Surface Structuring with Polarization-Singular Femtosecond Laser Beams Generated by a q-plate

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In the last few years femtosecond optical vortex beams with different spatial distributions of the state of polarization (e.g. azimuthal, radial, spiral, etc.) have been used to generate complex, regular surface patterns on different materials. We present an experimental investigation on direct femtosecond laser surface structuring based on a larger class of vector beams generated by means of a q-plate with topological charge $q = +1/2$. In fact, voltage tuning of q-plate optical retardation allows generating a family of ultrashort laser beams with a continuous spatial evolution of polarization and fluence distribution in the focal plane. These beams can be thought of as a controlled coherent superposition of a Gaussian beam with uniform polarization and a vortex beam with a radial or azimuthal state of polarization. The use of this family of ultrashort laser beams in surface structuring leads to a further extension of the achievable surface patterns. The comparison of theoretical predictions of the vector beam characteristics at the focal plane and the generated surface patterns is used to rationalize the dependence of the surface structures on the local state of the laser beam, thus offering an effective way to either design unconventional surface structures or diagnose complex ultrashort laser beams.

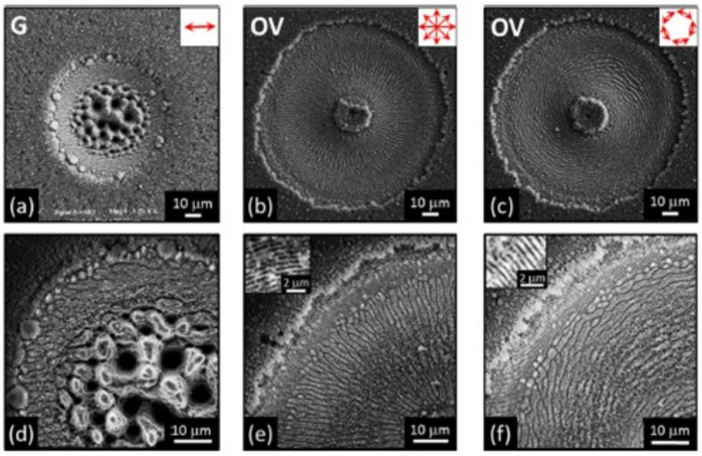

Fig.1: Panels (a–c) are examples of SEM images showing the surface morphologies developed on the silicon target after an irradiation sequence of N = 200 pulses at a pulse energy E_0 = 45 µ J for the Gaussian (G) beam (left panel, un-tuned q-plate at $\delta = 2\pi$) and the Optical Vortex (OV) beams (central and right panels, tuned q-plate at $\delta = \pi$, radial and azimuthal state of polarization, respectively). The panels (d–f) are SEM images acquired at higher magnification illustrating the finer details of the surface texture for the three cases. The two insets in panel (e) and (f) are zoomed views of the ripples generated in the peripheral, annular regions at lower fluence of the OV beams.