



METAMORPHA

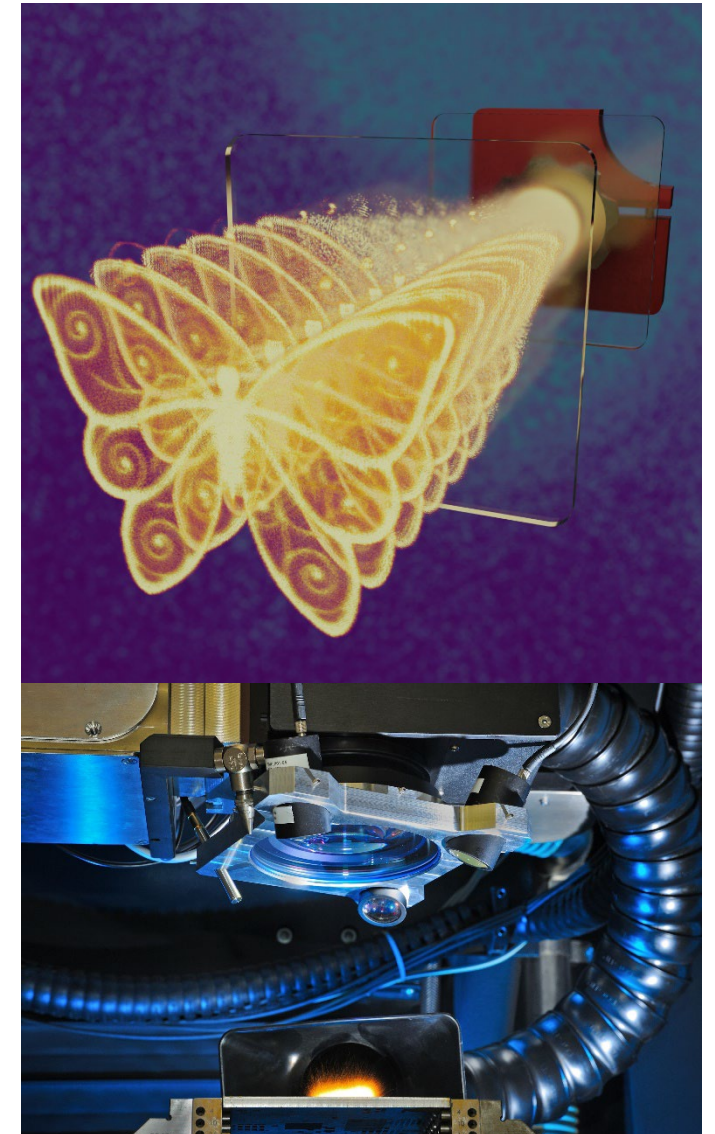
Made-to-measure micromachining with laser beams tailored in amplitude and phase

Horizon Europe 101057457

Project overview presentation

Presentation outline

- **Project overview**
- All-in-one USP laser module
- Beam tailoring and steering
- Made-to measure processes
- Real-time process control
- Industrial use cases
- Conclusions




Project overview

- Single agile USP laser micromachining platform
 - Replaces conventional manufacturing process chain
 - *E.g.* polishing, milling, drilling, cutting, EDM, ECM and wet chemical etching
 - Integrated galvo scanner
- Full control over phase and amplitude
 - Based on two cascaded SLMs
 - Allows digital beam steering for vertical structure walls
- Made-to-measure laser process
 - All-electric, all-digital, no waste chemicals
 - Using 3D sensor data and machine learning algorithms
- In-line process control using real-time feedback from photo diodes.



Industrial use cases

- Three industrial use cases to assess different manufacturing challenges
- Emphasis on energy reduction and increased recycling
- Quantified sustainability assessment.



PHILIPS

Small metal parts

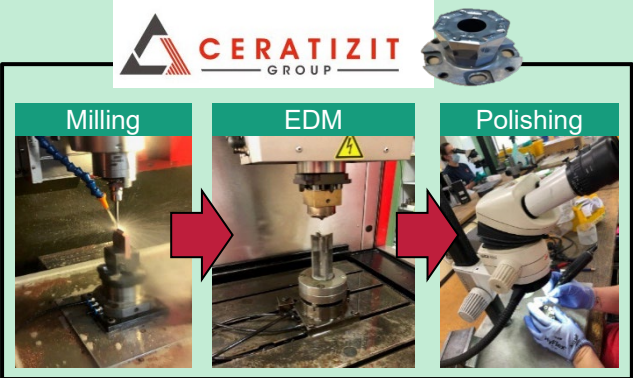
- Complex and fragile
- High precision



thyssenkrupp

Large area embossing rollers


- Manufacture
- Re-writing old rollers



CERATIZIT GROUP

Very hard carbide parts

- Manufacture
- Refurbishment

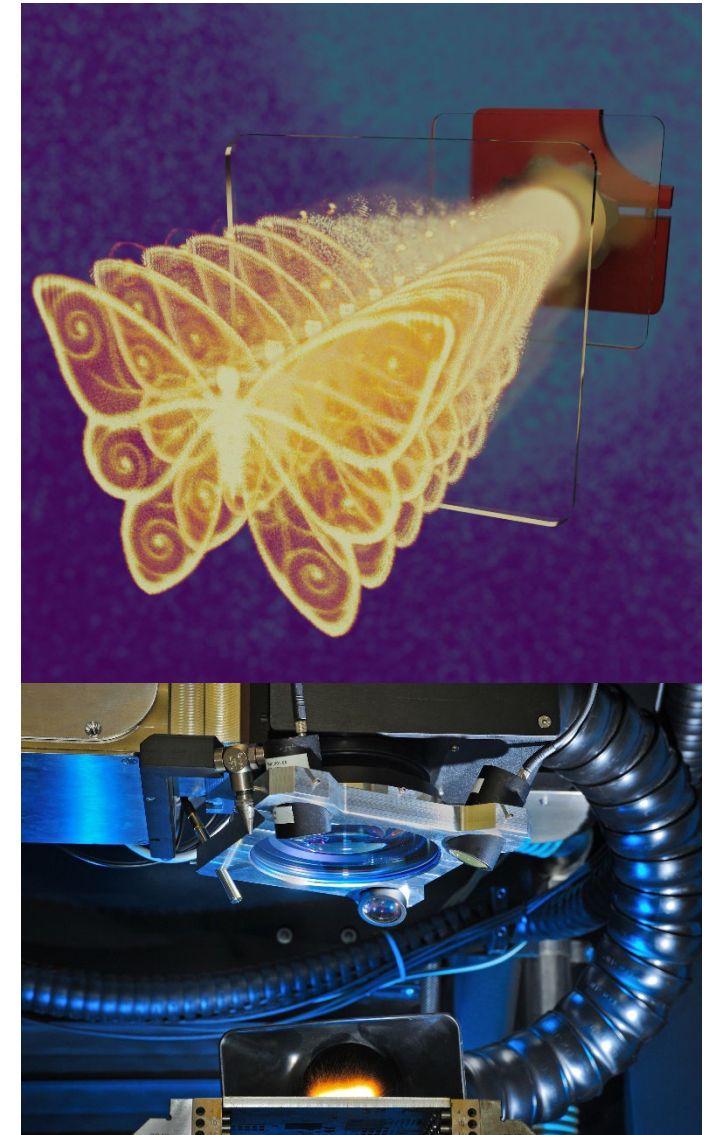


Quantified sustainability assessment

- Environmental
- Socioeconomic

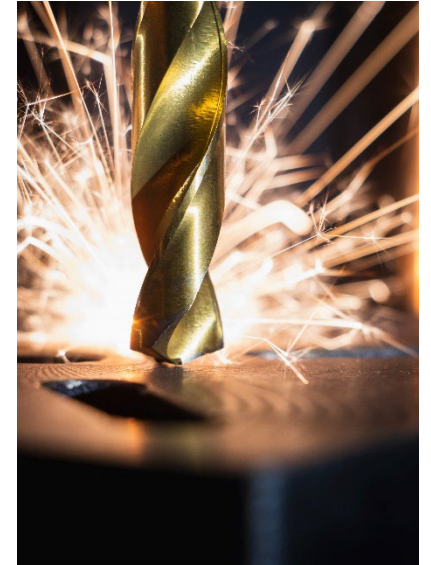
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Industrial micromachining process chains

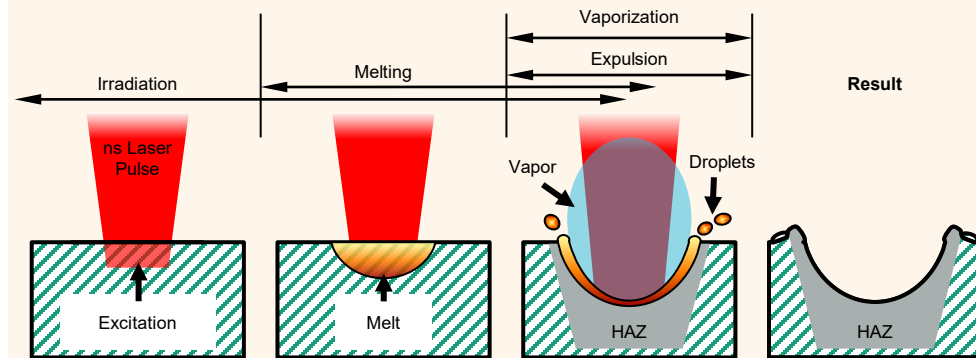
- State-of-the-art for modern micromachining
- A series of mechanical and (electro-) chemical operations, *e.g.*
 - Polishing, milling, drilling, cutting
 - Electrical discharge machining (EDM)
 - Electro-chemical machining (ECM)
 - Wet chemical etching
- These methods provide excellent results, BUT!
 - Lack flexibility
 - Cannot be easily adapted
 - Negative environmental impact
 - Harmful process chemicals
 - Waste products
 - High energy consumption
 - Minimal remanufacturing options.



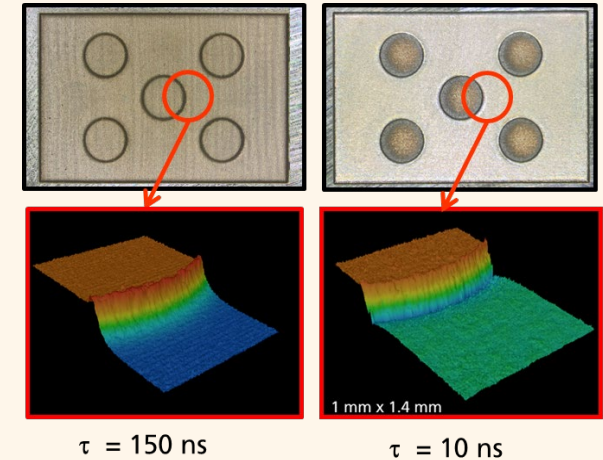
Ultrashort pulse (USP) laser processing

- Each electro-mechanical processes can be replaced by a USP laser process

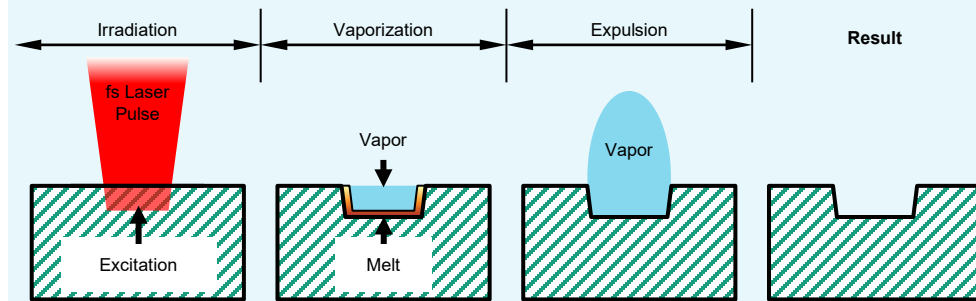
Nanosecond pulse duration



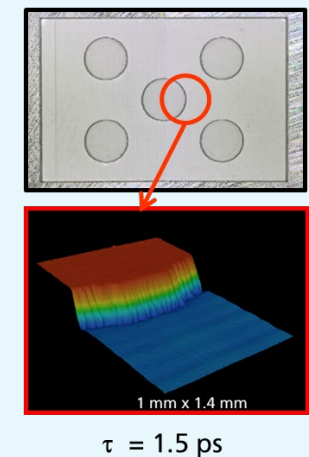
- High removal rate
- Low precision due to melt-dominated ablation
- Debris and burrs
- Pronounced heat affected zone



Pulse duration <10 ps

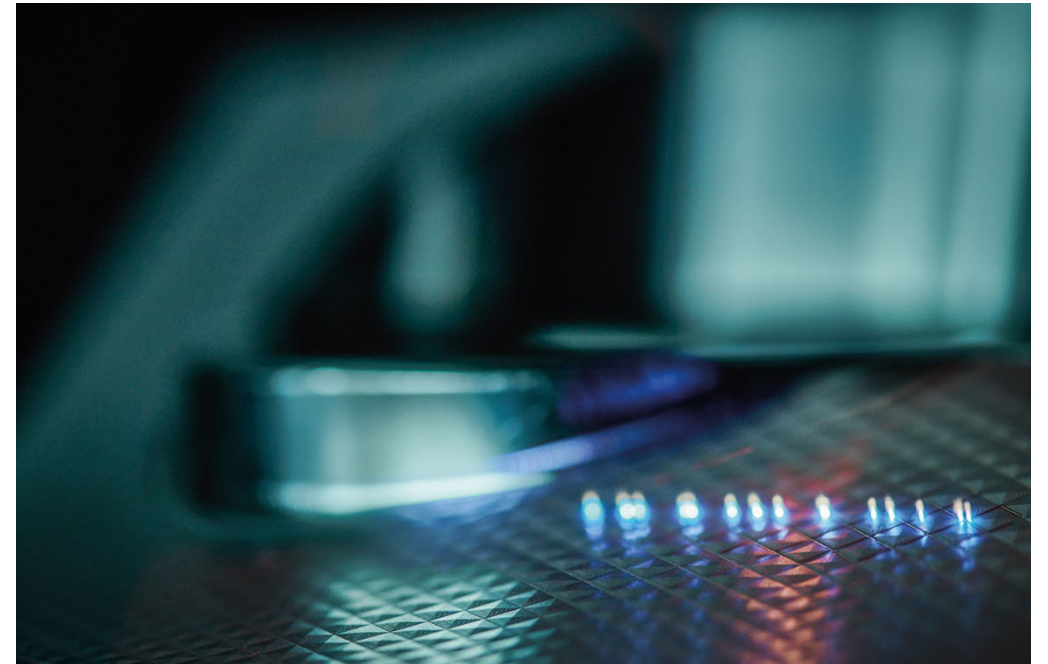


- High precision due to sublimation-dominated ablation
- Minimal thermal impact
- Processing of practically all materials due to non-linear absorption
- Relatively low removal rate



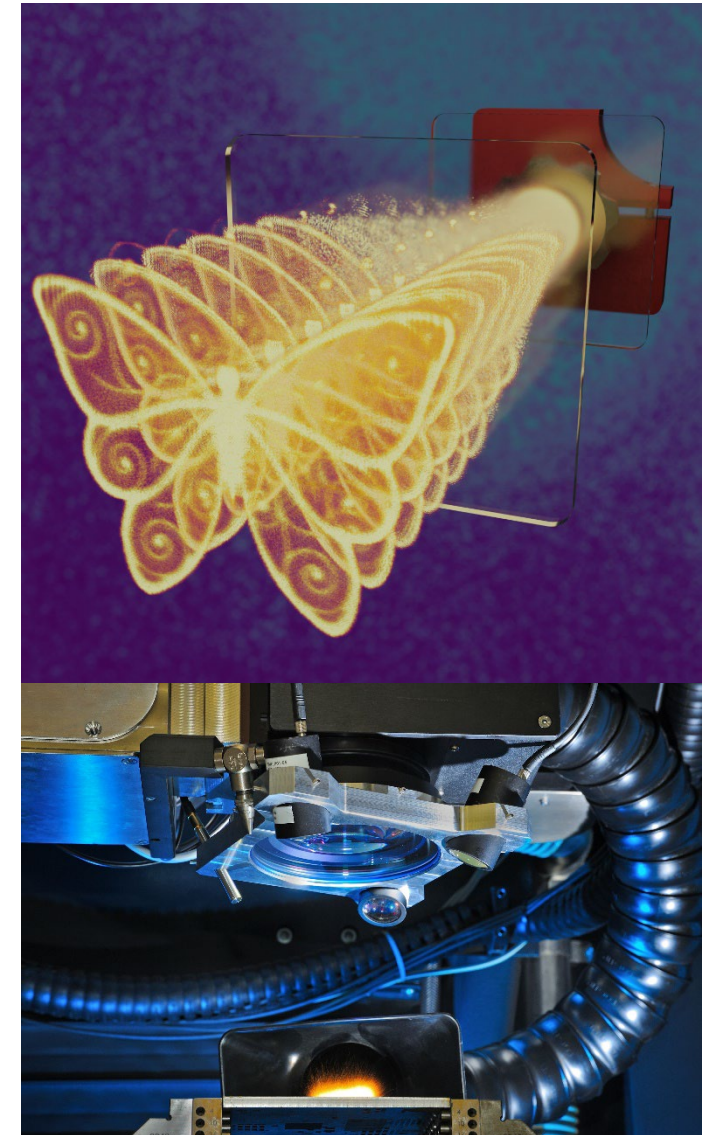
METAMORPHA solution: all-in-one

- METAMORPHA solution
 - *Replace the whole process chain with a single digital USP laser system*
- Not possible with any current single-beam laser machining system
 - This requires new degrees of freedom
- Achieved using high resolution SLM technology
 - Tailored beam profile
 - Digital beam steering.



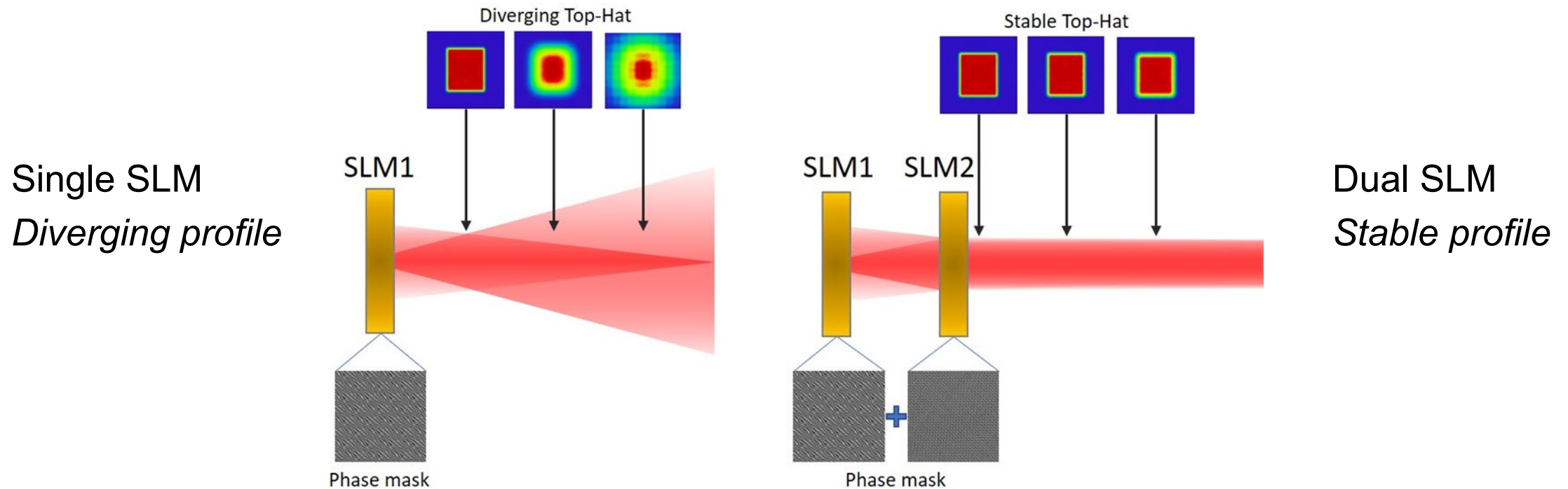
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- **Beam tailoring and steering**
- Made-to measure processes
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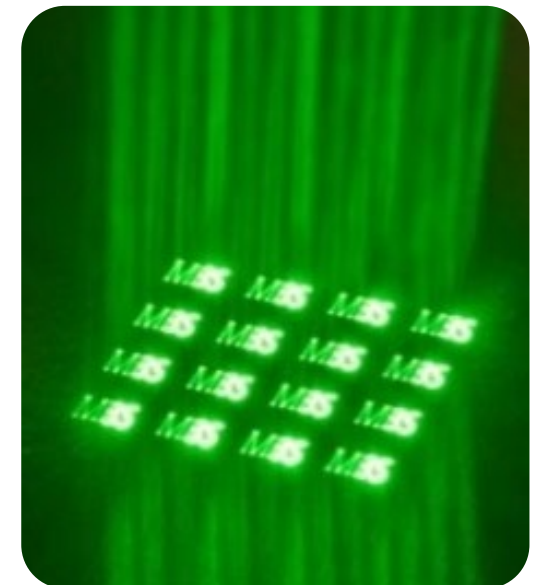
Cascaded SLM combination

- Cascaded dual SLM combination:
 - Tailoring beam energy distribution into arbitrarily complex patterns
 - Dynamic tailoring allows process optimisation in real time
 - Phase control enables all-digital steering of the cutting angle.



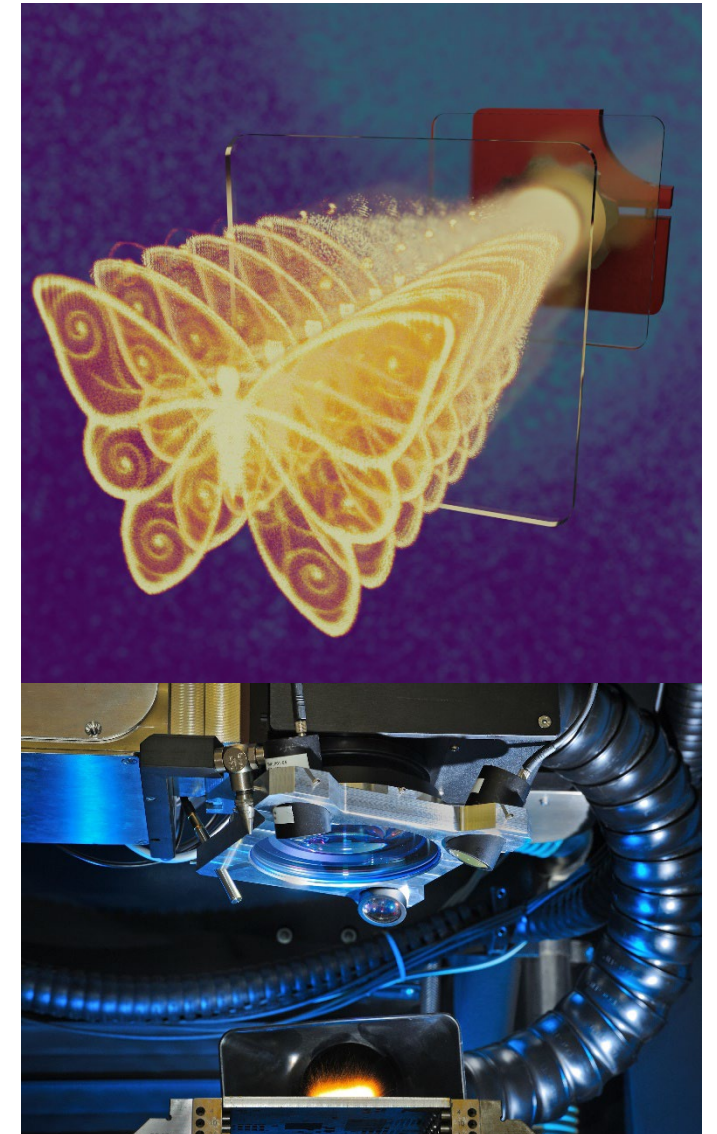
Beam intensity profile

- Tailored beam profile
 - Suitable for any arbitrary beam shape
- Single spot
 - Bessel beams, top hat *etc.*
 - Arbitrary patterns
- Multi-spot
 - Regular arrays
 - Arbitrary patterns
- Allows made-to-measure process definition
- Dynamic tailoring allows process optimisation in real time.



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High precision 3D scanners



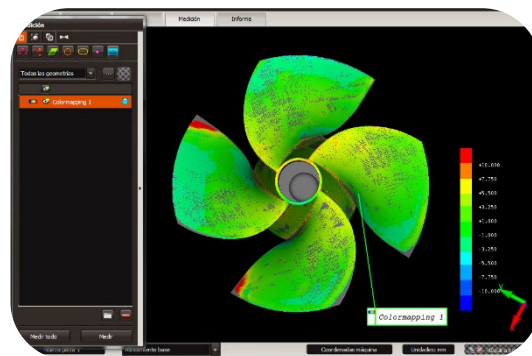
- High resolution 3D surface topography quality sensor
- Each workpiece is scanned before processing.



Non-structured point clouds



Geometry Feature Extraction



Deviation map

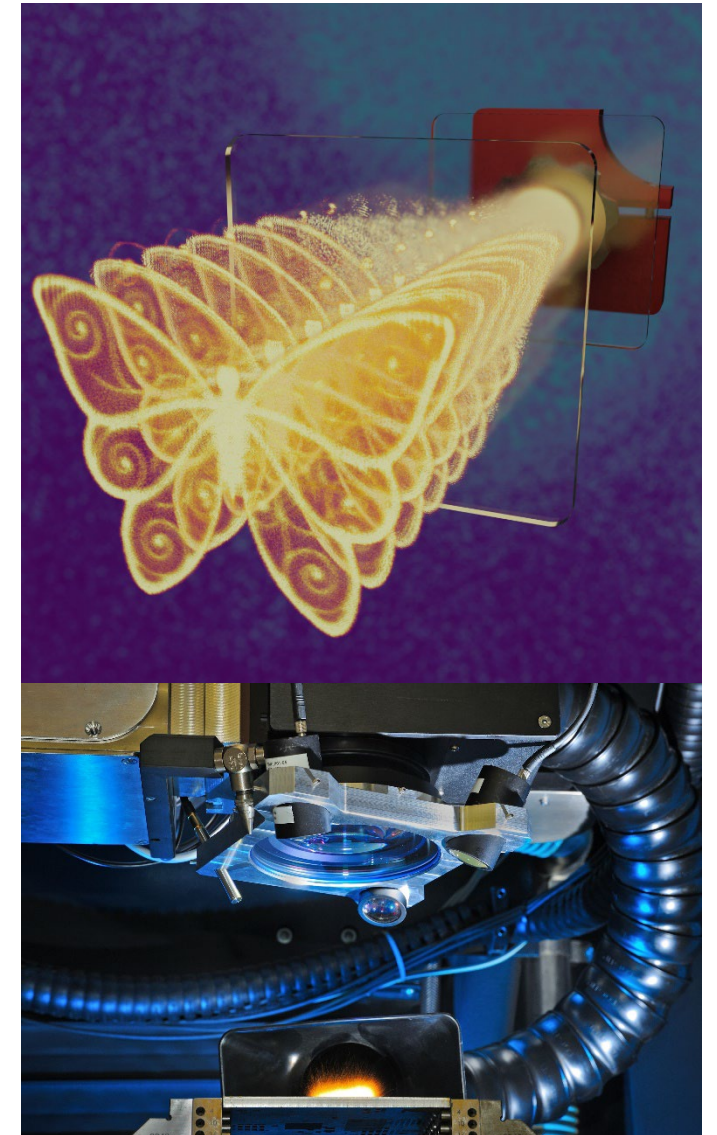
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ANSI ISO standard for metrology data

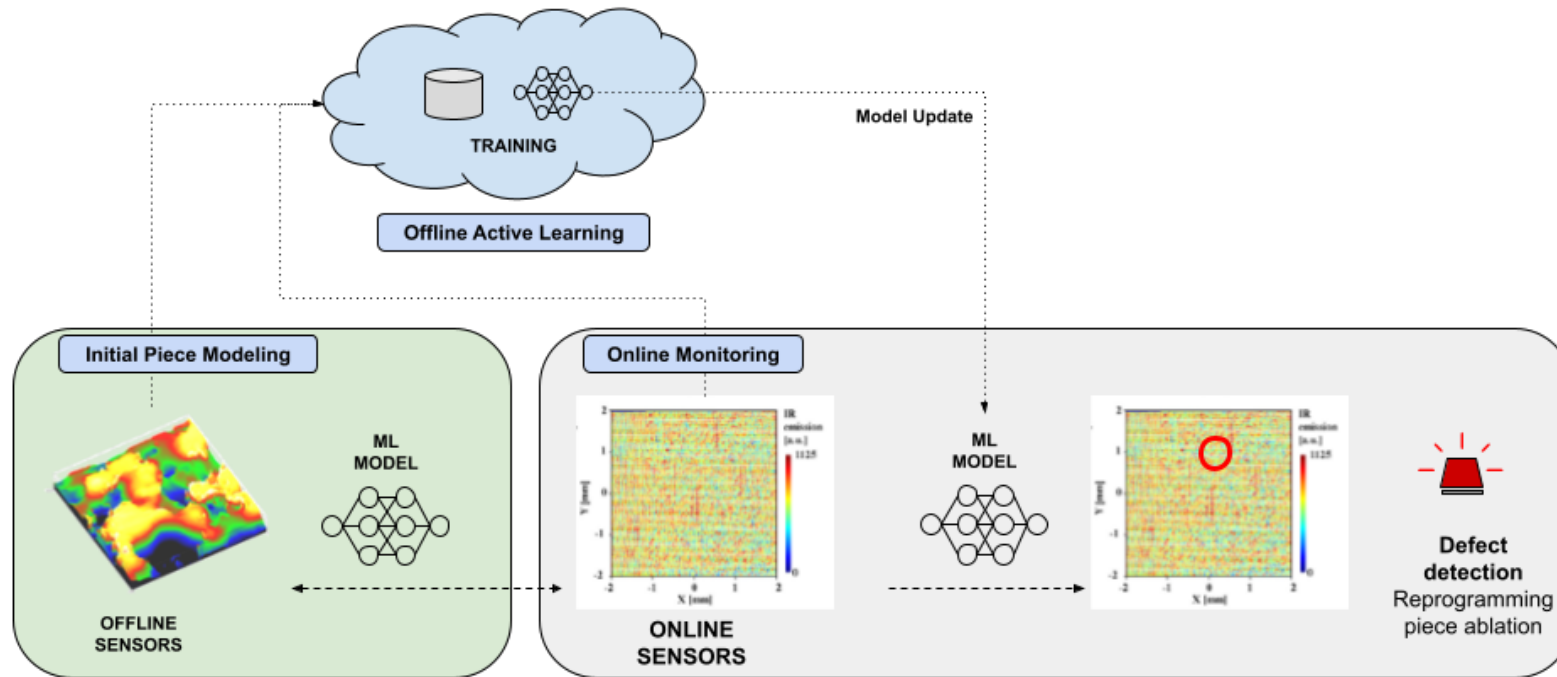
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Process optimisation with machine learning

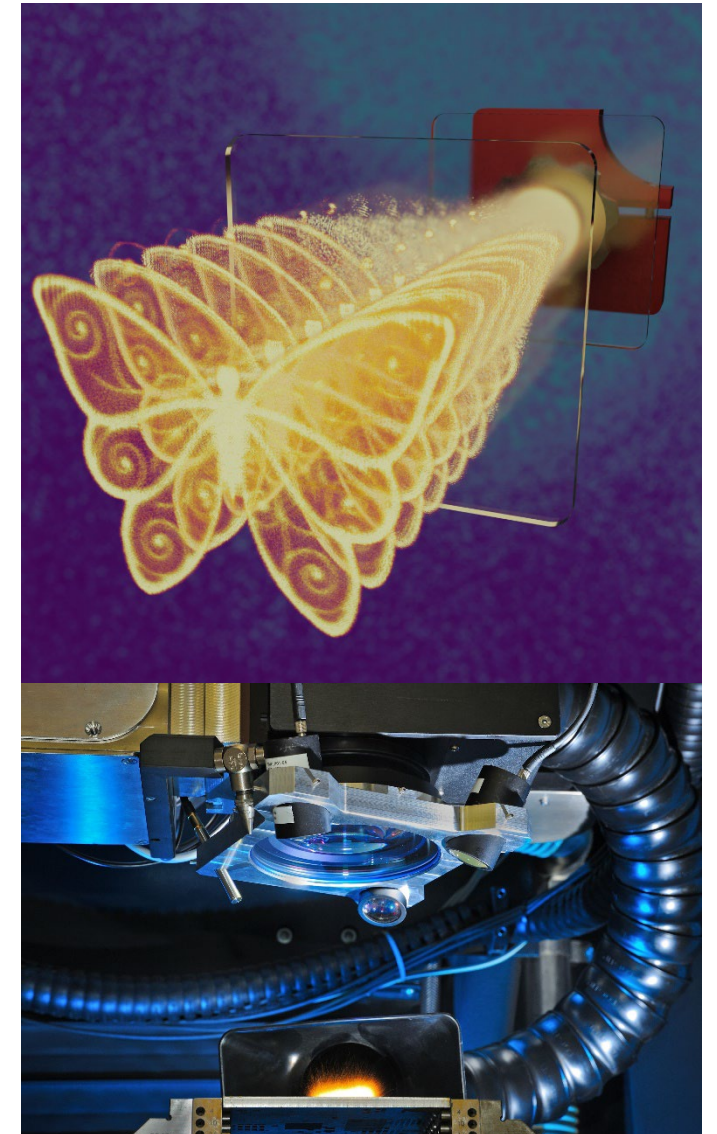
- Optimising system parameters for laser manufacturing tools is a complex task
- State-of-the-art is based on empirical studies and leads to:
 - Waste material and energy
 - Narrow exploration of the possible parameter combinations



- **Machine learning can bring**
 - Faster exploration of parameter space
 - Ongoing process improvement (continual learning)
 - Early defect detection
- Requires in-line process monitoring data
- High speed and high resolution.

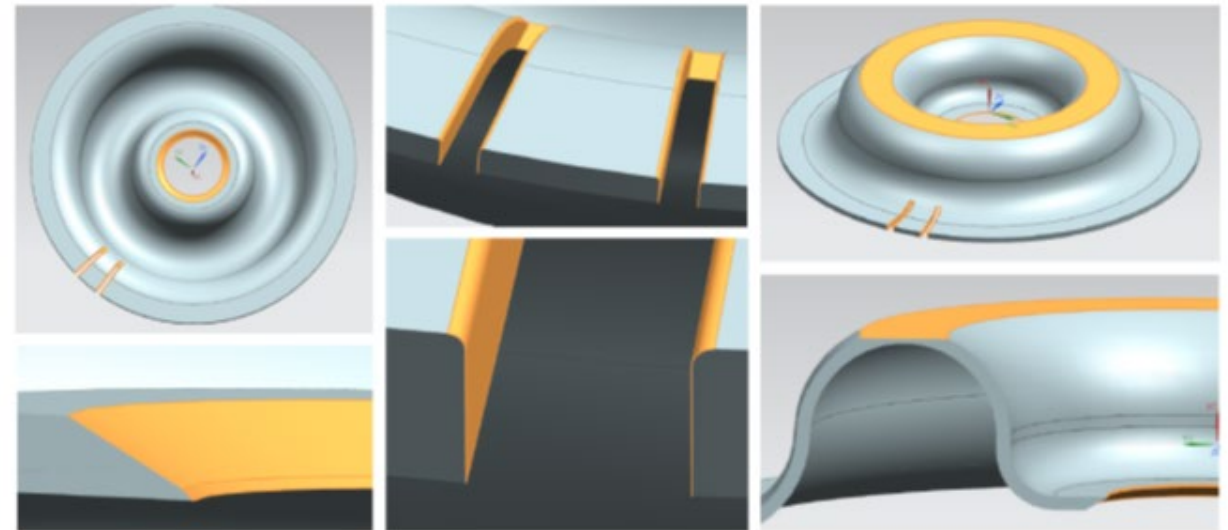
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Use case 1: Small metal parts

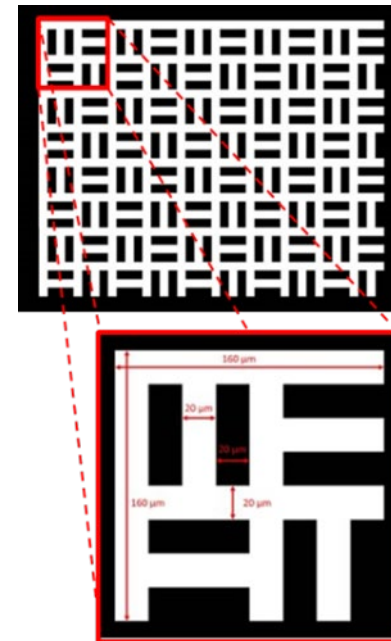
- Very high precision requirements
- High tolerances and demanding shapes
- Currently requires three separate conventional processes
 - Wet chemical etching
 - Electrochemical machining to cut slots
 - Second ECM to provide surface finish
- METAMORPHA targets
 - Elimination of three chemical processes
 - Avoidance of all waste products
 - Energy consumption reduction >40 %.



Use case 2: Large patterned steel rollers

- Rollers used for metal sheet embossing for a wide range of products, e.g.
 - Car bodies (to improve paint adhesion)
 - Food and drink cans (to improve grip in the forming process)
- Large roller size (>2 m length and 0.6 m diameter)
- Small feature size (in some cases 10 μm)
- No reworking of worn rollers is currently possible

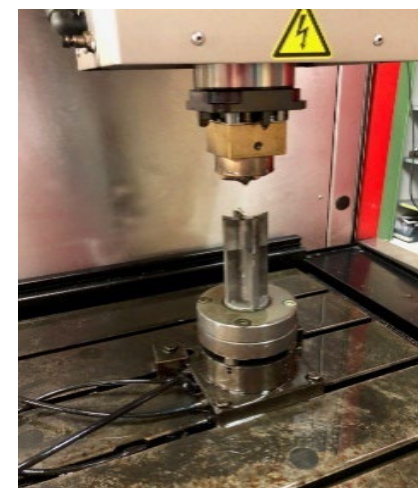
- METAMORPHA targets
 - Massive waste reduction >90 %
 - New re-work process
 - Energy consumption reduction >90 %
 - 10 \times longer roller lifetime.



Use case 3: Hard carbide parts

- Carbide punches for punching and embossing
- Extremely hard materials which are very difficult to machine
- Currently requires three electro-mechanical processes:
 - Electrode milling
 - Electrical discharge machining
 - Manual polishing
- Repair of microstructure of worn punches is not possible

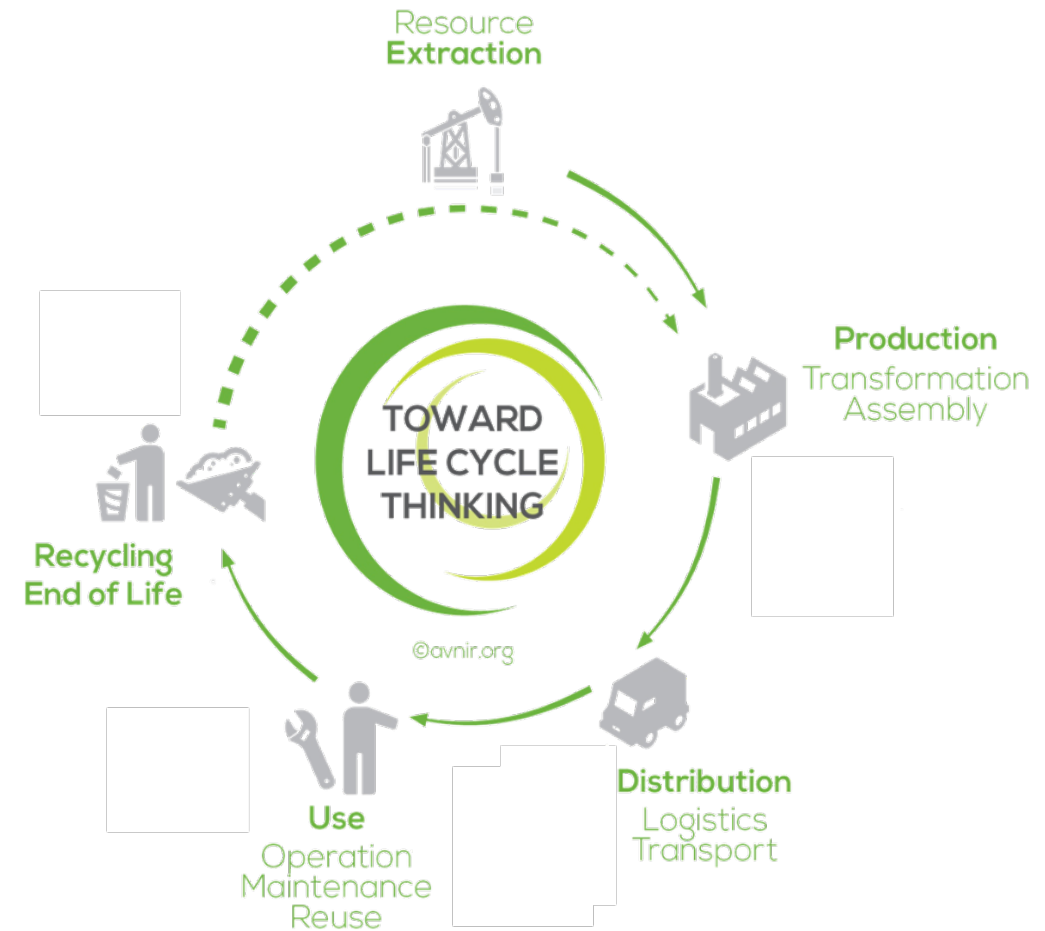
- METAMORPHA targets:
 - Avoidance of all waste products
 - Massive cut-down in time and cost
 - Energy consumption reduction >90 %.



Sustainability assessment

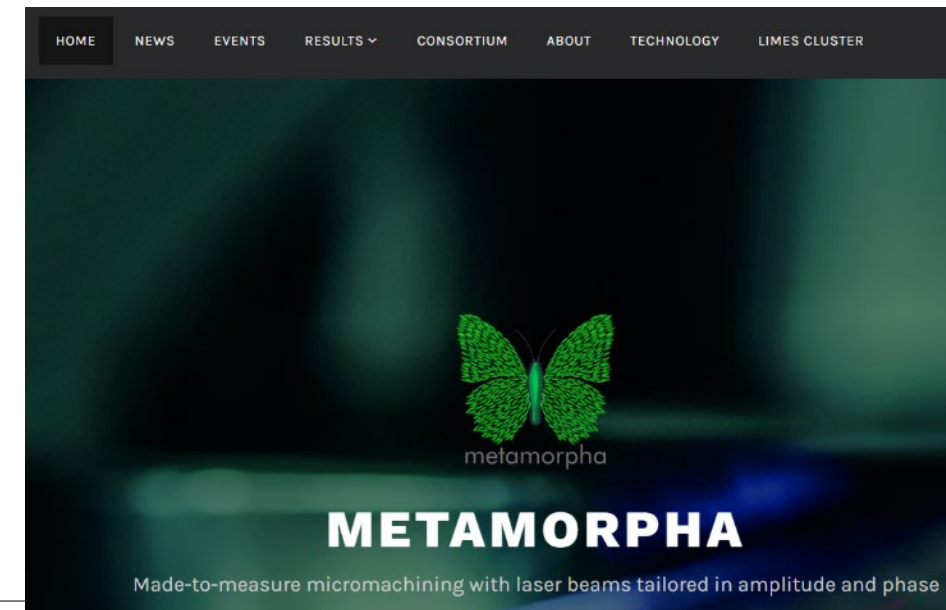
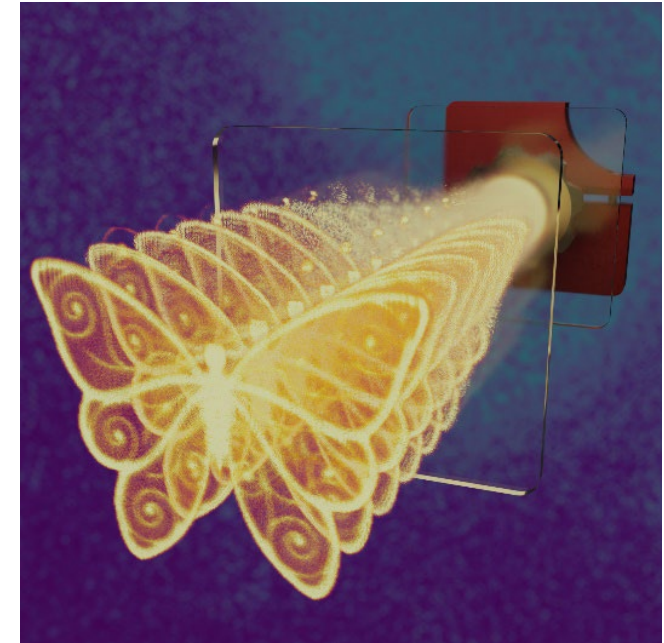
- A detailed sustainability assessment will be carried out on each of the three use cases, following standardised methodologies:
 - Techno-economic assessment (TEA)
 - Life cycle analysis (LCA); ISO 14040/14044
 - Life cycle cost (LCC); ISO guidelines (ISO, 2006)
 - Social impacts (social LCA); UNEP/SETAC

For each use case, environmental, economic & social benefits will be highlighted in comparison to current value chains aiming at producing similar workpieces.



Conclusions

- Single agile USP laser micromachining platform
 - Replaces conventional manufacturing process chain
- Full control over phase and amplitude using two cascaded SLMs
 - Digital beam steering
 - Arbitrary intensity profiles
- Made-to-measure laser process
- In-line process control using real-time feedback from photo diodes
- Three use cases
 - Small metal parts
 - Large embossing rollers
 - Very hard material parts
- **Progress will be reported on the website and in newsletters!**
- **www.metamorph.eu**



Thank you for your attention!



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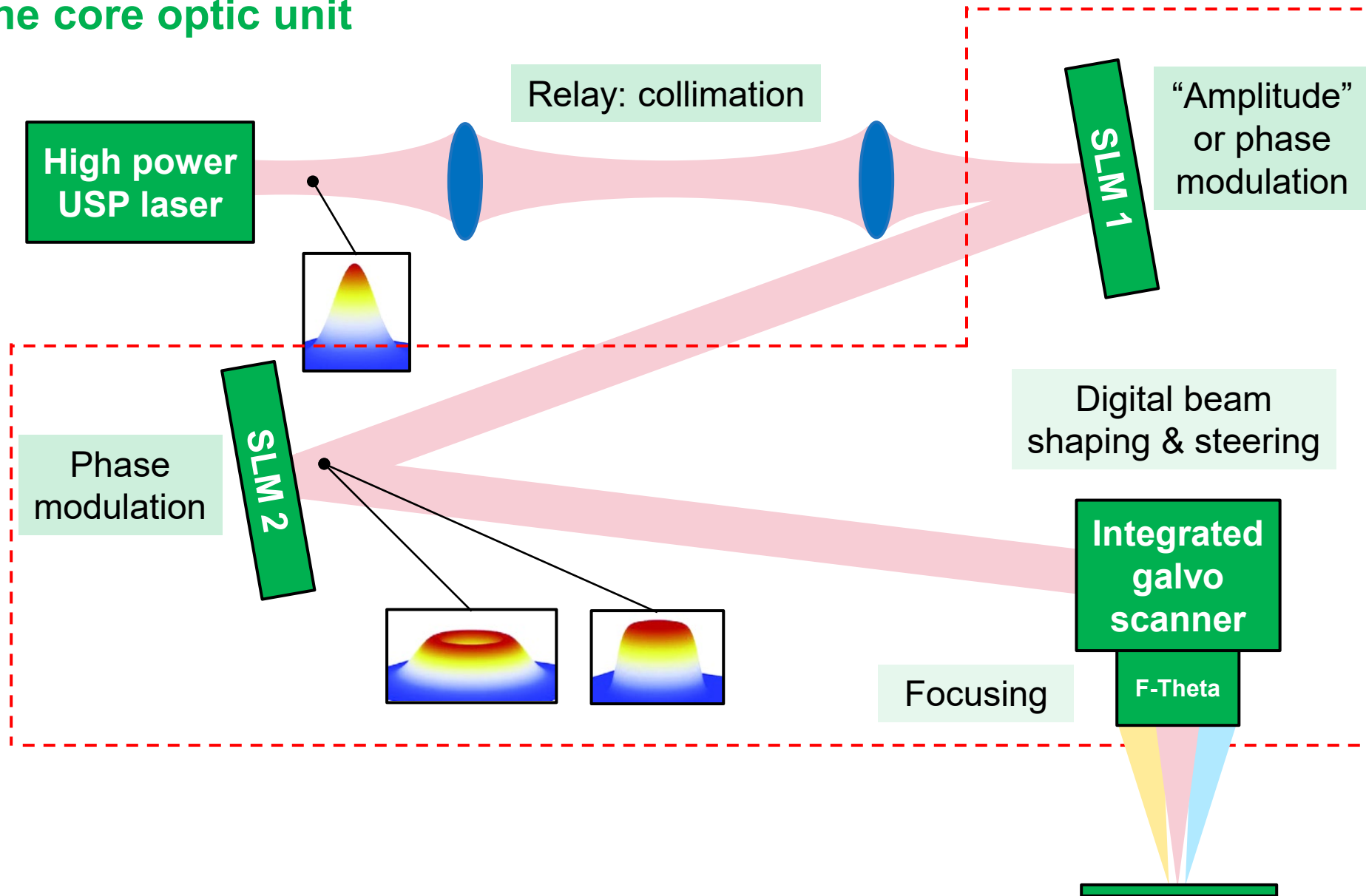
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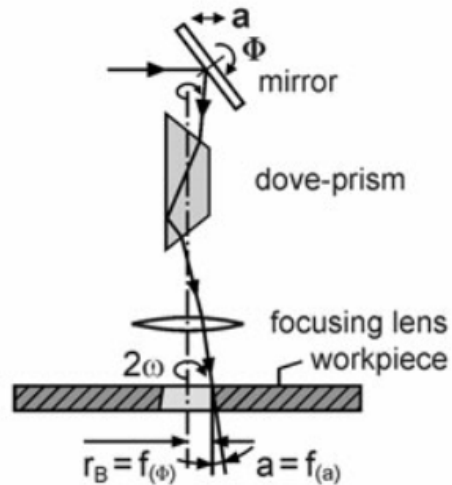
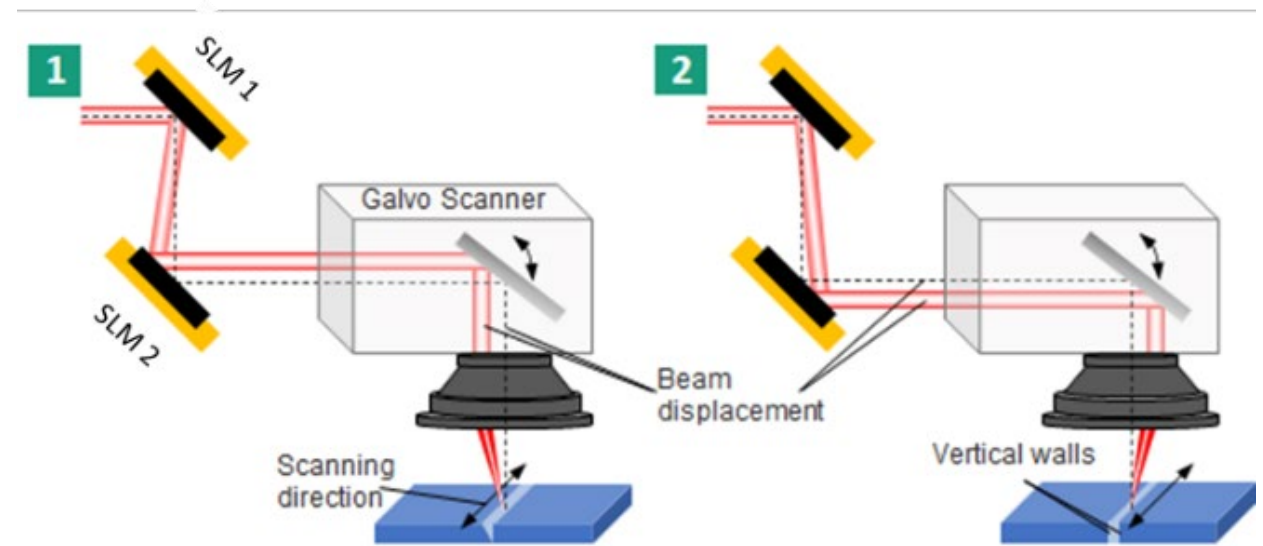


All-in-one core optic unit

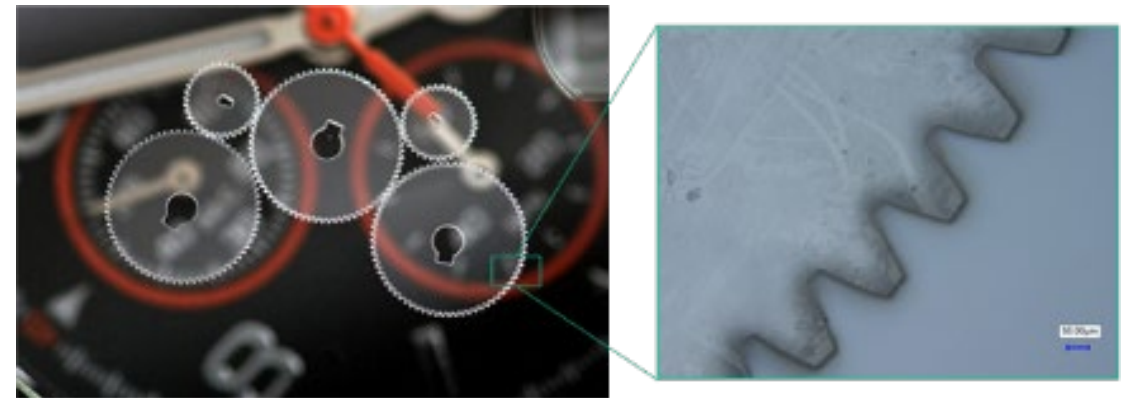


Digital beam steering

- Digital beam steering by phase control of beam
 - Control the angle of incidence of the focused laser beam
 - Allows full wall taper control without the need to manipulate the workpiece
 - Conventionally, this requires complex opto-mechanical methods, e.g. rotating Dove prism.



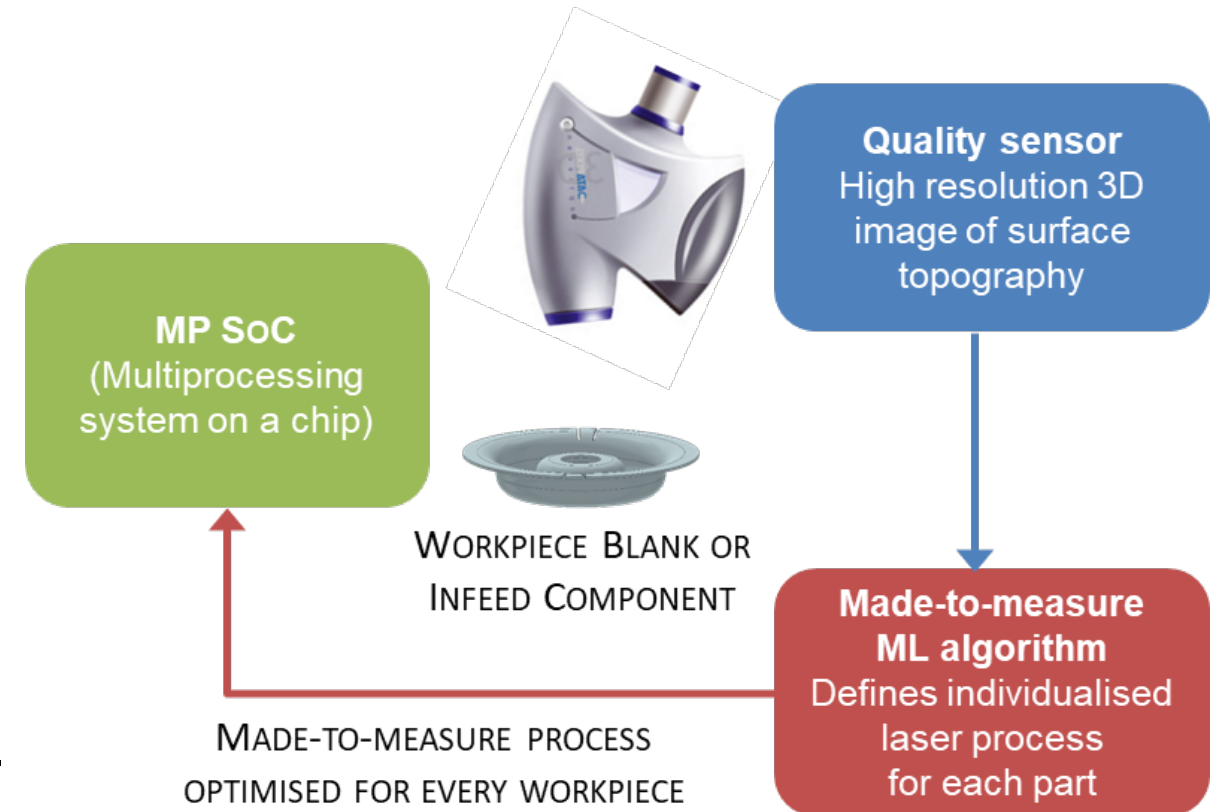
From Chapter 16, Tailored Light 2: Laser Application Technology; Reinhart Poprawe (Editor); Springer (2011).



Individual made-to-measure laser processes



- Off-line machine learning based algorithm
 - Calculates individualised laser micromachining process
 - Maximise efficiency
 - Optimal dynamic amplitude and phase modulation sequences
 - Tailored to each workpiece to account for variations in geometry or surface topography.



Process control loop

- Two-fold algorithm training methodology
 - **Offline training**
 - ML models are continuously improved
 - Using existing data from previous process runs
 - No real-time or resource restrictions
 - Semi-supervised approaches with both labelled and unlabelled data
 - **Edge-based in-line application**
 - Trained algorithms will be transferred to on-line evaluation
 - Used for in-line control loops and real-time tailored beam parameters
- Synchronisation of data flows is highly complex
 - METAMORPHA will use methodologies from safety critical real-time systems (e.g. aerospace).

