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Pulse Shaping Femtosecond Laser Beams for Rapid Drilling of High Aspect Ratio Features

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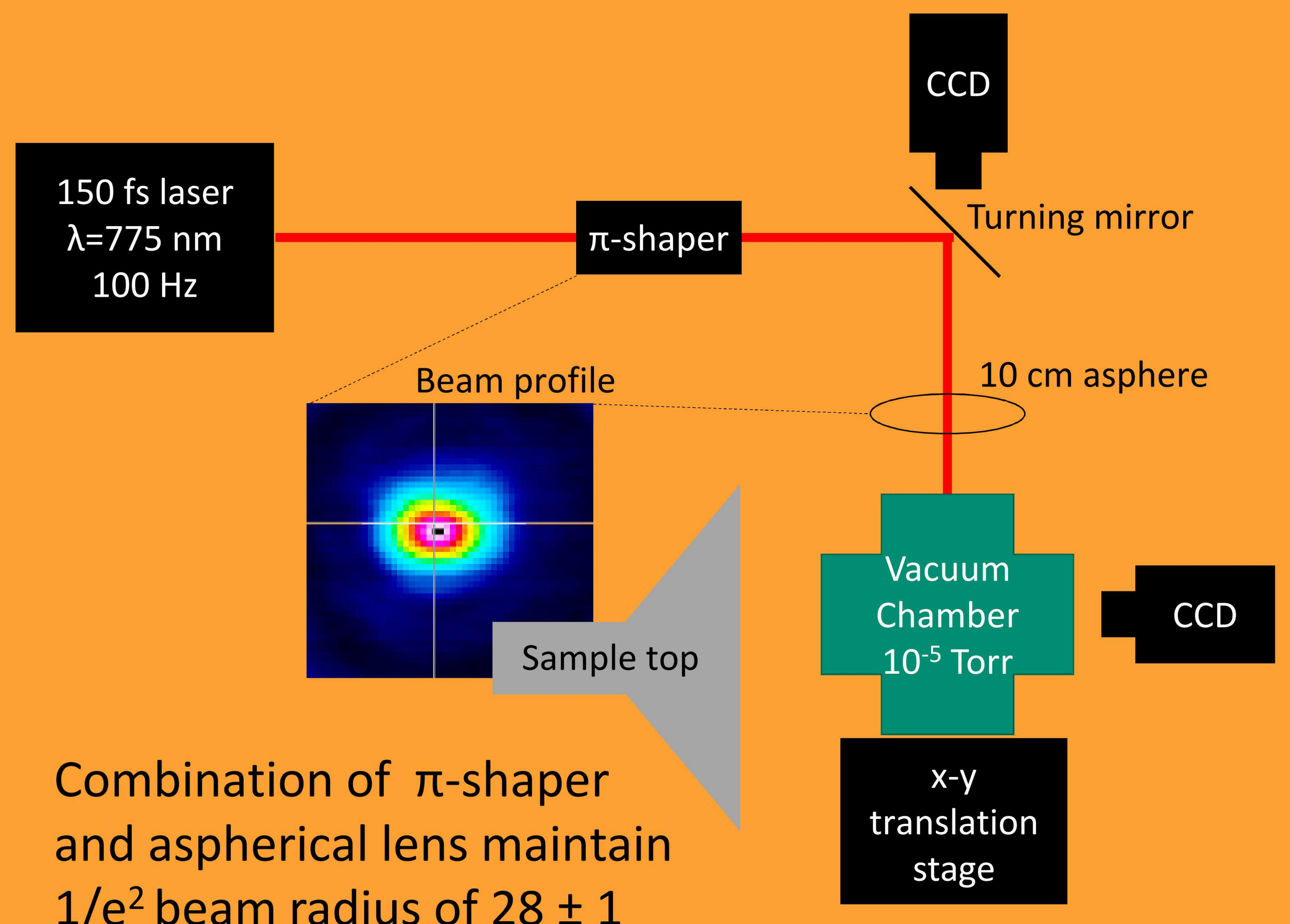
Abstract

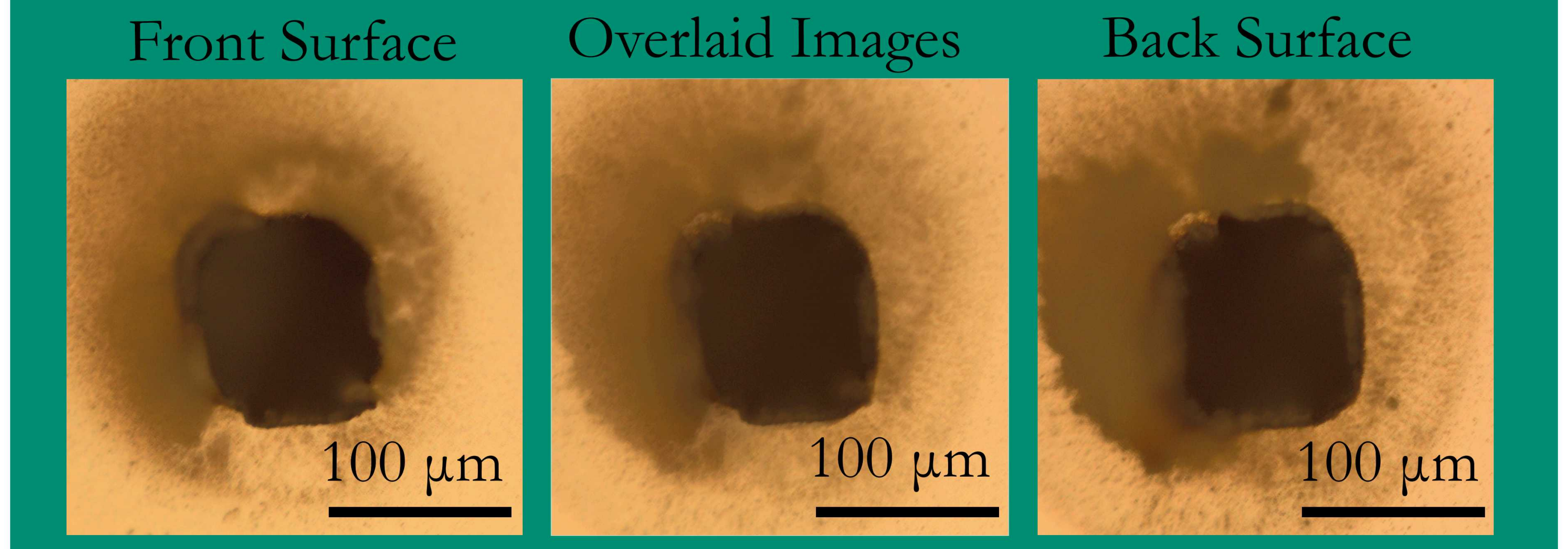
Femtosecond laser micromachining is conventionally performed by focusing the spatially Gaussian beam through Fourier optics onto a sample surface. This method leads to a focal spot that loses half of its incident fluence one Rayleigh length (z_R) away from focus. To increase the aspect ratio of a machined feature, one must translate the sample through focus, which adds both time and exposes the top surface to progressively increasing laser intensity from the beam tails. This work utilizes a Focal-πShaper to produce a femtosecond Bessel beam capable of making a 60 μm diameter hole 1 mm deep in 1 second.

Experimental



Combination of π-shaper and aspherical lens maintain $1/e^2$ beam radius of 28 ± 1 μm over z_R (87% fluence)

Sidewall Straightness from Bessel Beam Machined Surfaces

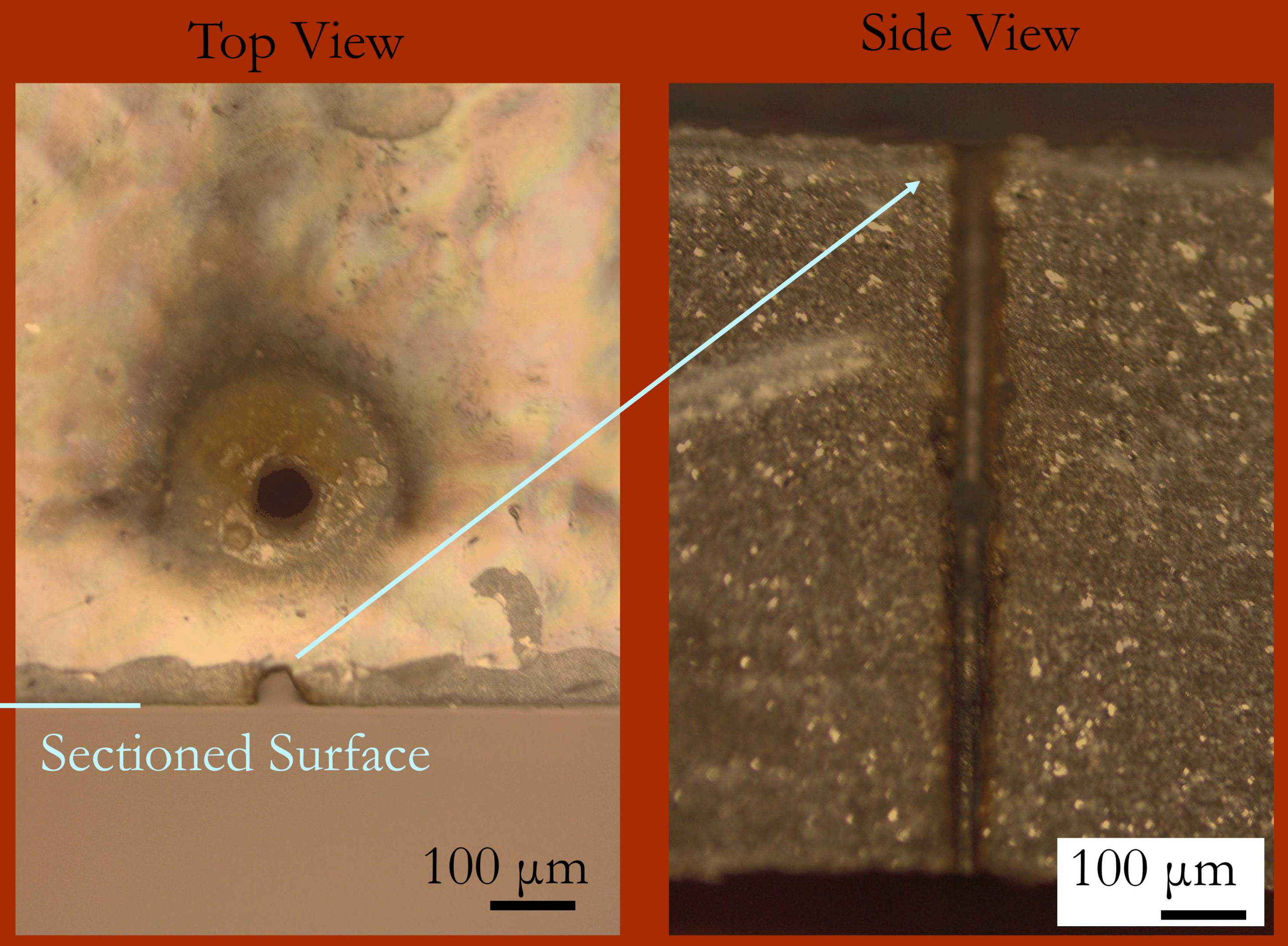

Front Surface

Overlaid Images

Back Surface

The entrance and exit hole diameters for a Si aperture vary by less than 2% through a 300 μm thick wafer

Characterization by Laser Cross-sectioning

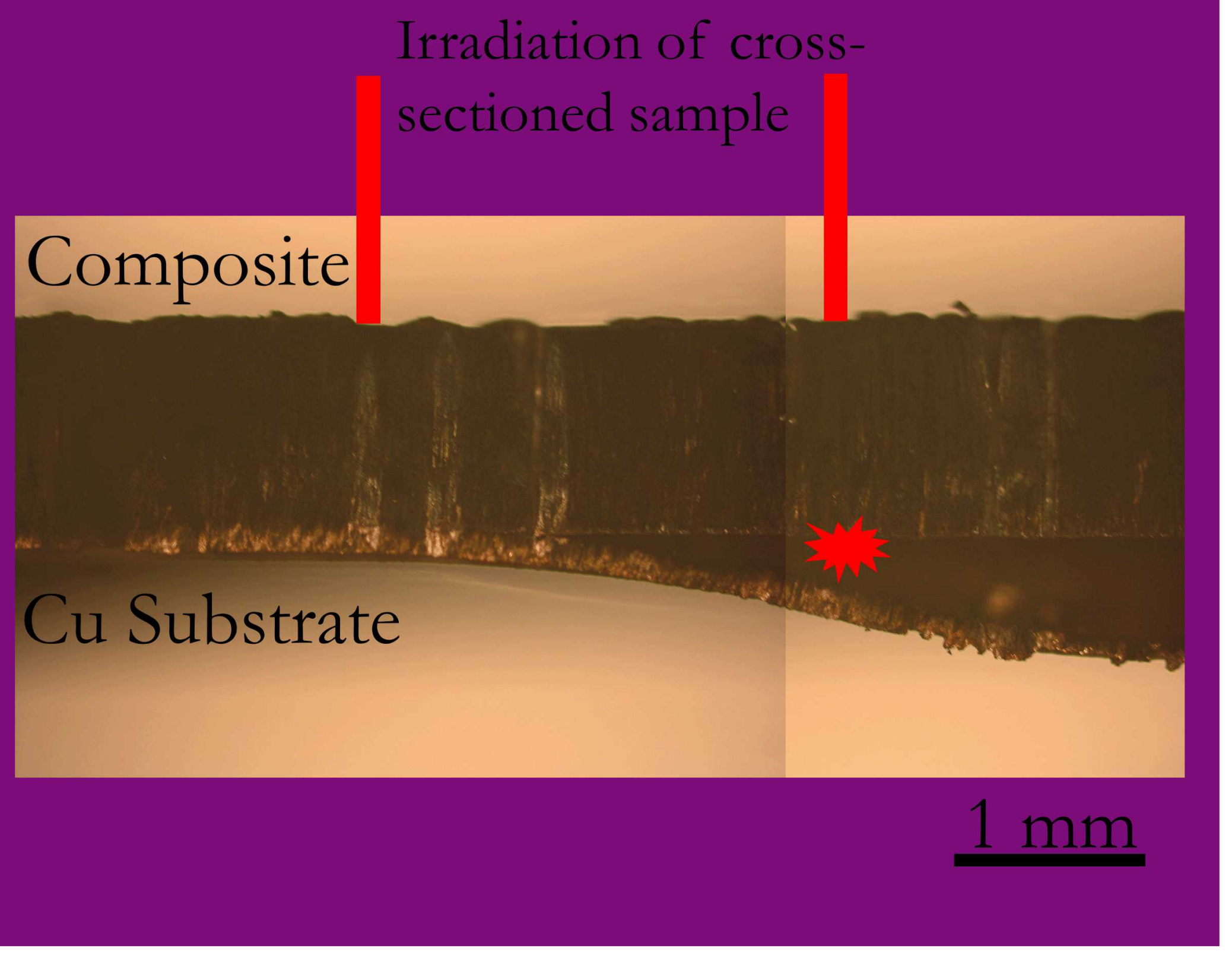

Top View

Side View

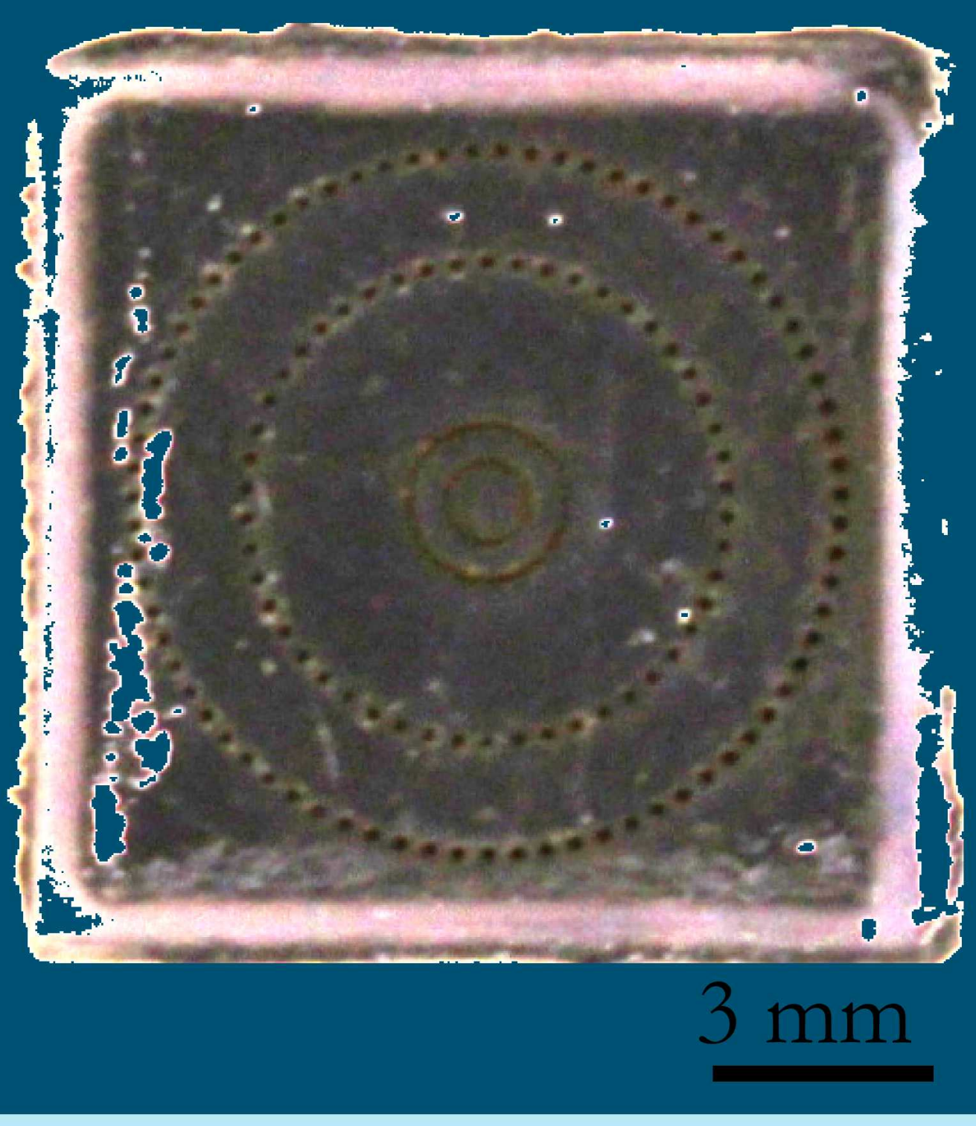
1 mm through hole at 10 J/cm^2 and 10000 laser exposures in an Fe microparticle/epoxy composite

Rapid Endpointing by Imaging Transmitted Beam

In-situ cross-sectional imaging shows transmission through delaminated composite but not region on substrate at 13 J/cm^2, scanned at 0.07 mm/s


Irradiation of cross-sectioned sample

Patterning Surfaces for Electrical Vias



Surface patterning times for a given diameter and 1 mm depth of:

- 1 second for 60 μm holes
- 2 seconds for 100 μm holes
- 4 seconds for 180 μm holes

are achieved for the laser micromachining of an Fe microparticle/epoxy composite (13 J/cm^2, scanned at 0.07 mm/s)

Take Home Message

Combining pulse shaping with ultrafast lasers enables the rapid micromachining of high aspect ratio, straight sidewall features.

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