Femtosecond Laser Ablation Damage on Single Crystal Ge

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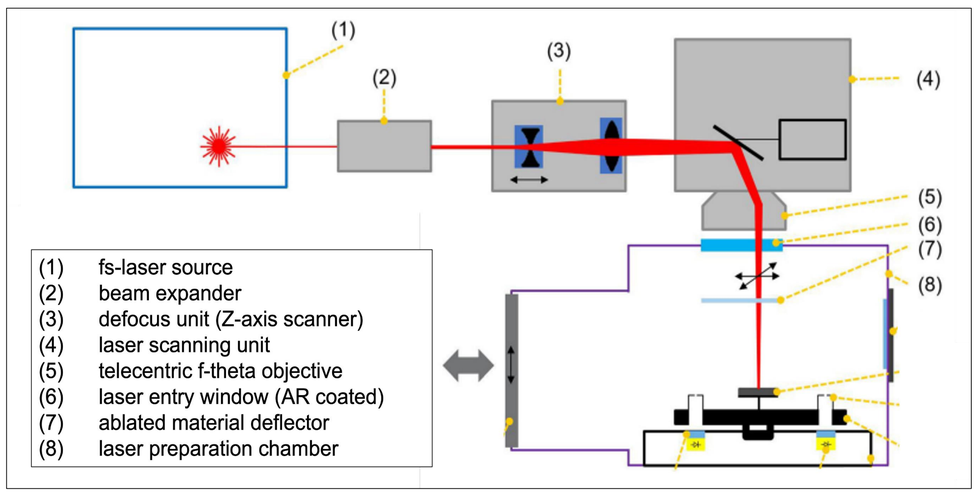
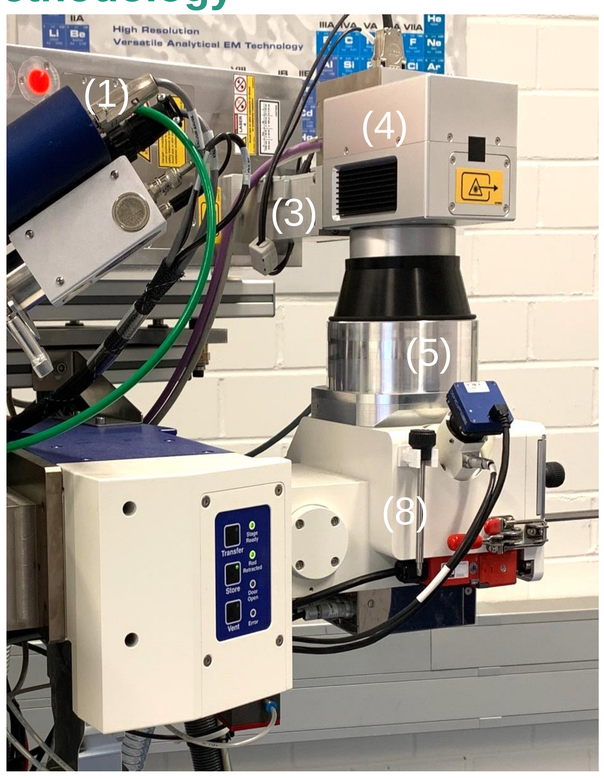
Motivation

- Femtosecond (fs)-laser has 4-6 orders of magnitude faster ablation rate compare to the gallium focused ion beam (FIB). [1]
- Its ability to provide time-efficient and athermal removal has initiated a novel ways for micromechanical sample preparation.
- To ensure the feasibility as a tool for micro-sized samples, the thermal impacts by fs-laser need to be inspected.
- The question is ***how large is the damage layer of fs-laser on mechanical properties of Germanium.***
- Compare with two controlled samples 1) pristine sample, and 2) FIB-prepared sample.

Methodology

- Fs-laser: Laser with pulse duration less than 350 femtoseconds which is shorter than the time needed for thermal diffusion. This nature minimize thermal effects unlike long-pulsed laser.
- Schematic design of ZEISS Crossbeam fs-laser. [2]

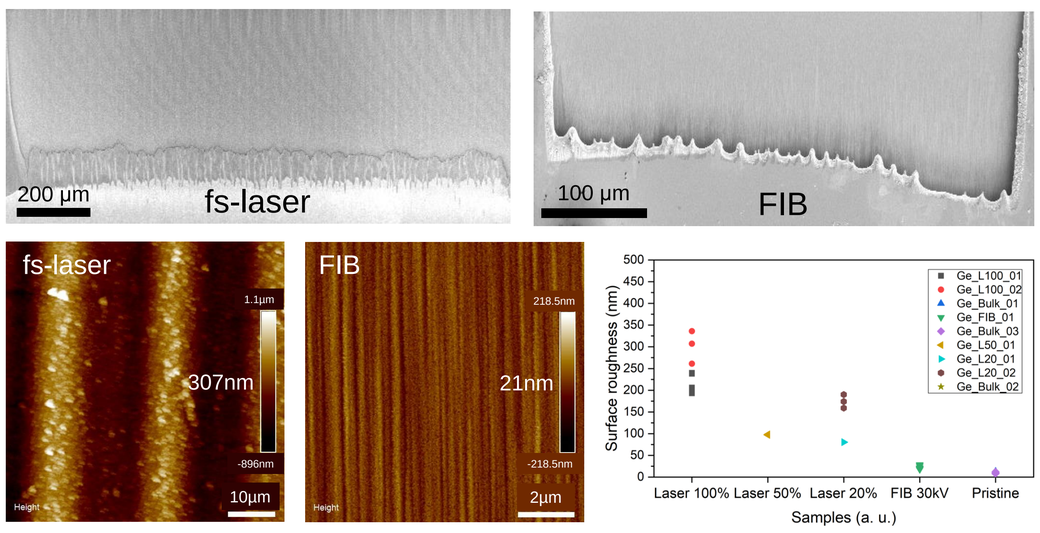




- Quantification of surface roughness using atomic force microscope (AFM).
  - To deconvolute the effect of laser ablated damage and surface roughness.
- Mechanical testing using nanoindentation in continuous stiffness measurement (CSM) mode.
  - Berkovich tip.
  - Maximum indentation depth of 2 micrometers.

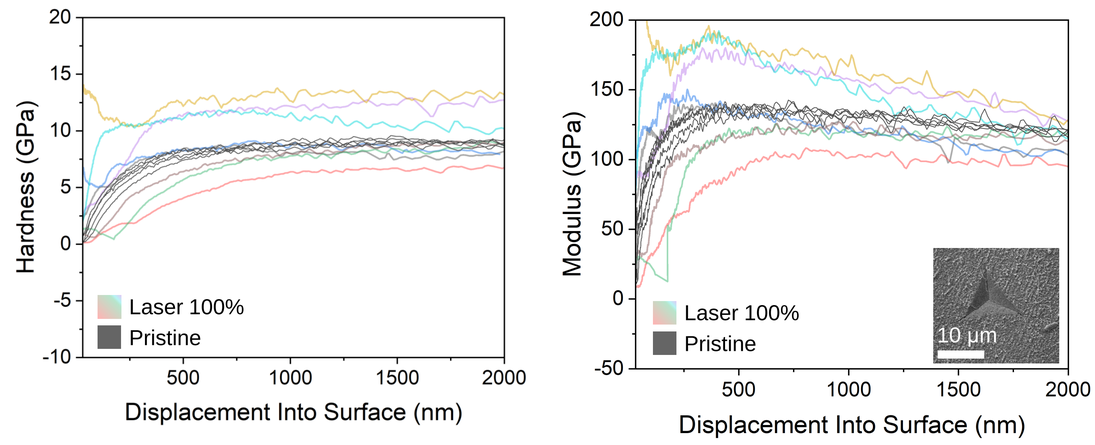
Results

- Surface roughness after milling

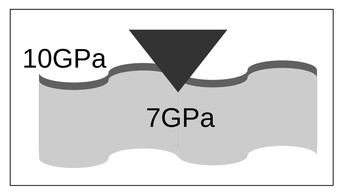


- Rougher surface is obtained after fs-laser milling.
- Laser induced periodic surface structure (LIPSS) is shown after fs-laser milling.
- LIPSS type is low spatial frequency LIPSS (LSFL).

- Hardness and modulus over displacement curve



- Except few curves, fs-laser milled and pristine samples show a similarity on hardness and modulus over displacement curve.
- Topological change after fs-laser milling may dimmed the effect of surface damaged region.



Summary

- Observation
  - Negligible difference in hardness and modulus between fs-laser milled and pristine samples.
- Speculation
  - No significant impact on mechanical property change.
  - Below our detection limit; Damage region is only limited to shallow depth.
  - LIPSS may dominates the mechanical properties of the milled surface.

Next steps

- Re-experiment with Cu since Ge is a brittle material for nanoindentation.
- Further optimization of fs-laser parameters to enhance the surface quality.

References

[1] Manuel J. Pfeifenberger, *et al.* The use of femtosecond laser ablation as a novel tool for rapid micro-mechanical sample preparation, *Materials & Design*, **121**, 2017.

[2] Tordoff, B., *et al.* The LaserFIB: new application opportunities combining a high-performance FIB-SEM with femtosecond laser processing in an integrated second chamber. *Appl. Microsc.* **50,** 2020.

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