High aspect ratio nanopillars in single shot from femtosecond higher-order Bessel beams

V.V. Belloni, M. Hassan, L. Furfaro, L. Franchois, R. Giust, F. Courvoisier

Ultrafast zeroth-order Bessel beams have proven to be highly versatile. With their needle-like focal volume, they find applications in creating high aspect ratio nanovoids in transparent solids and efficient glass cutting. Here, using the higher-order Bessel beam class, we introduce a novel method for generating high-aspect ratio positive nanostructures on sapphire using a single ultrafast laser pulse.

A zeroth-order Bessel beam with radial or azimuthal polarization has its focal region shaped like a hollow cylinder. When this ultrafast pulse interacts with a sapphire sample, it causes very high pressure within the bulk material. The result is the ejection of elongated structures. The resulting nano-pillars can reach heights exceeding 15 µm with a sub-micrometer diameter, resulting in a remarkably high aspect ratio. We propose a mechanism that explains the different generation regimes based on the observed morphologies of these pillars. Depending on the irradiation parameters, the pillars can be formed by translating solid material or by a hydrodynamic process. The validity of our mechanism is supported by transmission electron microscopy characterization, revealing the crystalline structure of the nano-pillars and the presence of amorphous zones.

Our innovative approach offers an efficient way of producing positive nanostructures. Preliminary results show the possibility of extending this method to other transparent materials. What makes it particularly appealing is the process simplicity, as it does not necessitate clean room facilities or pre- and post-processing. Furthermore, our discovery provides insights into how matter in transparent materials behaves following ultrafast laser irradiation. This research opens new perspectives in laser-based material processing and provides a deeper understanding of the intricate interactions between femtosecond lasers and matter.