Strategic Focus Area
Advanced Manufacturing

Ultrafast Laser Closed-loop Manufacturing using mid-IR Spectroscopy

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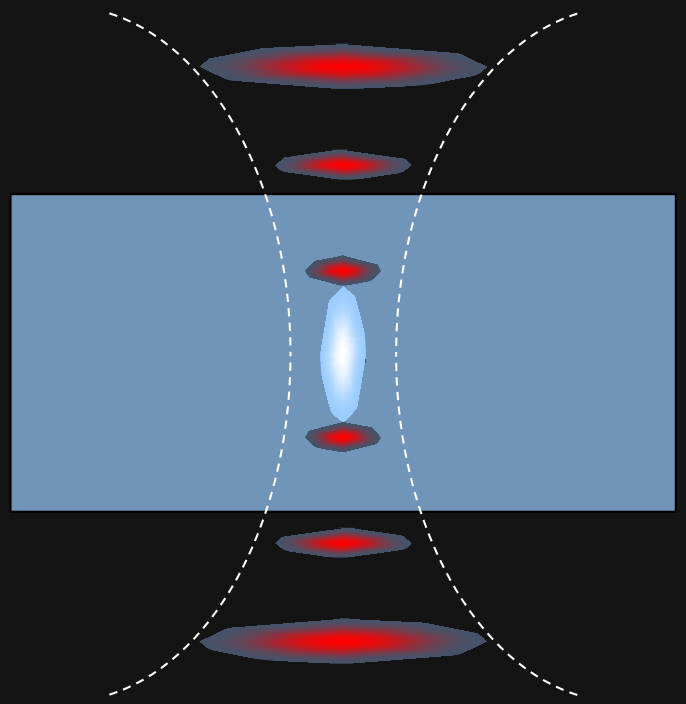
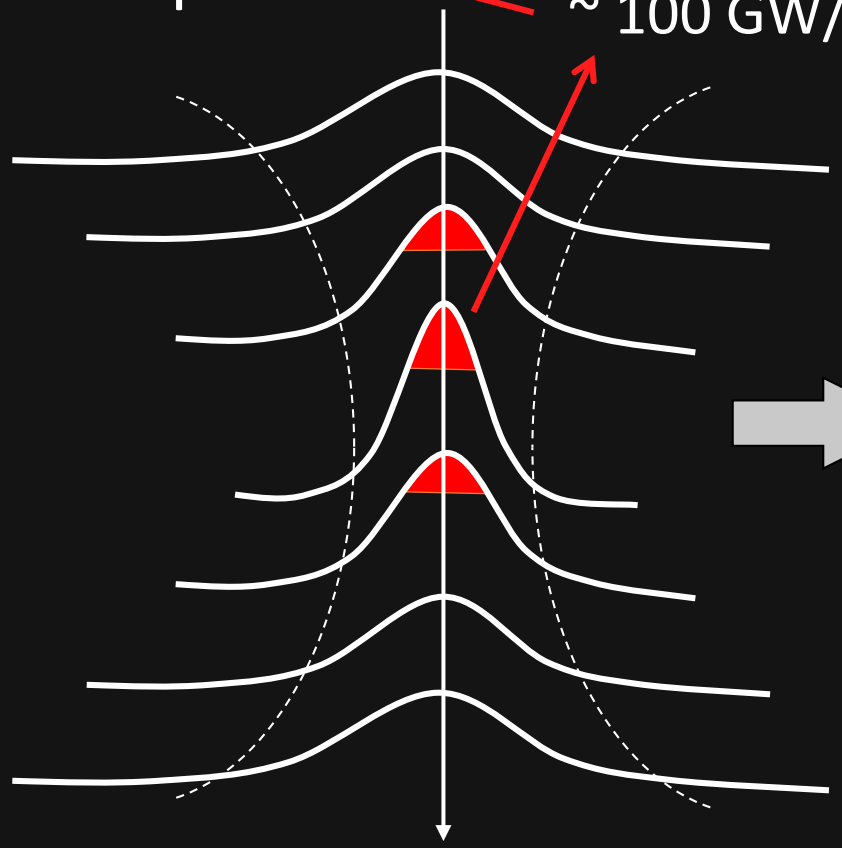
EPFL Empa Materials Science and Technology ETH zürich PAUL SCHERRER INSTITUT PSI

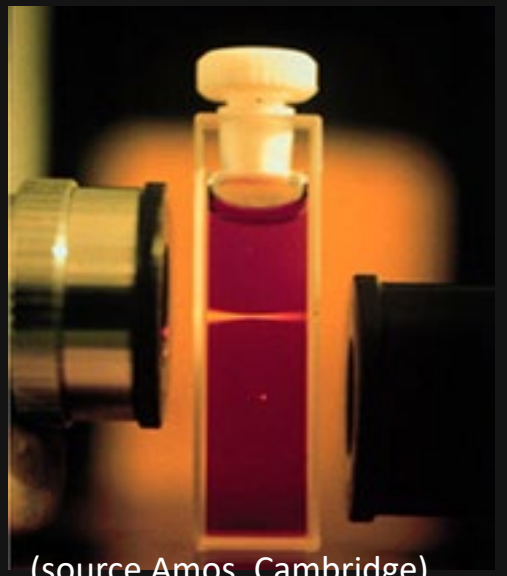
Non-linear absorption

Femtosecond lasers pulses

~ 100 GW/mm^2







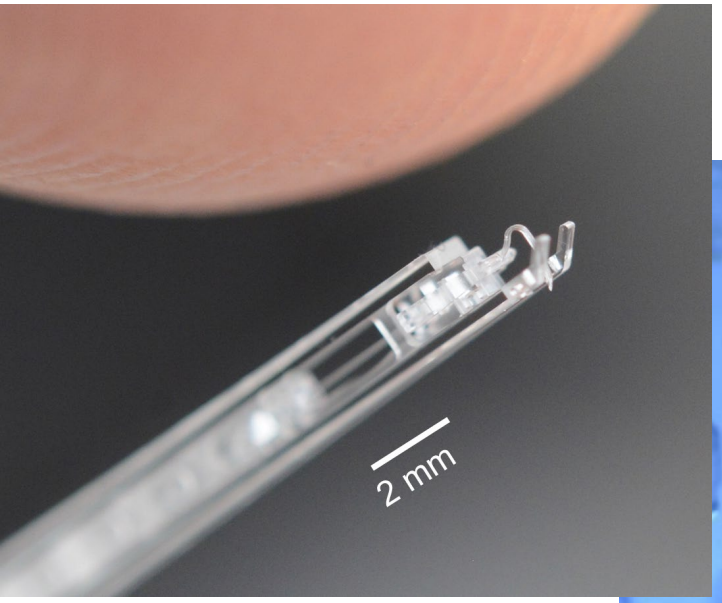
(source Amos, Cambridge)

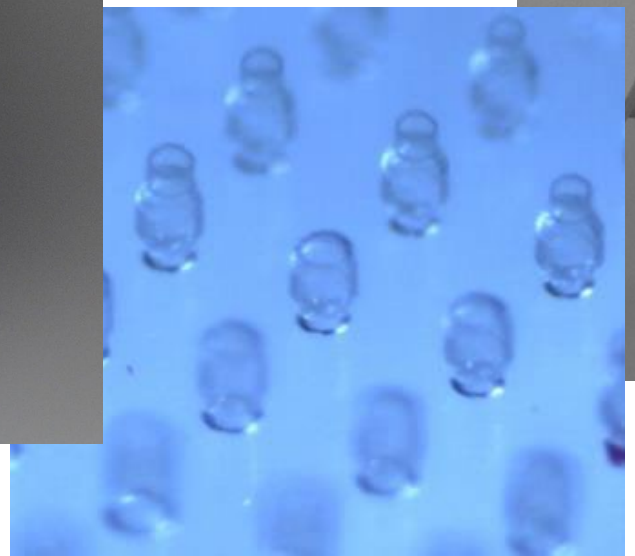
Energy is only absorbed at the focal volume

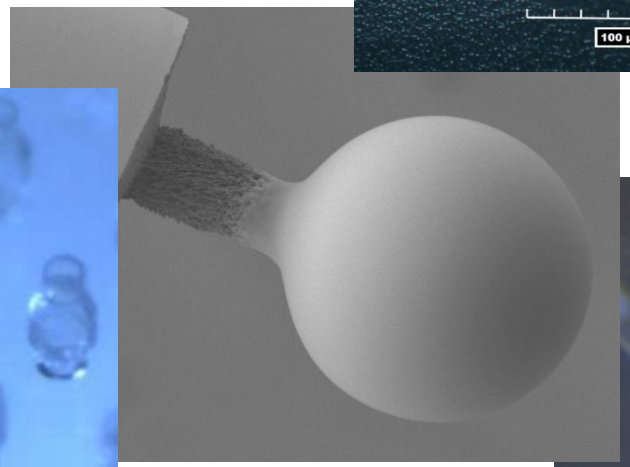
In a transparent material, energy can be absorbed in the volume

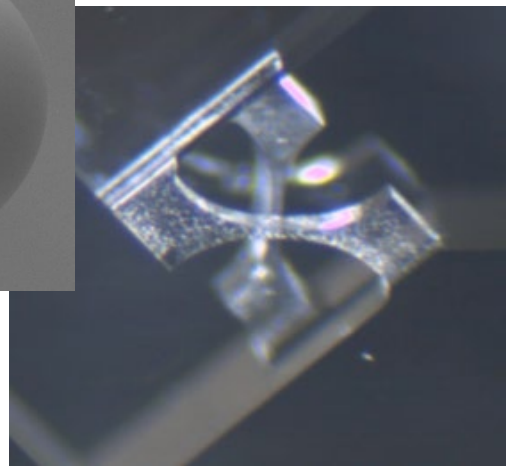
Femtosecond laser processing

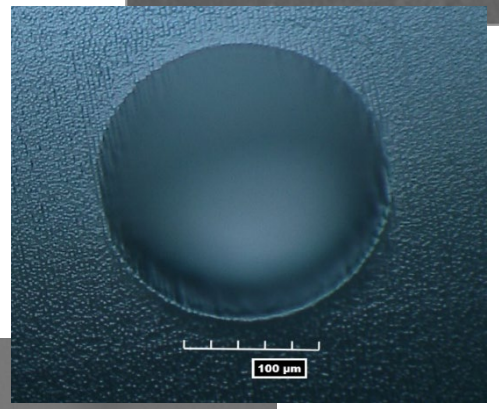
- Beyond diffraction limit: nanoscale resolution (non-linear absorption process triggered by multi-photon processes)
- High-aspect ratio after etching (>1:300)
- Arbitrary 3D shapes
- Scalable

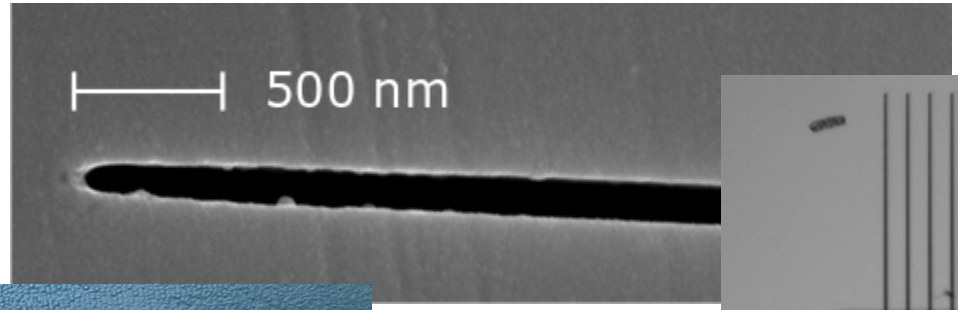


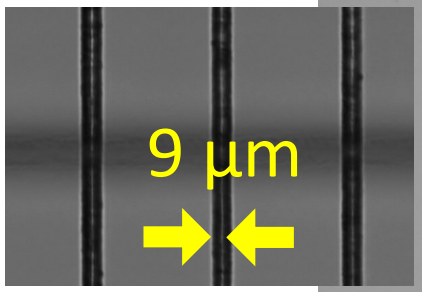


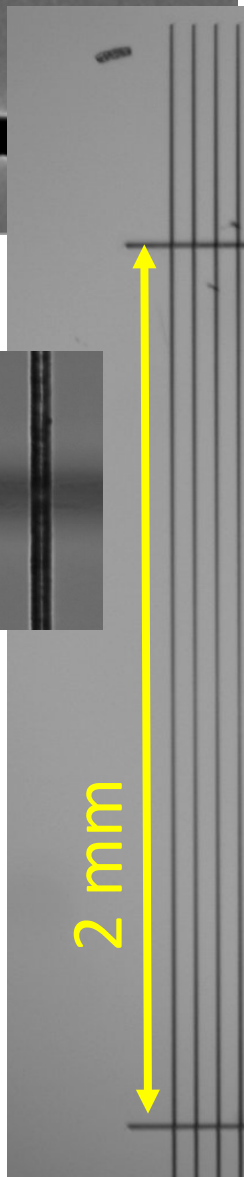






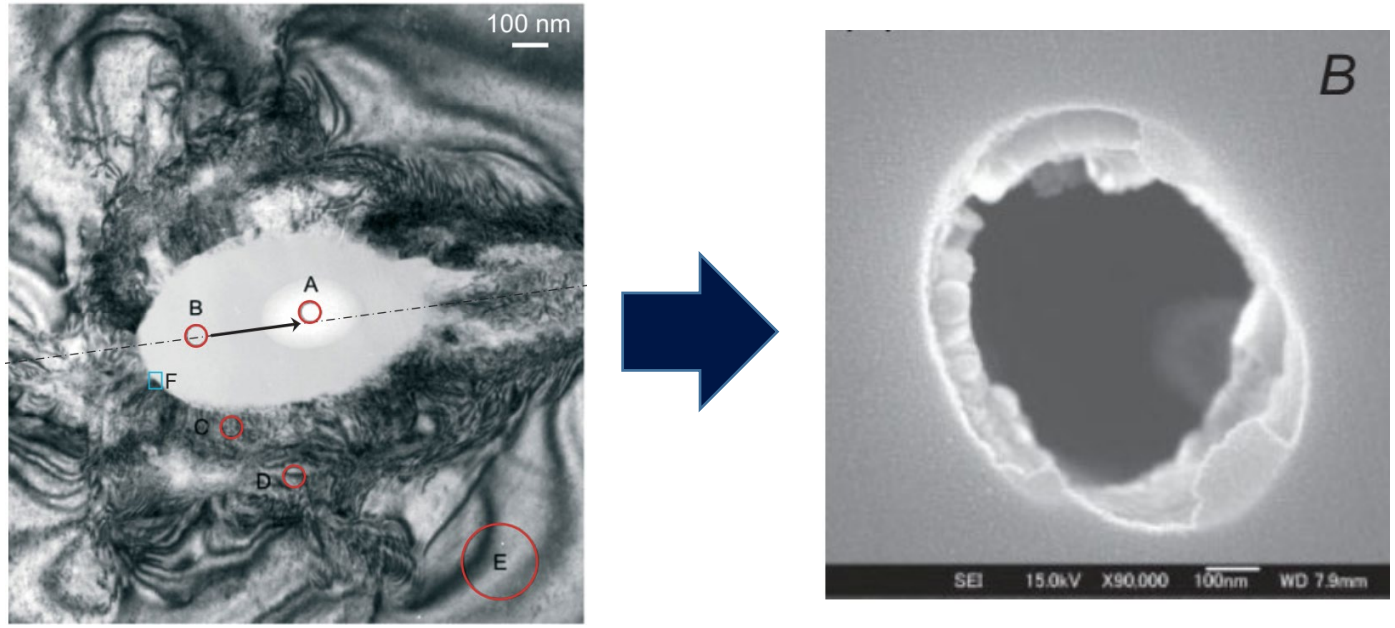






Future prospects: how to go further?

1. Expand these processes to other key engineering materials (e.g. sapphire, aluminosilicate, mid-IR materials, etc.)
2. Controlled formation of crystalline phases in dielectrics / amorphous state in crystals



Source: S. Juodkazis, et al. Adv. Mater. ***18****, 1361–1364 (2006).*

Teams

Yves Bellouard (Project coordinator), Ernesto Gribaudo, Benedikt Hermann, (Gözden Torun, Ruben Ricca)

Luka Emmenegger (PI), Matthew Singleton, Michele Gianella, Bela Tuzson

Jérôme Faist (PI), Mathieu Bertrand

Christoph Bostedt (PI), **Rasmus Ishebeck** (co-PI), Daniel Groliemund, Dario Ferreira Sanchez

Project objectives

Objective 1: to demonstrate **in-situ** sensing of **structural** modifications in realistic laser manufacturing conditions.

Objective 2: to develop a compact and **ultrafast mid-IR dual comb** sensing instrument compatible with a laser manufacturing setup.

Objective 3: to benchmark **dynamic information** during processing with data acquired during direct observations at SLS and SwissFEL.

Objective 4: to implement a **feedback control** on a laser-processing representative case study.

To provide industry with a manufacturing platform concept able to achieve unprecedented control on laser-exposed material properties with unmatched accuracy and reproducibility.

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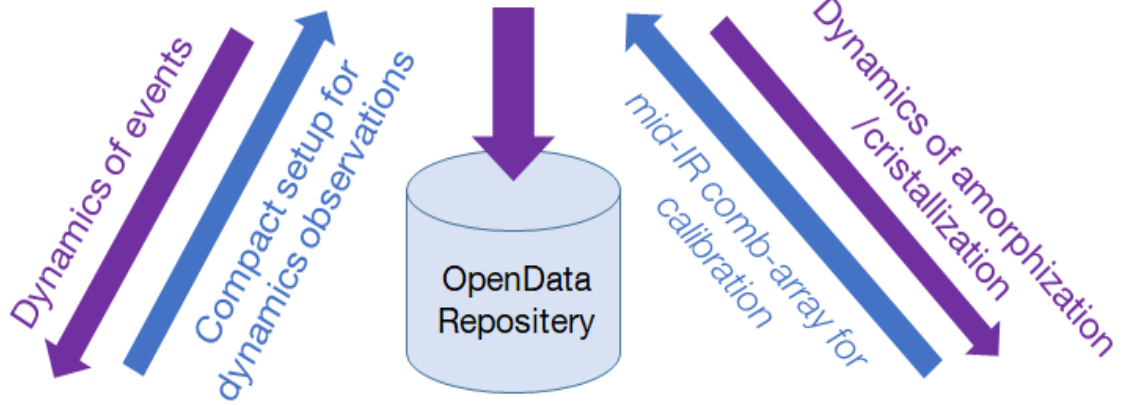
WP 1 / From fundamental processes to operando conditions, correlation of IR fingerprints with X-ray investigations (**PSI**, Empa, EPFL)

1.1. Static comparison of representative specimens
1.2. Dynamic processes of a single pulse to pulse train from the femtosecond timescale to equilibrium
1.3. Operando characterization and correlation to IR



Information
Prototypes / specimens

EPFL

Empa
Materials Science and Technology

ETH zürich

WP 3 / Demonstration activities using a tabletop system (EPFL, Empa, ETHZ)

Specifications

Miniaturized mid-IR comb-array

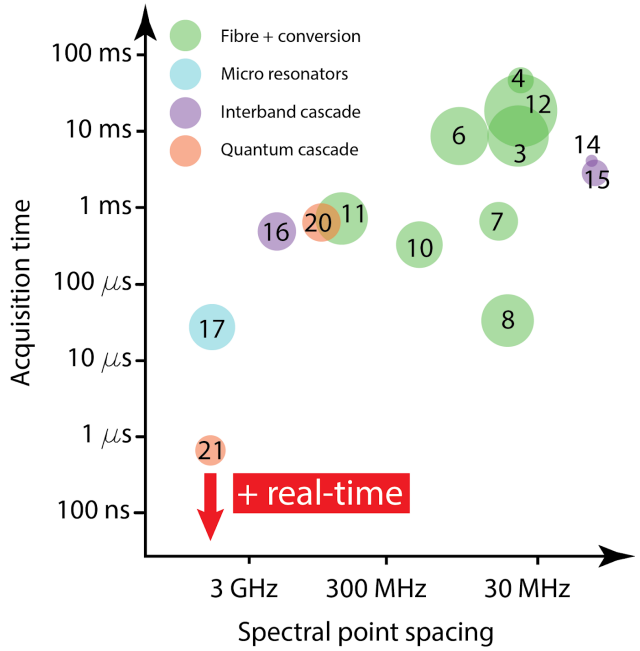
WP 2 / Compact Mid-IR dual comb sensing (**Empa**, ETHZ, EPFL)

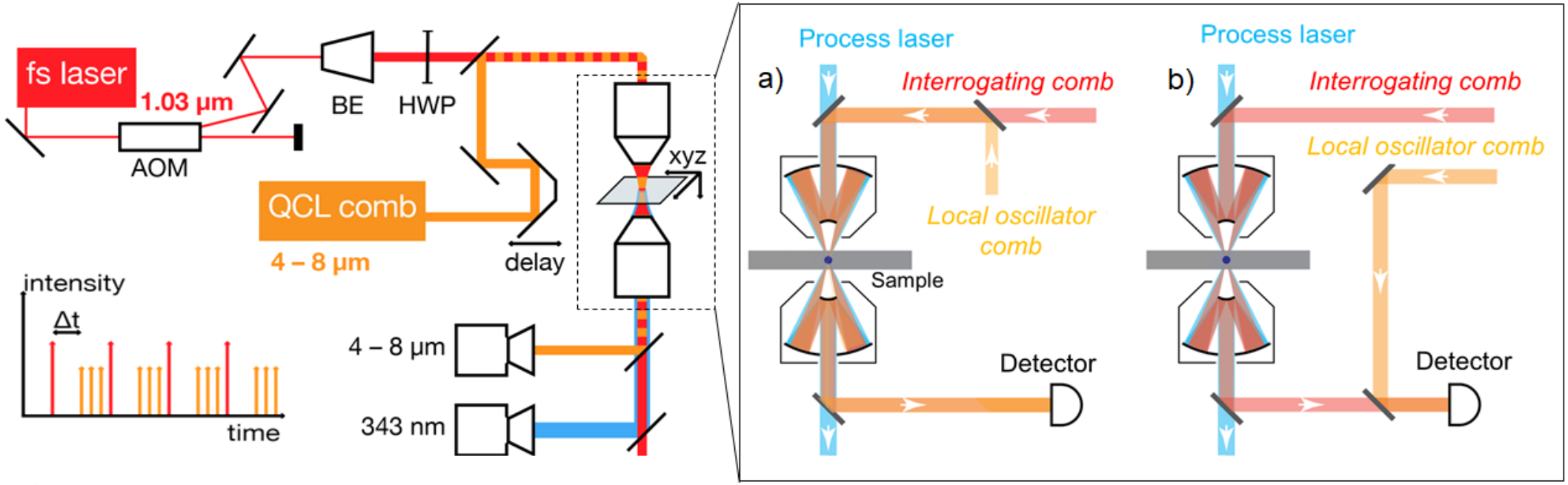
3.1. Portable laser platform with embedded mid-IR sensing capabilities
3.2. Close-loop algorithm implementation
3.3. Demonstration on representative laser-induced structural transformations

2.1. Fabrication of laser devices with suitable repetition rate and center frequency
2.2. Third generation devices using integrated optic components
2.3. Fast dual-comb spectrometer
2.4. Second generation fast spectrometer with 100% duty cycle and 100 ns temporal resolution

In-situ dual-comb mid-IR spectroscopy

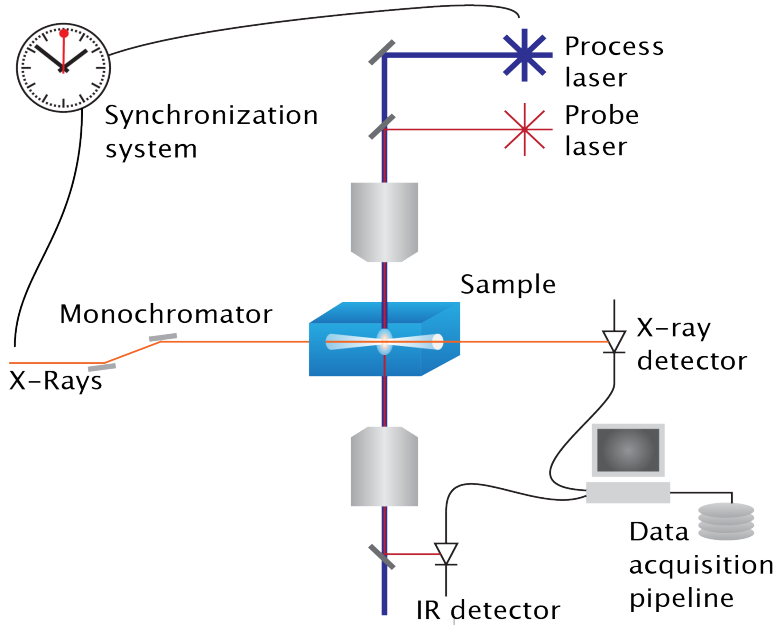
- ‘Convert optical absorption signal into radio frequency signal’
- In-situ
- Use of Quantum Cascade Lasers (QCL) for mid-IR
- Non-scanning spectroscopy method (unlike FTIR)
- Fast (< 1μs)

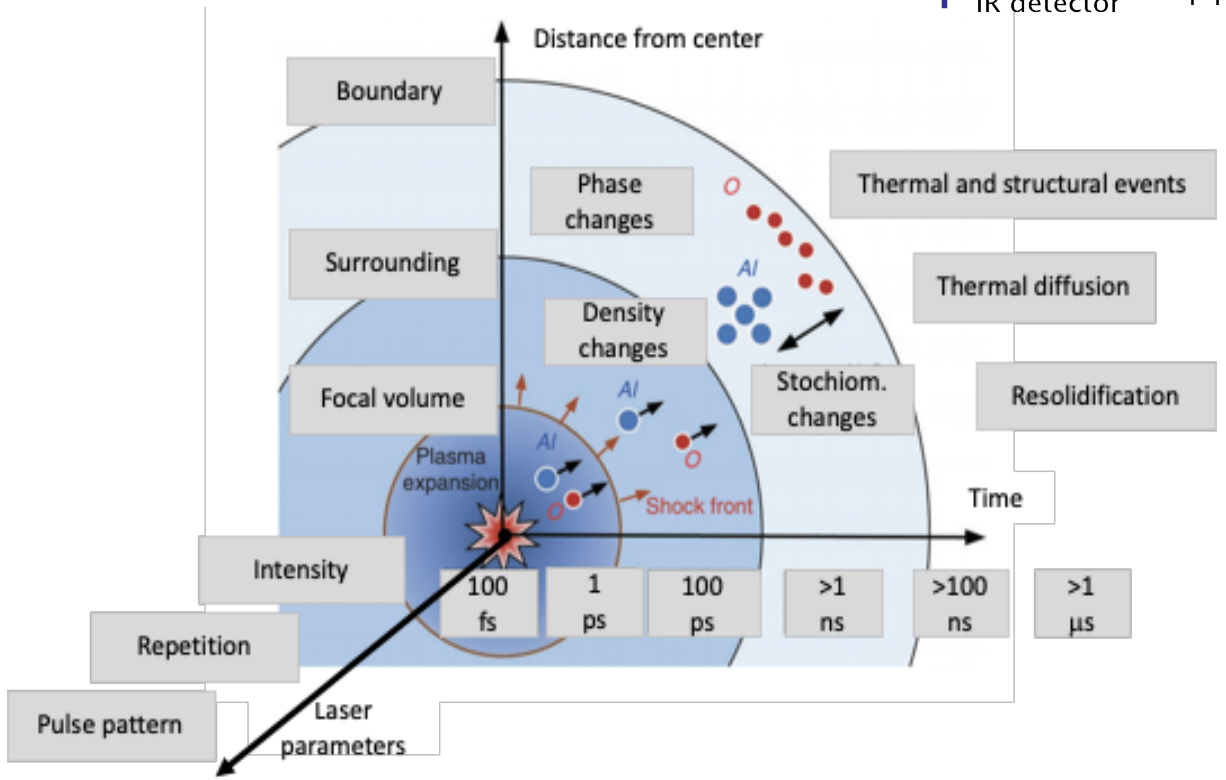




Benchmark dynamic observations

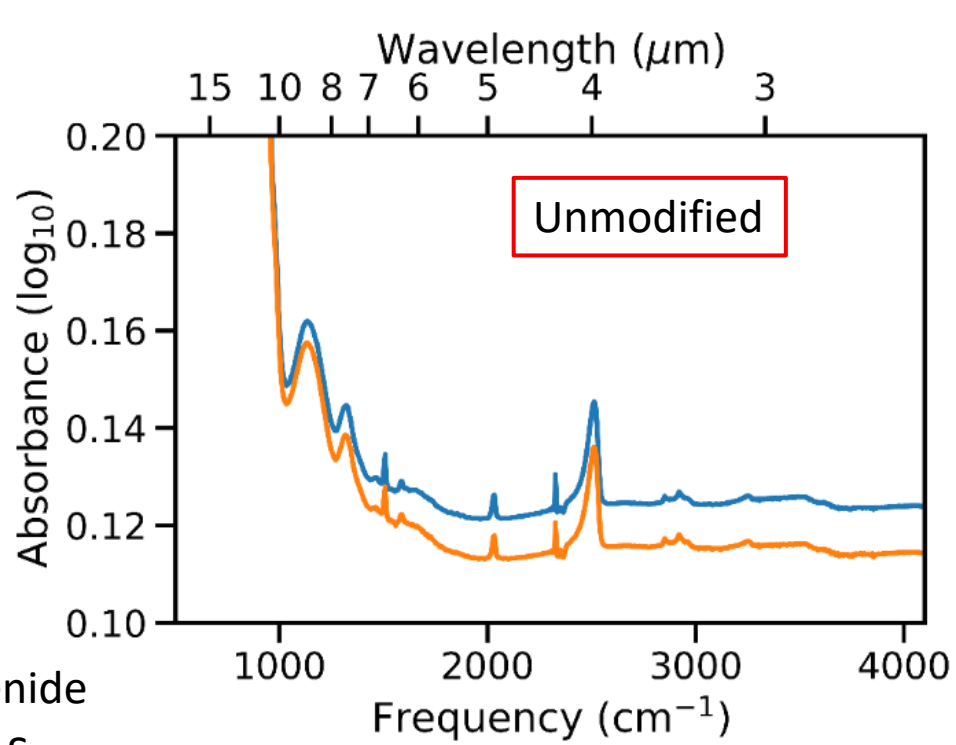
- When to look? What are important information to capture?
- Requires both temporal and high spatial resolution (XFEL)
- In-situ experiments (XFEL) / (SLS)



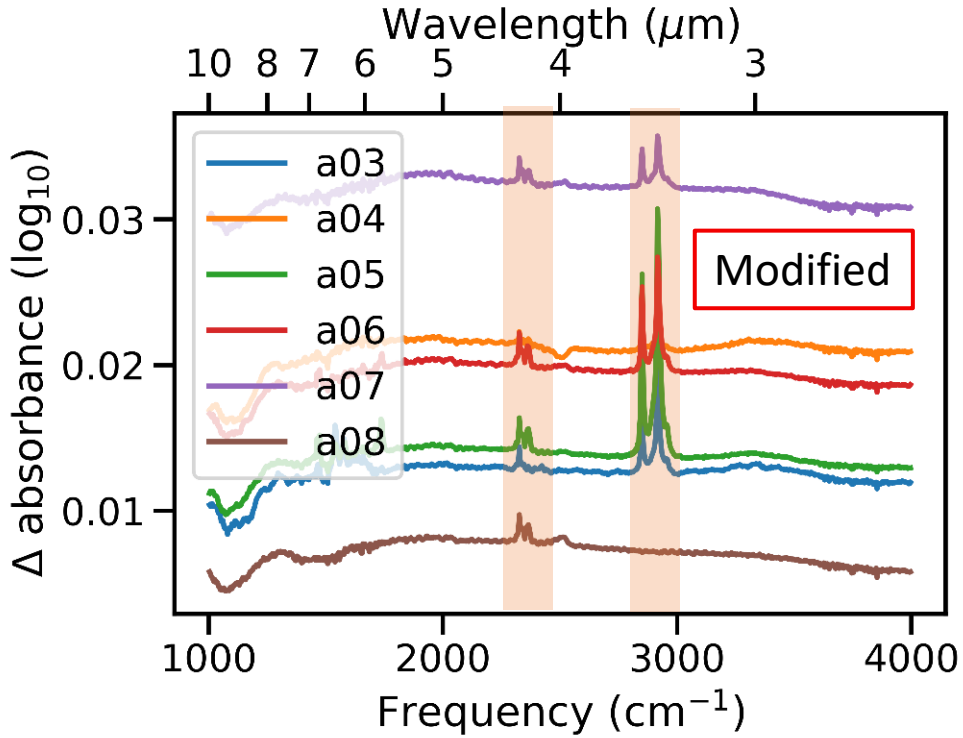


Progress to date

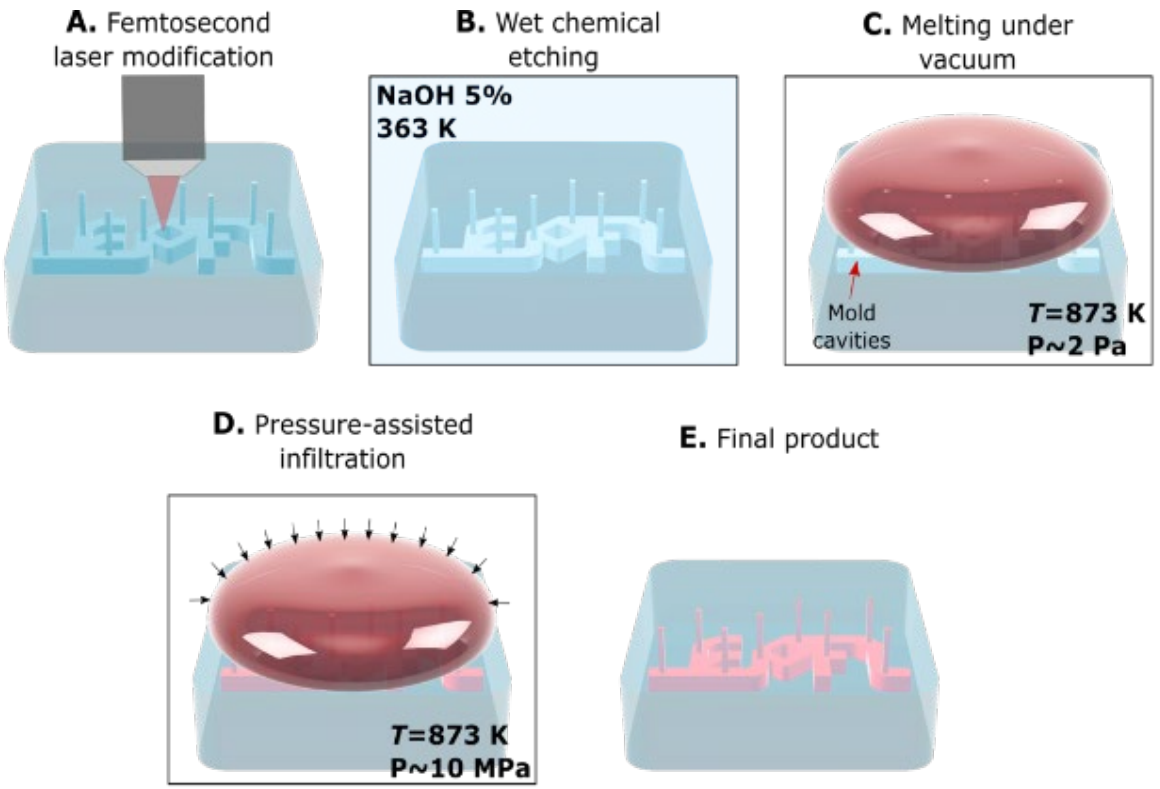
- Acquisition of FT-IR spectroscopic data of various laser-modified materials (fused silica, chalcogenide glass, sapphire)
- Production of first QCL combs
- First observations at the SLS observations on sapphire and other candidate materials
- Planning for the in situ platform for observation at the XFEL

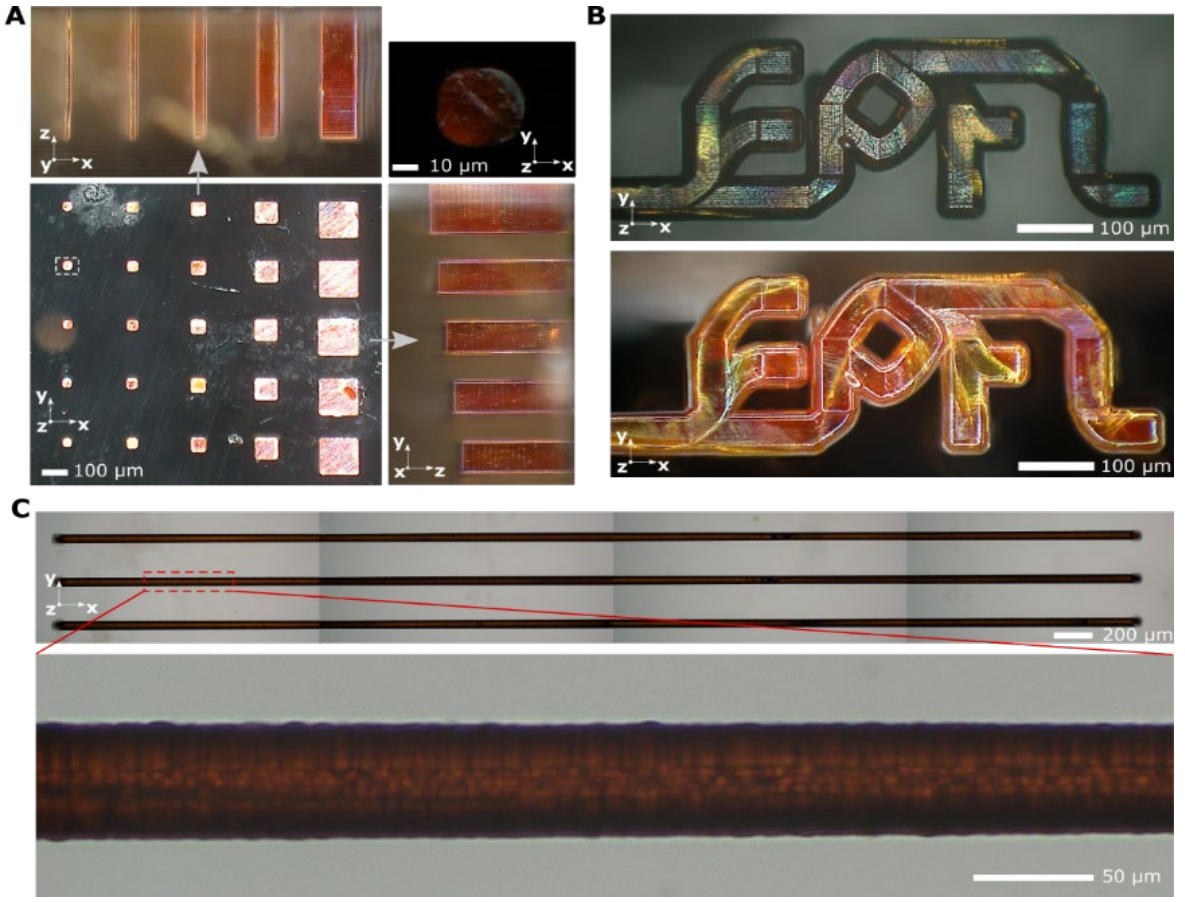


Chalcogenide
$Ge_{23}Sb_7S_{70}$



A (very) recent highlight... Infiltration of mid-IR glass in a fused silica mold... Glass-in-glass composites





(Collaboration between EPFL LMM / Galatea Lab and ETHZ)

(In press)

Thanks!

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PSI