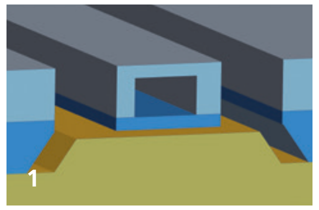


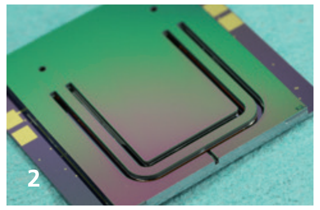
1 Detail of spinal electrode array | 2 Spinal electrode array with interface and electric connector

MEMS U-tube resonator

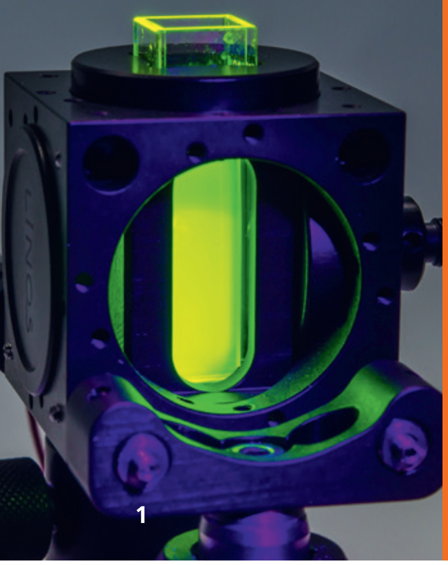
Core element of a microfluidic system for precise determination of the density of liquids

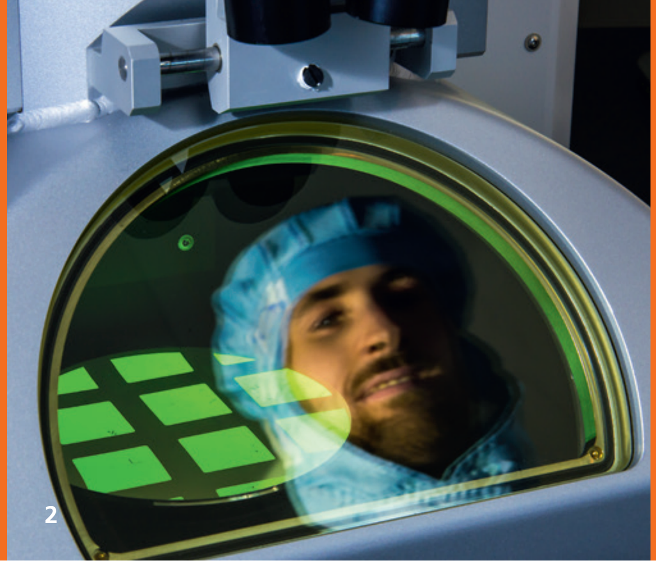
- Freestanding U-Tube realized by ASE
- Assembled on wafer level from three individually structured silicon substrates
- Electrostatic excitation
- Can be combined with optical readout
- Obtainable accuracy comparable to laboratory devices for density measurement



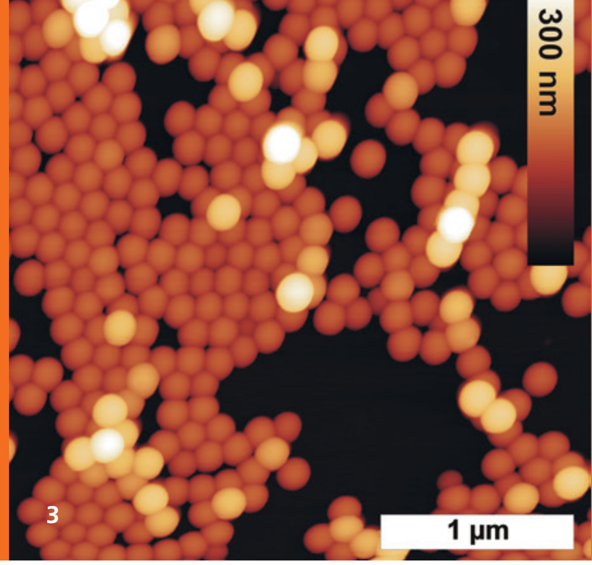


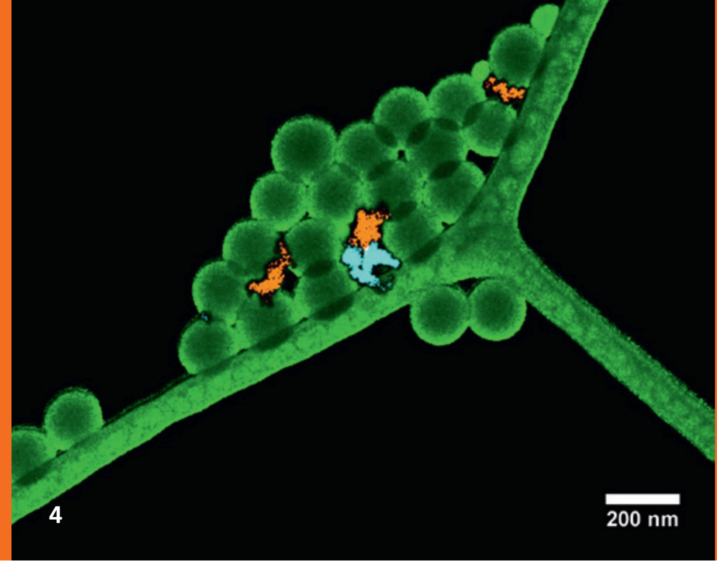
1 CAD detail of the cross section of the channel structure | 2 U-tube resonator for density measurement





1 Fluorescent CdSe quantum dots
2 TEM fluorescent screen
3 Topology of polystyrene nanoparticles by AFM
4 Nanoparticles mixture (TEM / EELS, orange: Ti, blue: Si, green: C)





PARTICLE ANALYSIS & SURFACE TREATMENT

Nano analytics

In accord with our efforts to developing continuous processes for nanoparticle synthesis, we have a number of analytical methods for material characterization available.
We are specialized in bulk and on-line analysis of nanomaterials. This includes nanoparticles of different materials under various conditions, e.g. colloids in aqueous solutions, physiological environments, organic solvents, or embedded in solid matrices.

Dynamic light scattering (DLS):
- Size characterization of colloids and dispersions of ~5–5000 nm, best suited for sub-micron particles
- Benchtop and advanced multi-angle systems available
- Measurements under physiological conditions, on-line measurements for quality control

Static light scattering (SLS):
- Size characterization of colloids and dispersions, for micron and sub-micron particles, molecular weight determination
- Multi-angle and multi-wavelength setups

Optical spectroscopy:
- Absorbance, fluorescence, turbidity
- Measurements possible in standard cuvettes or in-line

Analytical centrifugation:
- Characterization of size and size distributions of colloidal particles, nanometers to microns in diameter
- Excellent resolution for polydisperse materials

Size exclusion chromatography (SEC / GPC):
- Size characterization and semi-preparative purification of nanoparticles

Field-flow fractionation (FFF):
- Asymmetrical flow-FFF, characterization of size and size distributions, fractionation of polydisperse materials
- Variety of detectors available (e.g. UV-vis, fluorescence, light scattering)
- Custom method development

Surface charge detection (zeta potential):
- Characterization of charged particles
- Colloidal stability in different media
- Automated titration with salt or acid / base, measurement of isoelectric points

Atomic force microscopy (AFM):
- Surface topology and roughness, friction and viscoelastic properties
- Detection and mapping of surface potential differences (Kelvin probe force microscopy, KPFM)
- Detection and mapping of local magnetic properties (Magnetic force microscopy, MFM)
- Force-distance curves for mapping of viscoelastic properties
- Resolution down to 0.5 nm in imaging (~30 nm in KPFM and MFM mode)

BET measurement:
- Specific surface area and porosity by nitrogen adsorption

Our expertise together with a variety of different, complementary techniques enables us to gain a comprehensive picture of the sample properties. We provide our customers with tailored solutions for their specific needs, e.g. in regard to the development of protocols for material characterization, handling, processing, and for quality assurance of processes and products.

Electron microscopy
- Scanning Electron Microscopy (SEM, cryo-SEM): Leo 1550 VP, 0.1 – 30 keV
  Dry and vitrified samples, resolution down to 5 nm (conducting materials)
  Energy-dispersive X-ray spectroscopy (EDX) for elemental analysis.
- Transmission Electron Microscopy (TEM, cryo-TEM): Zeiss Libra 120 keV
  Dry and vitrified samples, single nanometer resolution
  Contrast enhancement by energy-filtering (EFTEM) and elemental analysis by electron energy-loss spectroscopy (EELS)

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Nanoparticle Technologies
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Surface etching, activation and coating

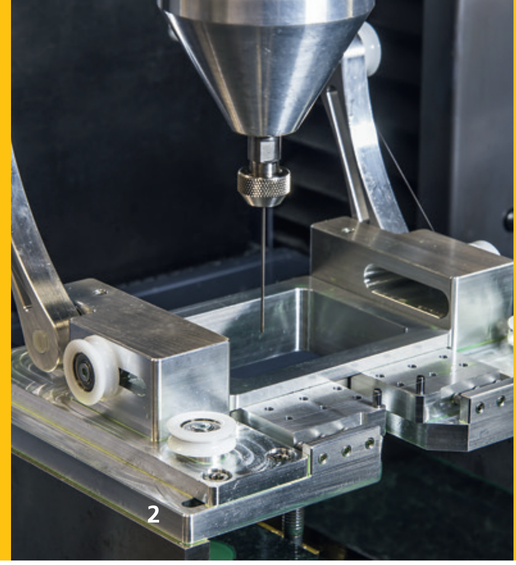
Many years of experience in plasma processing and polymers allows us to provide individual solutions from lab scale R&D to industrial manufacturing. A series of atmospheric and low pressure CVD, PECVD and radiation techniques are applicable to accomplish customer requirements like:

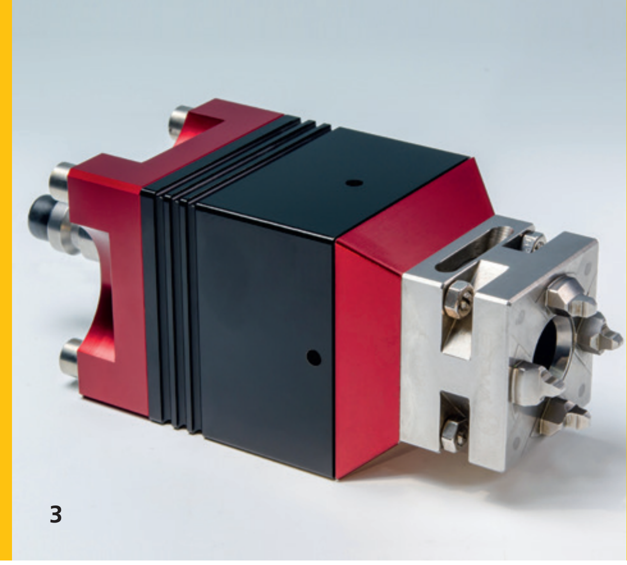
- Biomedical relevant coatings
- Nano scale coatings
- Chemical surface functionalization
- Adhesion improvement
- Stable coating of PTFE etc.
- Smart / Functional coatings
- Barrier layers
- Surface etching
- Surface activation

By using cold plasmas at ambient atmosphere or at reduced pressure, even sensitive materials like semiconductors and biomaterials are processable. Also sophisticated surfaces can be coated precisely:

- Flat surfaces
- Granulates
- Textiles / non-woven
- Screws
- Springs
- Implants
- Capillaries
- Micro channels
- Wells

1 *Die-sinking tool shop*
2 *Wire dressing unit*
3 *Microvibe 300 vibrating electrode chuck*
4 *SONODRIVE 300 vibrating EDM drilling spindle*



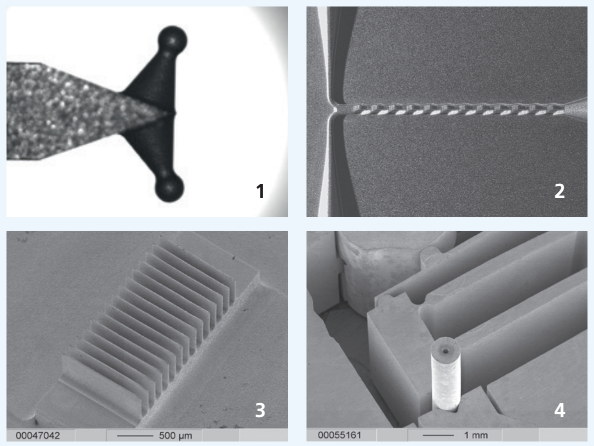


PRECISION ENGINEERING

Technology expertise

With almost 20 years of experience in micro machining and in co-operation with our strong partners, we are able to achieve outstanding results. We stand for: multi-axis die sinking, wire electro discharge machining (EDM) and fine wire EDM, micro EDM-turning, tight tolerances at HQ surface finish. We use the ideal combination of our broad range of technologies for R&D work, prototyping and pilot lot production.

EDM sample parts



1 Double ball end sensing probe (process EDM turning) | 2 Caterpillar hot embossing tool (process die sinking) | 3 Micro die sinking electrode (fine wire EDM) | 4 Micro fixation unit (process wire EDM)

Workshop equipment

IMM provides services for developing and realizing precision and micro structuring. Our workshop (approximately 500 sqm) is equipped with the following state-of-the-art machines:

Machinery	Operation parameters
Die sinking EDM	
Mitsubishi EA12Adv. Mitsubishi EA8PV Adv.	4-axis CNC-controlled EDM die-sinking machines, 0.1 µm resolution
Both	Additional 2-axis CNC-table, rotation axis, vibrating electrode chuck, vibrating rotation spindle, µ-electrode dressing unit
Wire EDM	
Mitsubishi FA20S Adv.	Wire diameter 0.1-0.3 mm
Mitsubishi PA20	Wire diameter 0.05-0.3 mm
Both	Additional CNC B-Axis high speed micro spinner devices
Agie-Charmilles Vertex 1	Twin wire machine wire diameter 0.02-0.2 mm high speed micro spinner device
Ultra precision machining	
Precitech Nanoform 350	UP-lathe with add. Y-axis table for diamond turning and linear milling operations

Processes

Combining different processing technologies is the key to solving your problem

Fraunhofer IMM has a large variety of in-house manufacturing technologies which we are able to flexibly combine in order to create new machining strategies. We can also increase number of ways to realize microparts and microstructures. Optional add-on devices like vibrating electrode chucks, vibrating drilling devices, electrode dressing unit and integrated high precision zero-point fixation allows advanced and combined manufacturing in a continuous process chain.

- CNC turning and milling, micro-milling
- Wire and die sinking EDM (micro EDM machining, EDM turning)
- Ultra precision machining (diamond cutting)
- Laser manufacturing (cutting, welding, ablation, micro drilling)
- Photolithography
- Advanced silicon etching
- Thin film technology

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Technology development

Add-on devices providing an electrode vibration can improve die-sinking processes. This additional vibration causes a current flow in the EDM gap and provides a better removal of material particles leading to a stable EDM process with reduced machining time while having the same or lower electrode wear rate.

Meanwhile IMM has developed and patented the "Sonodrive 300" system, a high precision vibrating EDM drilling spindle. This device combines an electrode vibration and rotation with a max. runout of 1-2 µm providing a more efficient and precise EDM drilling operation than traditional EDM spindles.

The "family" of add-on EDM devices will be expanded with the "Microvibe 300" vibrating electrode chuck. This system provides a vibration in the z-axis direction for die-sinking operations. To hold the electrodes, the Microvibe 300 can be equipped with any kind of electrode chuck providing a ± 2° leveling mechanism. Both systems are "plug 'n play" units, equipped with self-sufficient controller units and are compatible with any commercially available clamping system.

Furthermore, a wire dressing unit has been designed in order to shape micro electrodes right on the die-sinking machine without any runout and stagger. A combination of Sonodrive 300 and the wire dressing unit enables to machine e.g. drilling electrodes with diameters as small as 10 µm.

With the integration of these units, the application area of your existing die-sinking machine will increase remarkably.

1 Workshop
2 Micromilling of an caterpillar-structure (cutter diameter: 0.2 mm, material: hastelloy)

PRECISION ENGINEERING

With more than 20 years of experience in the field of chip-making machining and in combination of our broad range of technologies for R&D work, prototyping and pilot lot production, we are able to achieve distinguished results.

Toolshop machinery	Operation parameters
Fehlmann Picomax 60-HSC, 60-M	3D CNC- milling system ■ Max. travel 500*350 mm, z-axis 610 mm ■ High-speed spindles ■ Automatic tool changer ■ High pressure cooling system with internal tool cooling option ■ Minimal quantity lubrication system ■ Laser tool measurement
Fehlmann Picomax 54	2.5D CNC- milling system ■ Max. travel 500*260 mm, z-axis 160 mm
EMCO E45	CNC lathe with driven tools ■ 12 tool holder, 6 driven tool holder ■ Various clamping systems ■ High pressure cooling system
Jung JF500	Surface grinding machine

Processes

With the in-house installed chip-making machinery, we are able to fulfill most of our customer´s needs in the field of high volume machining as well as micro machining. We offer the possibility to machine a large variety of workpiece materials from standard metal parts, to special alloys and ceramics. We also offer a high precision machining of hardened steel parts e.g. mold inserts and the realization of micro parts and micro EDM-electrodes. The use of integrated high precision zero-point fixation allows advanced and combined manufacturing in a continuous process chain.
To preserve and extend our core competencies, we practice a continuing education of our employees and pass the apprenticeship for precision mechanics.

Metrology	
Mahr MS222	3D CNC-optical measuring system ■ Max. travel 250*200 mm, z-axis 200 mm ■ Measuring length uncertainty according to VDI / VDE 2617 E1= (2.2+L/150) µm E2= (3.2+L/125) µm E3= (3.9+L/100) µm L= measuring length in mm
Nikon Profile Projector V12-P	■ Magnification lenses 50x; 200x; 500x
Mitutoyo QM-Data 100 E45	Linear height gauge ■ 600 mm measuring heights ■ Repeatability 4 µm
Garant measuring scope MM1 300	Optical measuring scope ■ Max. travel 300*200*200 mm
Various microscopes, inspection tools and portable measuring instruments