Large area materials processing via unfocused beams of high-energy femtosecond lasers

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Petawatt-class lasers produce easily intensities in the 10^{12} – 10^{14} Wcm^{-2} domain, sufficient for effective materials processing, even *without focusing*. These ultrafast laser systems, with output beam diameters ranging from tens to hundreds of millimetres, have thereby the potential to facilitate *large-area material processing without the need for beam scanning*. However, due to the unique spatio-temporal characteristics of their beam profiles, which significantly deviate either from homogeneous or Gaussian distributions, they are not inherently suitable for generating macroscopically homogeneous surface patterns over extended areas.

Here we introduce an original approach that transforms this inherent limitation into an advantage. We exploit the inhomogeneous beam characteristics within a combinatorial materials processing concept, where the target is exposed to the full beam cross-section, producing a structured surface that encodes variations in beam parameters as a material library. This approach allows for a systematic exploration of the relationship between surface properties and beam characteristics, particularly laser energy, serving as a powerful optimization tool, facilitating process parameter refinement, while also enabling the identification of thresholds, offering e.g. an alternative to LIDT protocols.

As an implementation of this concept we present a proof-of-concept experiment, where the process parameter is local laser energy and the investigated parameter is local reflectance. A copper surface is exposed to the static beam of a high-energy diode-pumped Ytterbium laser operating at 1030 nm central wavelength, delivering pulses up to 500 mJ energy and 500 fs duration at 50 Hz. The energy distribution across the beam cross-section (left side) materializes in form of a reflectance map (right side), the segments of which are quantified by recording the local changes in the energy of a He-Ne beam reflected while scanning over the processed surface. The origin of the energy dependence of the darkening is explained by analyzing the surface morphology map determined simultaneously by scanning electron microscopy. The high spatial resolution of both encoding and readout underscores the potential of this approach as an innovative screening tool for material characterization and optimization.