Technological applications for surface functionalization via ultrashort pulsed laser systems laser

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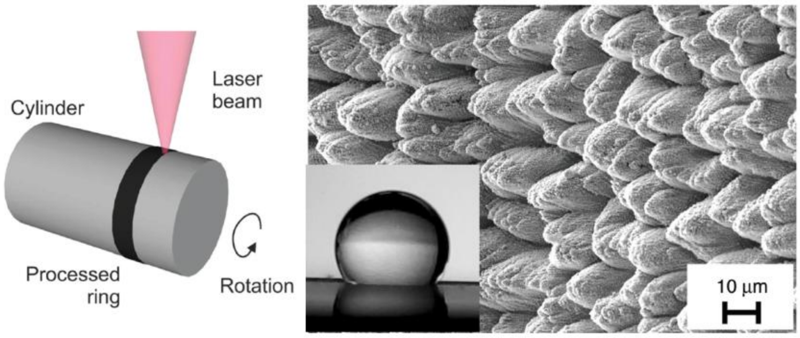
Femtosecond laser processing has emerged as a powerful technique for high-precision material modification due to the possibility of modifying virtually any material thanks to the nonlinear absorption mechanisms enabled by ultrashort, high-peak-power pulses. These interactions allow fabrication of micro- and nanoscale surface structures across metals, semiconductors, and dielectrics, making femtosecond lasers attractive for both fundamental studies and industrial applications.



Fabrication of LIPSS structures around a cylindrical pace maker encasing to avoid the growth of muscle cells on its surface. With fs laser pulses, it is possible to produce hydrophobic surfaces with hierarchical structures ranging from few nanometers to some microns.

Among these modifications, laser-induced periodic surface structures (LIPSS) are particularly relevant because they can be fabricated under loose focusing conditions while preserving sub-micrometric periodicities, enabling high-throughput processing compatible with industrial environments. Their formation is increasingly attributed to a combination of electromagnetic surface interactions, including scattering, surface plasmon excitation, and interference, coupled with selective melting and material redistribution. Understanding how fabrication parameters influence morphology is essential for tailoring surface functionalities in optics, biology, medicine, tribology, and energy-related applications. In parallel, in our research group we dedicate particular attention to temporal pulse shaping strategies, as they have demonstrated new capabilities for controlling laser–material interactions beyond conventional bandwidth-limited Gaussian pulses. As an example, we will show applications in dielectrics, where pulse shaping enables deeper energy deposition and single-shot fabrication of high-aspect-ratio nanochannels in fused silica and glass. In crystalline silicon, asymmetric pulses promote amorphous thin-film formation with variable depths, while in Al-based alloys they facilitate homogeneous LIPSS formation at reduced fluences.

These results highlight how both conventional and temporally engineered femtosecond pulses expand the control of laser-induced structuring, opening new pathways for advanced material functionalization and precision manufacturing towards industrial throughputs.