Ultrafast Single-Shot Laser-Induced Extrusion in Sapphire

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Ultrafast lasers are particularly efficient for material processing since non-linear processes such as multiphoton absorption strongly confines in 3D the laser-matter interaction. Until now, ultrafast pulses were mostly related to ablative processes, modifying and/or removing material in the volume. Here we report a drastically novel femtosecond laser-induced phenomenon, that is neither additive or subtractive. Positive structures are generated atop a sample by matter translation over several micrometers, as a single-shot laser-induced extrusion process [1]. We are able to extrude high aspect ratio nano-pillars, featuring sub-micron diameter and sup10 µm height. We obtain such structures from sapphire samples using single 100-fs pulses, spatially shaped as a radially polarized zeroth-order Bessel beam, which exhibits a non-diffractive hollow core profile.

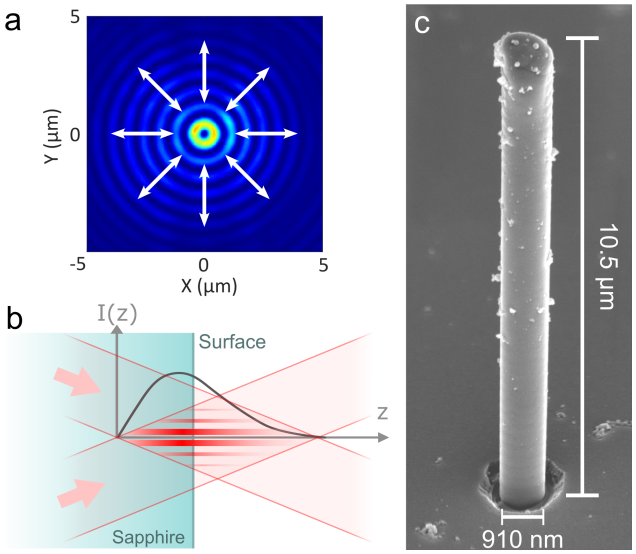

Figure 1: Radially polarized zero-th order Bessel beam (transverse cross section, a) is used to illuminate at sapphire sample in single-shot regime, while crossing one of the sample surfaces (b). We demonstrate extrusion of high aspect ratio nano-pillars (SEM image, c), featuring mono-crystalline structure

Strikingly, Transmission Electron Microscopy (TEM) demonstrates that all extruded structures are mono-crystalline. Using crystalline orientation analysis (reported in [2]), we identify three main regimes in the extrusion process, ranging from material translation without phase change to a jet of liquid undergoing capillary instabilities before resolidification. From a fundamental perspective, our findings open new insights on physical mechanisms of transparent dielectrics intense excitation, showing that ultrafast pulses can induce extreme temperatures on scales as small as 50 nm. From applications point of view, this provides exciting opportunities for rapid writing of positive micro-structures on solids, which are particularly interesting as arrays with direct applications to metamaterials, photonic, phononic and mechanical systems.

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References

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