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Laser Fabrication of 1D Micro-Optical Components by Localized Vaporization and Bumping

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Abstract

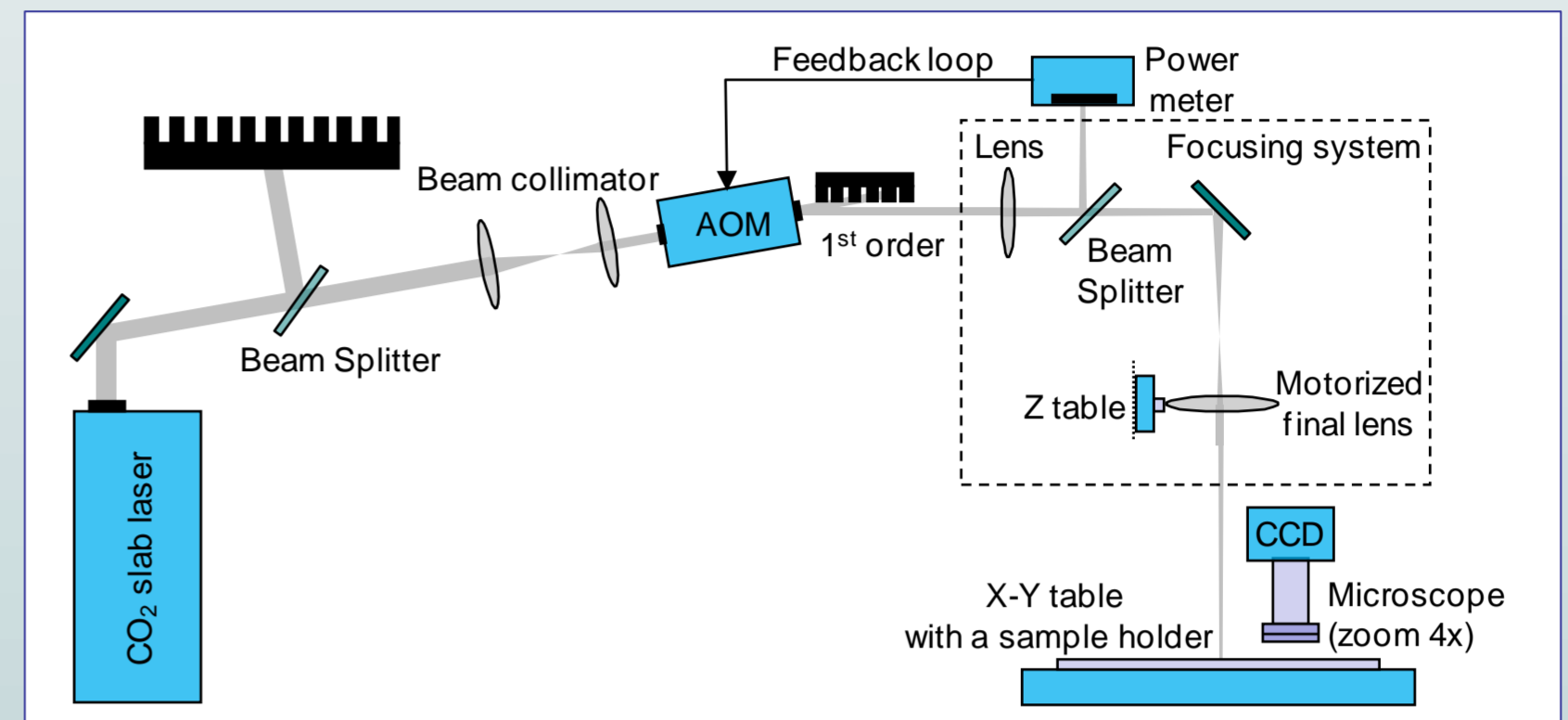
Fused silica has low CTE and good absorption at $10.6\mu\text{m}$ wavelength, thus efficient CO_2 laser processing of glass without cracking can be carried out. Our previous works have shown that pulsed CO_2 radiation in the $2.5\text{-}100\mu\text{s}$ pulse width region is able to remove a precise amount of glass by surface ablation [1], whereas longer pulses with high repetition, but at laser powers below the vaporization threshold, generate a thin melt layer at the glass surface that flows under surface tension [2]. These two different machining conditions are used for fabrication of custom micro-optics, e.g., dual-axis corrective phase plates for high power diode lasers [3].

Here, we present a new approach for fabrication of sub-millimetre width mirrors in silica (HPFS 7980 Corning) using a CO_2 laser polishing setup, but at laser powers that are higher than usual, producing vaporization of glass.

Research objectives

- Investigation of 1D surface shape generation by single line laser scan.
- Generation of grooves in silica plates by multiple laser scan treatment.
- Development of the fabrication process for toroidal mirrors using partial overlapping of laser scans.

CO_2 laser setup description



- 1mm diameter laser beam on a target (measured at $1/e^2$).
- Laser operated at $10.59\mu\text{m}$ wavelength.
- A sample moved with a constant speed of 5mm/s .
- Laser power of up to 10.5W , controlled by the acousto-optic modulator.
- Power fluctuations during processing less than 1%, obtained by the feedback loop between the AOM and the power meter.

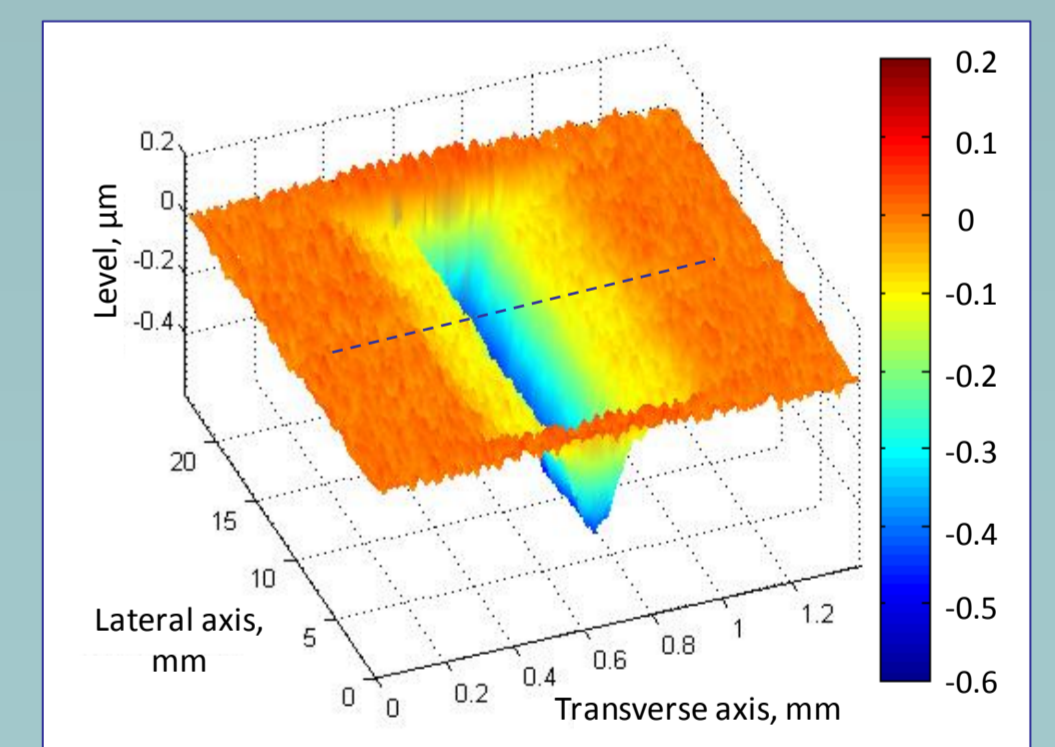
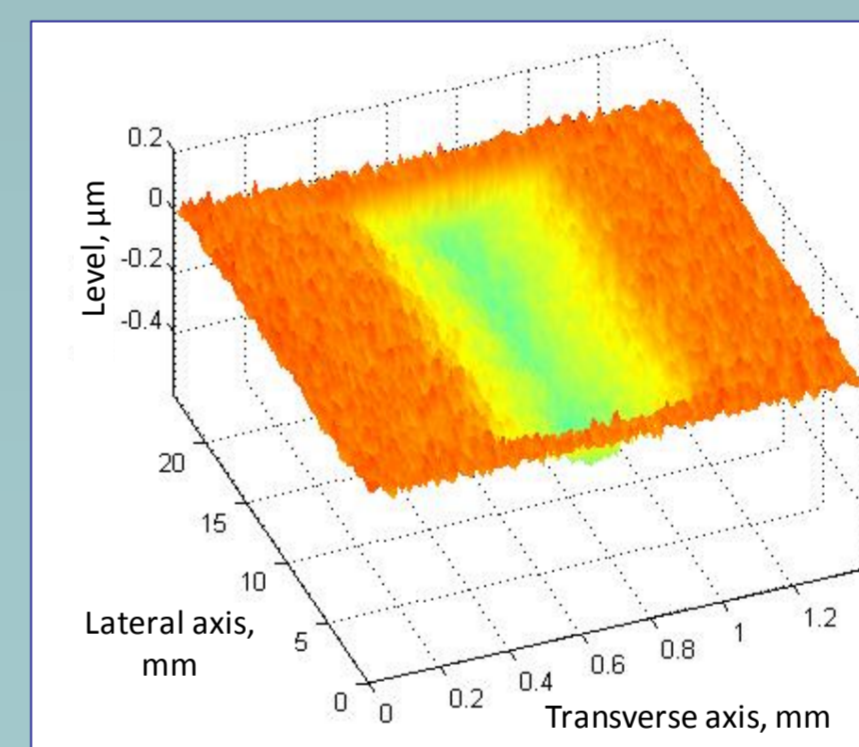
Reverse “bumping” and evaporation thresholds for single line scans in silica

Experimental conditions

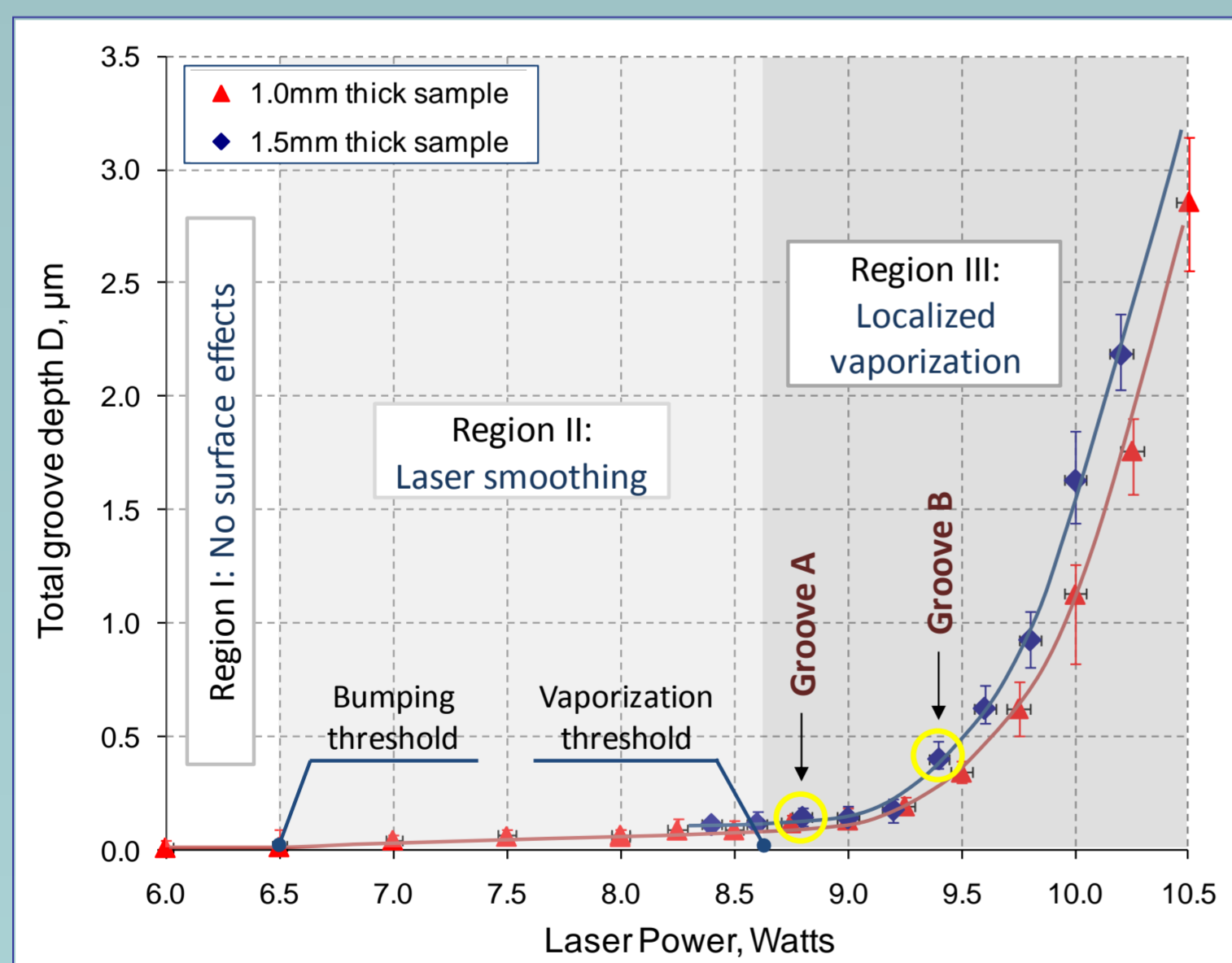
Two silica plates with thicknesses of 1mm and 1.5mm have been irradiated by a moving laser beam at different laser power levels. The beam was crossed the sample only once (a single line laser scan), creating either nothing or a 20mm long groove at the glass surface.

Surface profiles of two selected grooves, obtained from a non-contact 3D surface profilometer (Proscan 1000)

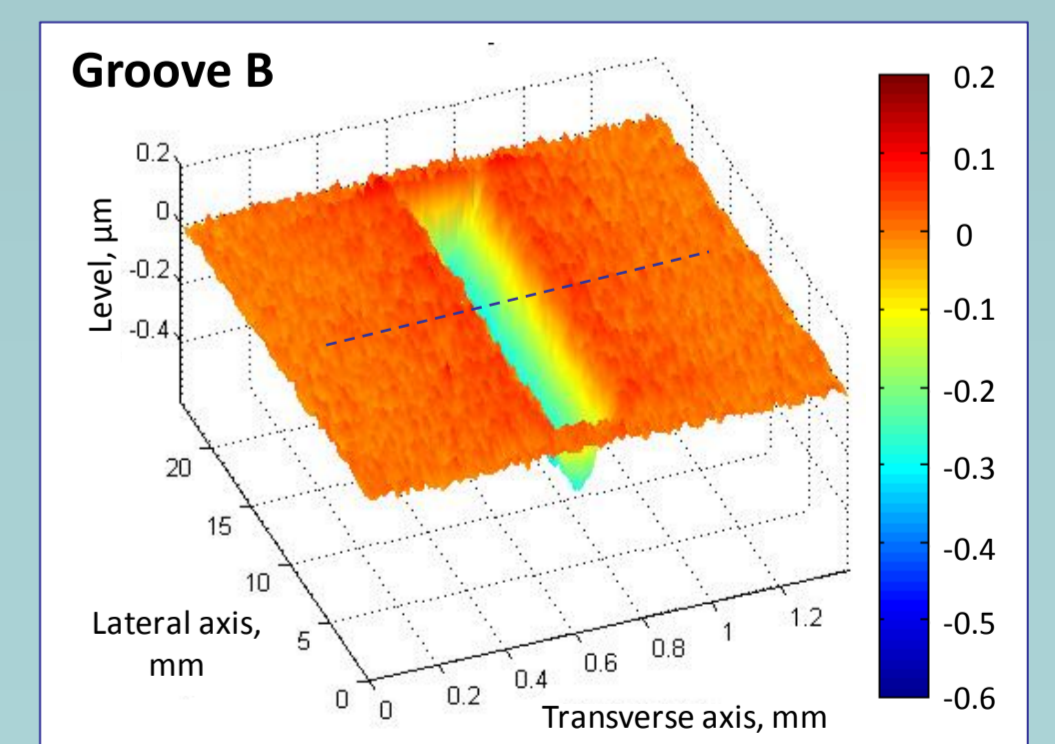
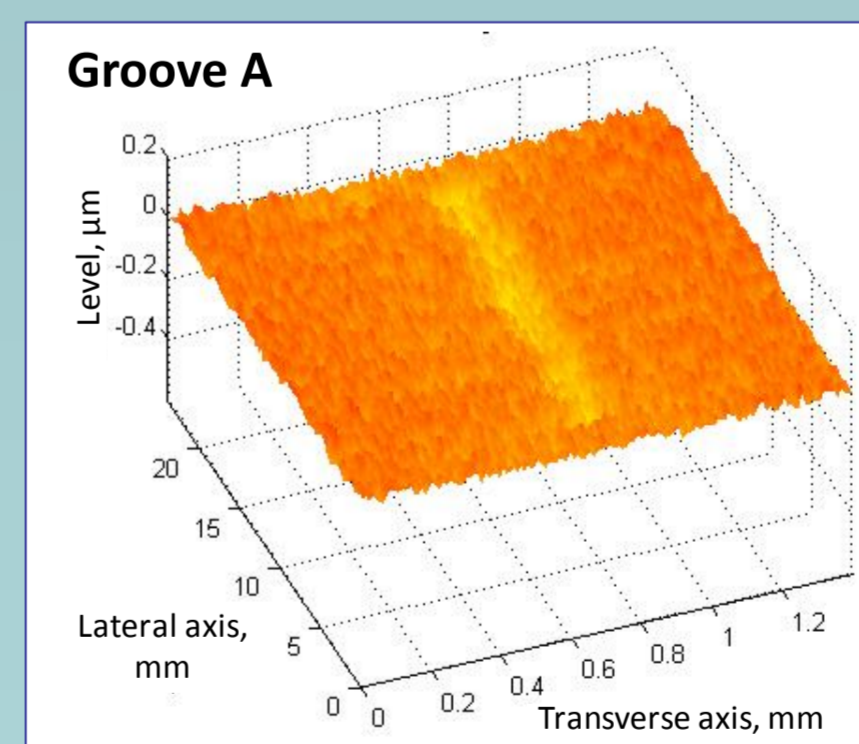
- Groove A** machined at 8.8W – close to vaporization threshold
- Groove B** machined at 9.4W – significantly above vaporization threshold



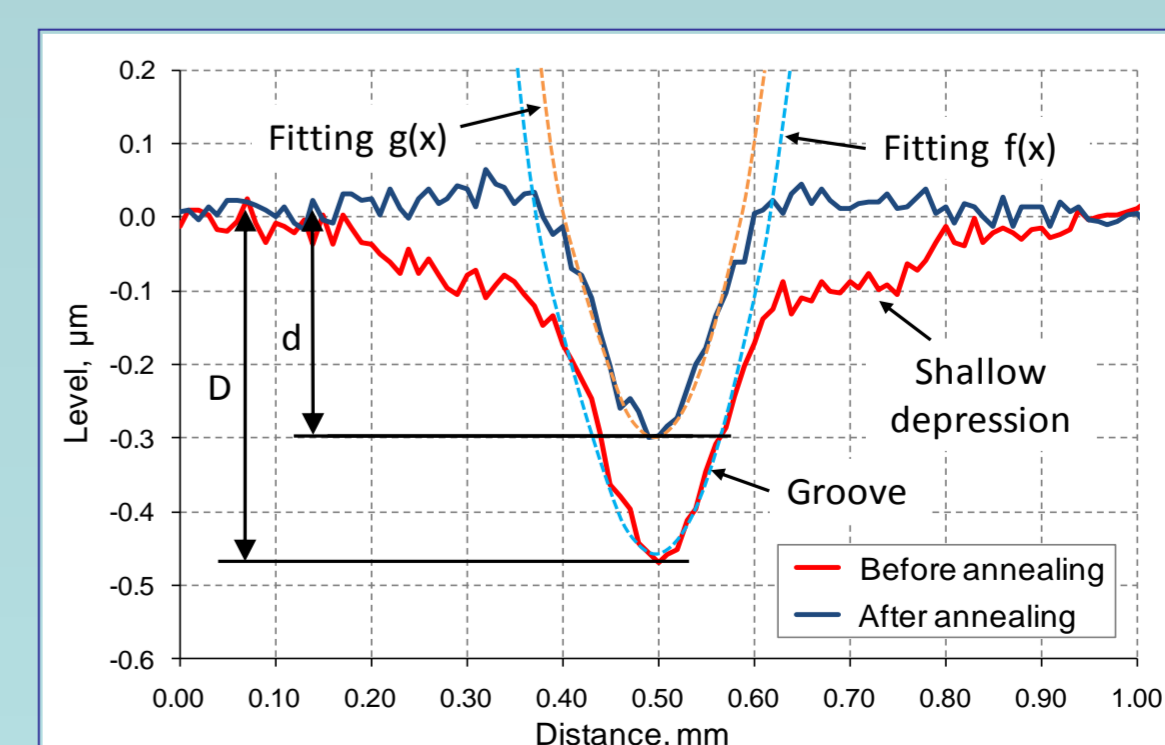
Groove depth vs. laser power used for two samples with different thickness.



Affect of annealing on reverse bumping



Changes in a cross-section of the groove made at 9.4W



Depression is removed by annealing at 1100°C !

- Three characteristic machining regions have been distinguished:

Region I: Any changes on a glass surface are not observed.

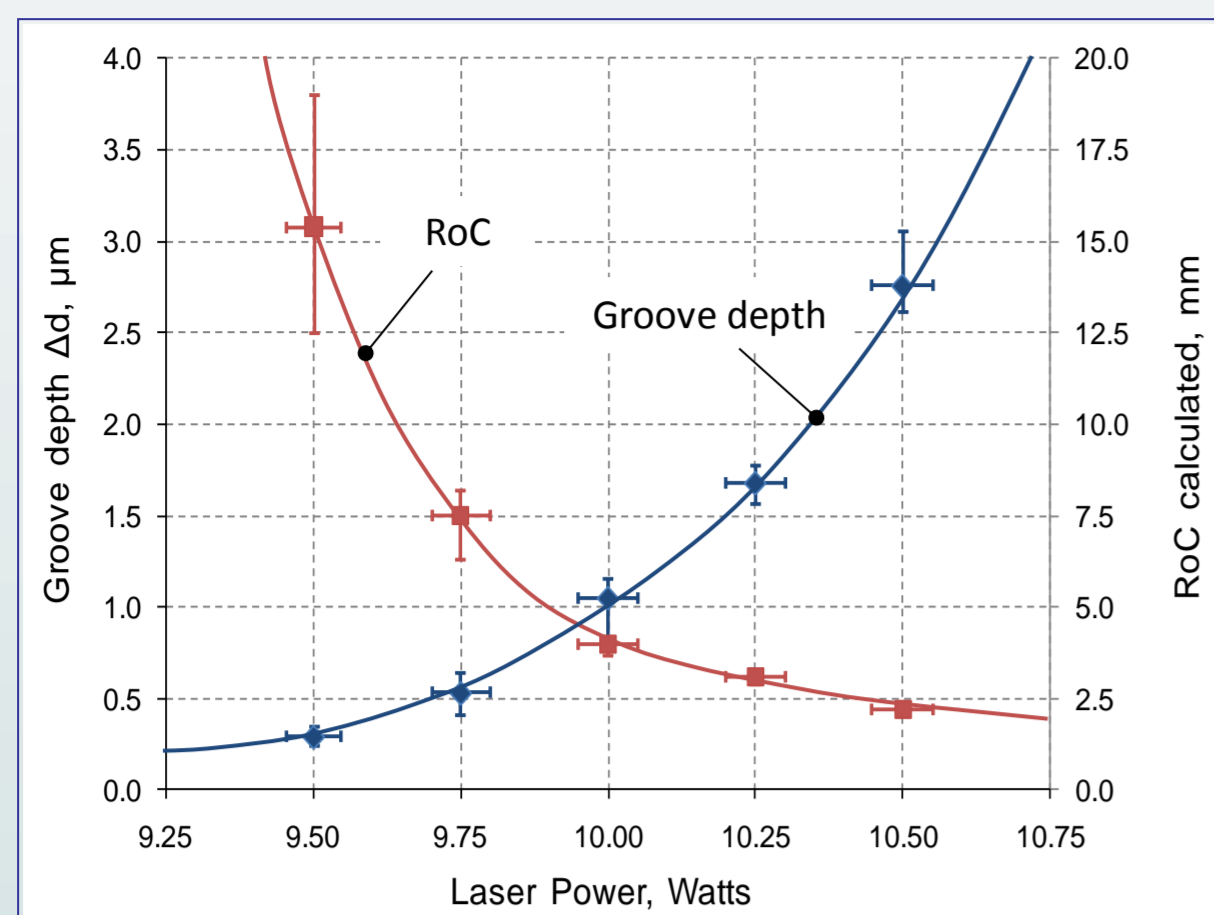
Region II: A shallow depression is generated in the glass.

Region III: A groove surrounded by the depression is visible.

- Bumping threshold at 6.5W – shallow depressions generated on a glass surface are observed. The *reverse* bump is related to local fictive temperature change which increases the density of silica [4].
- Vaporization threshold at 8.6W – glass evaporates. Typical width of grooves is $\sim 180\mu\text{m}$ which corresponds to the size of melt pool for this particular beam [2].
- Stronger vaporization observed for 1.5mm thick plate. This is related to higher thermal impedance.

Machining of silica using laser scan overlapping

Relation between a radius of curvature and laser power used for a single laser scan. Results for a 1mm thick annealed sample.

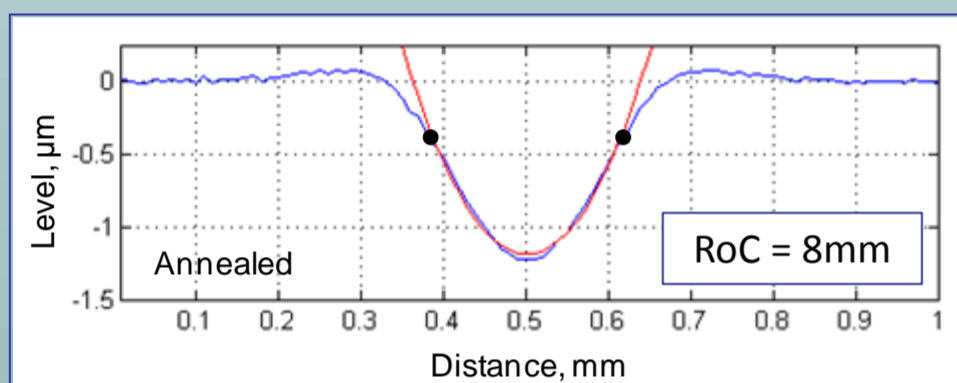
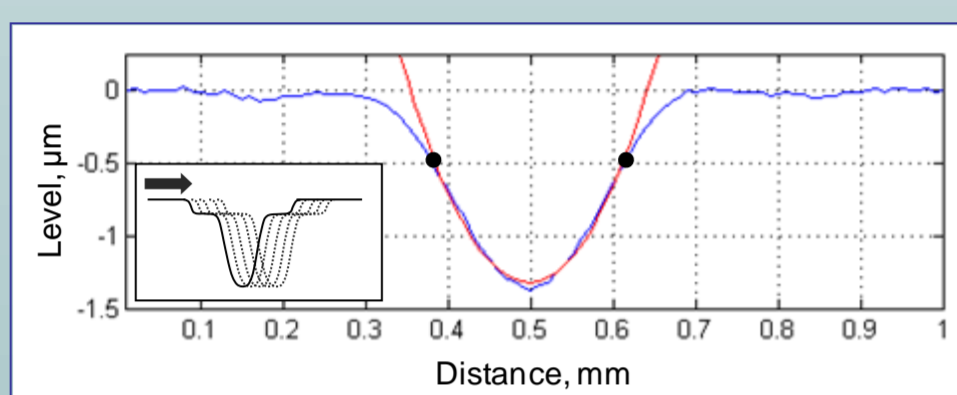


- Radius of curvature calculated from fitting function $g(x)$
- RoC in a range from 2mm to 20mm.

Generation of grooves with larger aperture

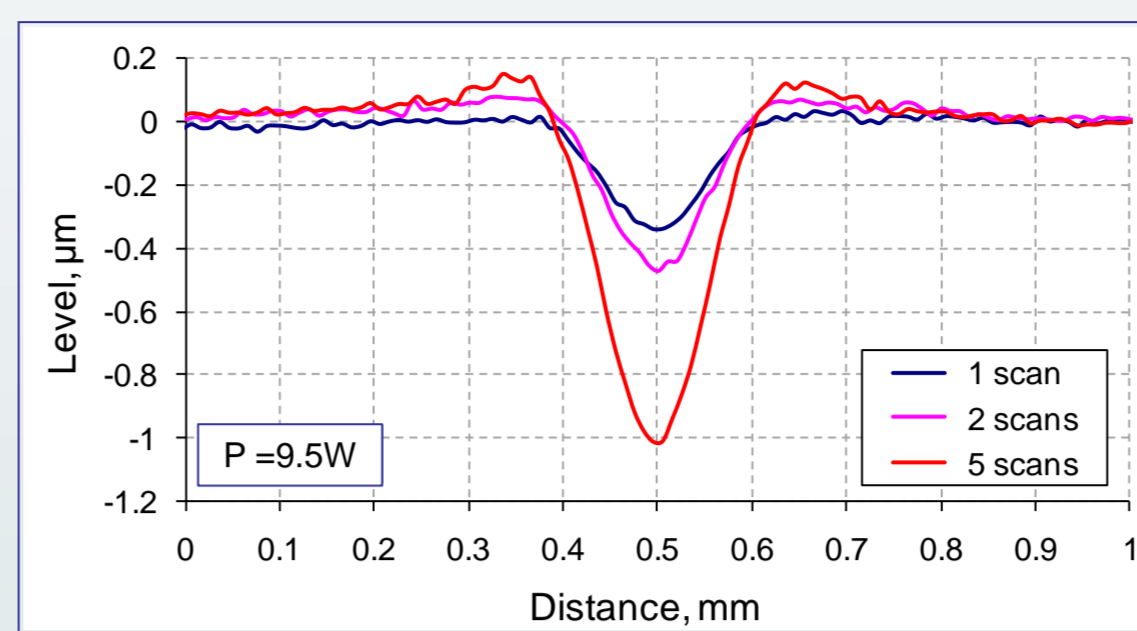
- The sequence of partially overlapped laser scans is applied
- Raster pitch and number of scans chosen experimentally.

Groove generated by 5 linear laser scans overlapped with a $40\mu\text{m}$ pitch at 9.5W laser power

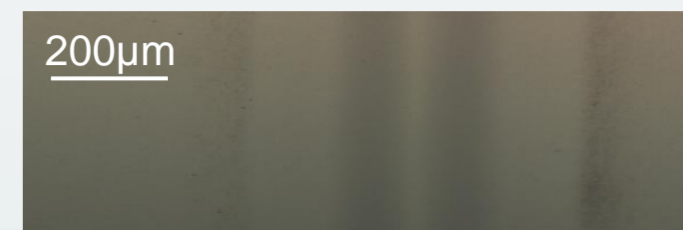


- Groove aperture increased
- Parabolic shape of the groove is maintained
- The re-deposited bulges are lower than for the fully overlapped track.

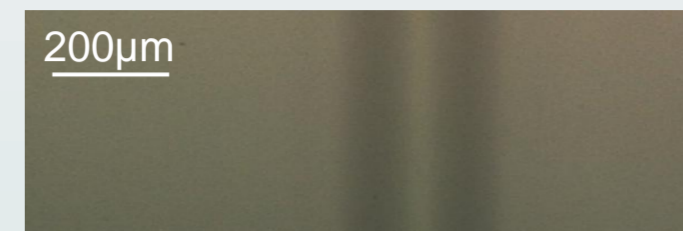
Influence of overlapping laser scans on a groove shape



As machined



Laser smoothed at 7W

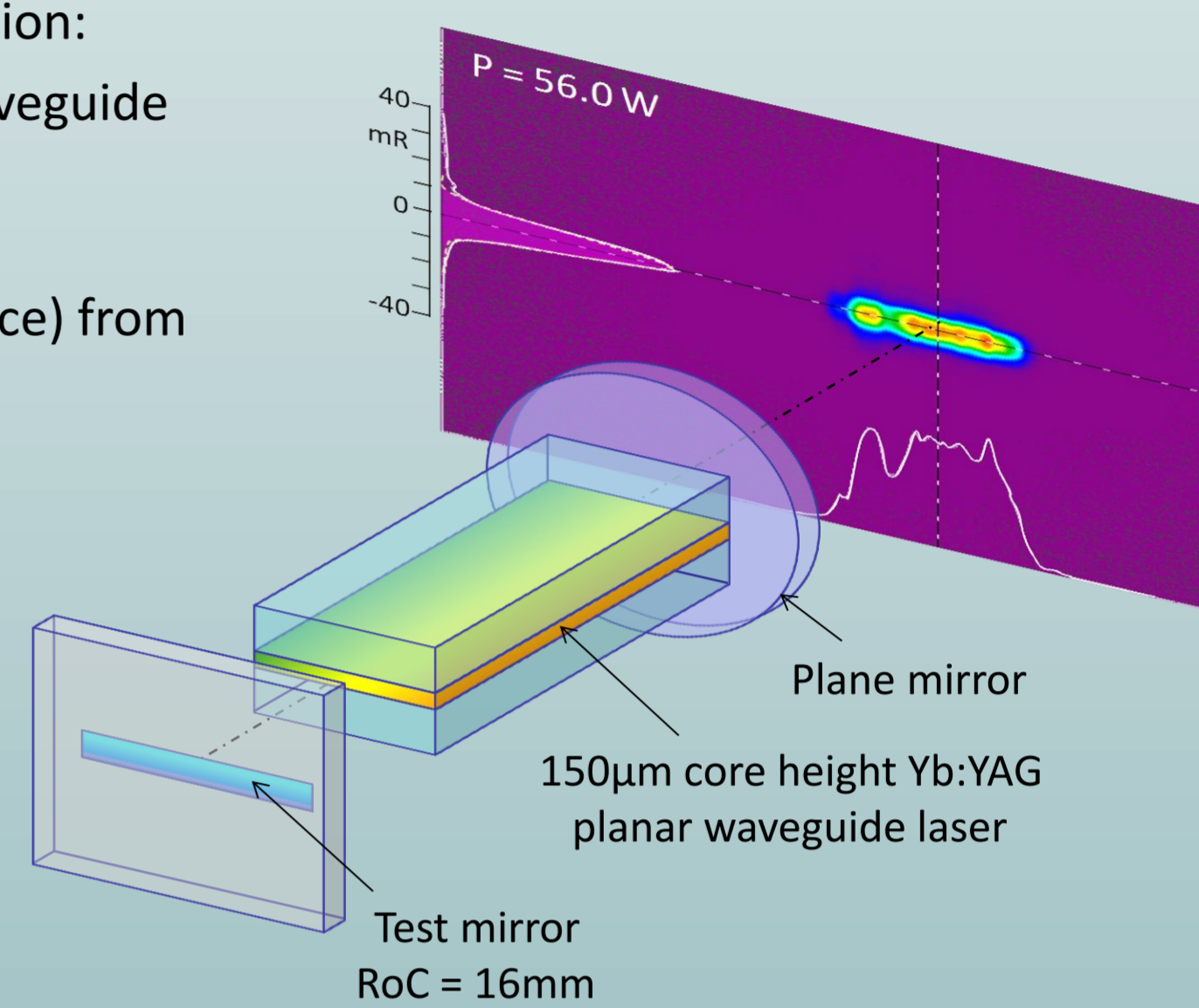


- Groove width is unchanged compared with the groove made by a single laser scan.
- Non-linear relation between a groove depth and a number of scans.
- Problem with re-deposition, but it can be reduced by laser smoothing.

Test of the fabricated mirror in a mode-selective Yb:YAG laser setup [5]

Mode-matching configuration:

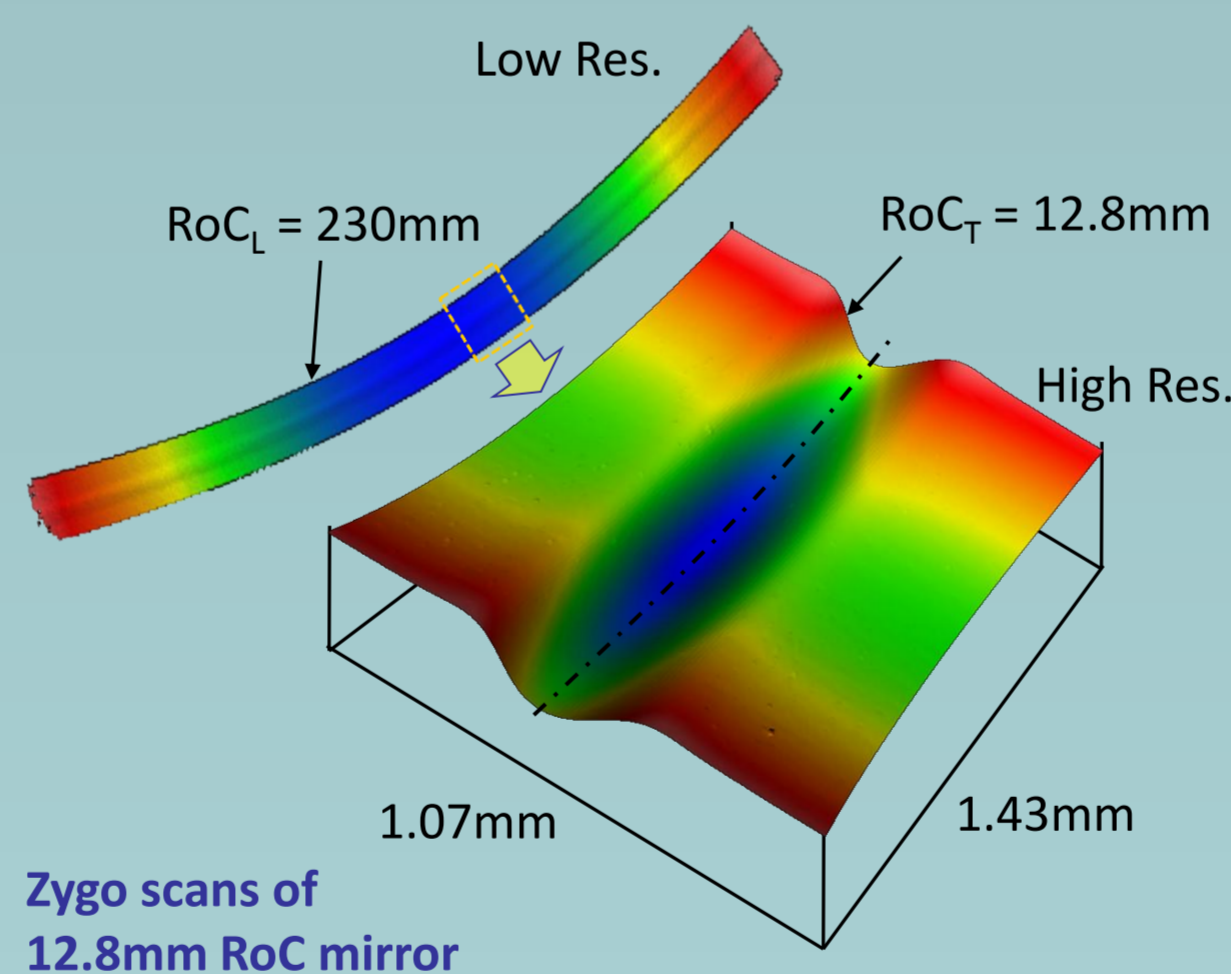
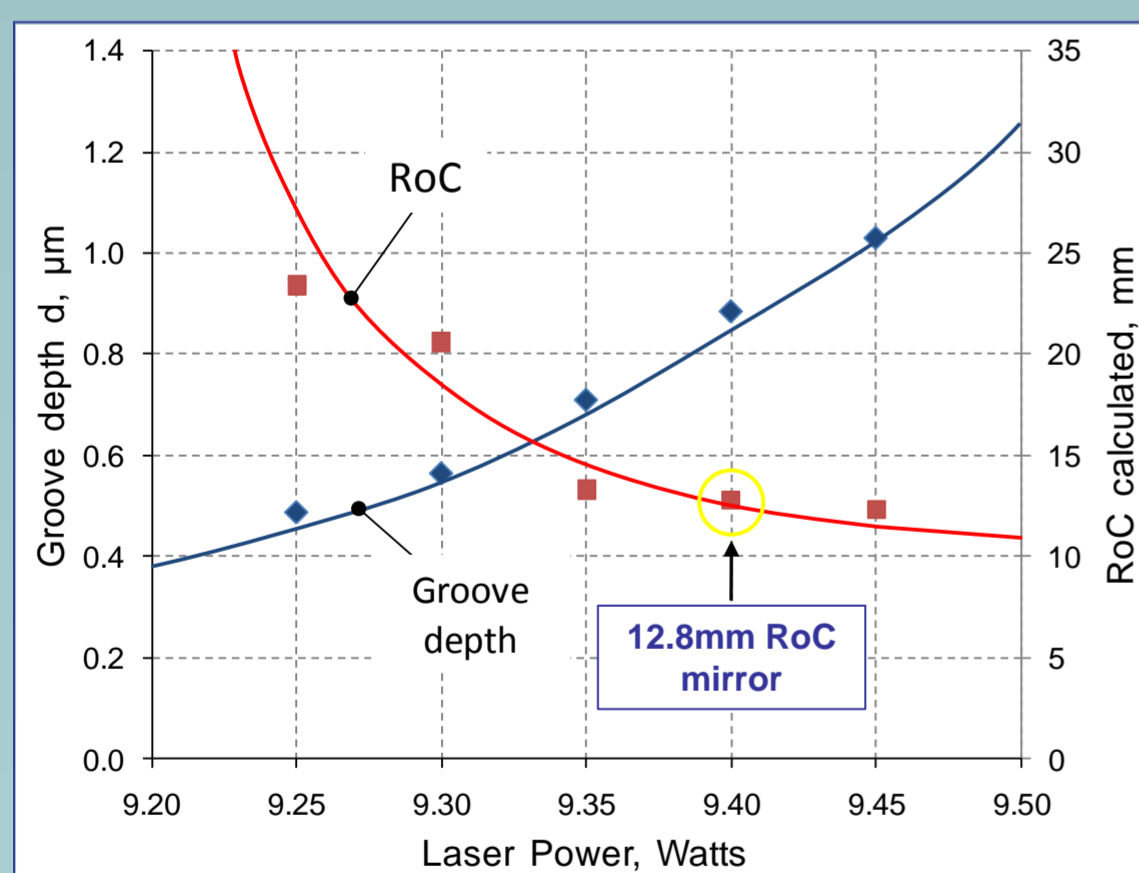
- Plane mirror close to waveguide facet
- Test mirror placed 8mm (a half of Rayleigh distance) from waveguide facet



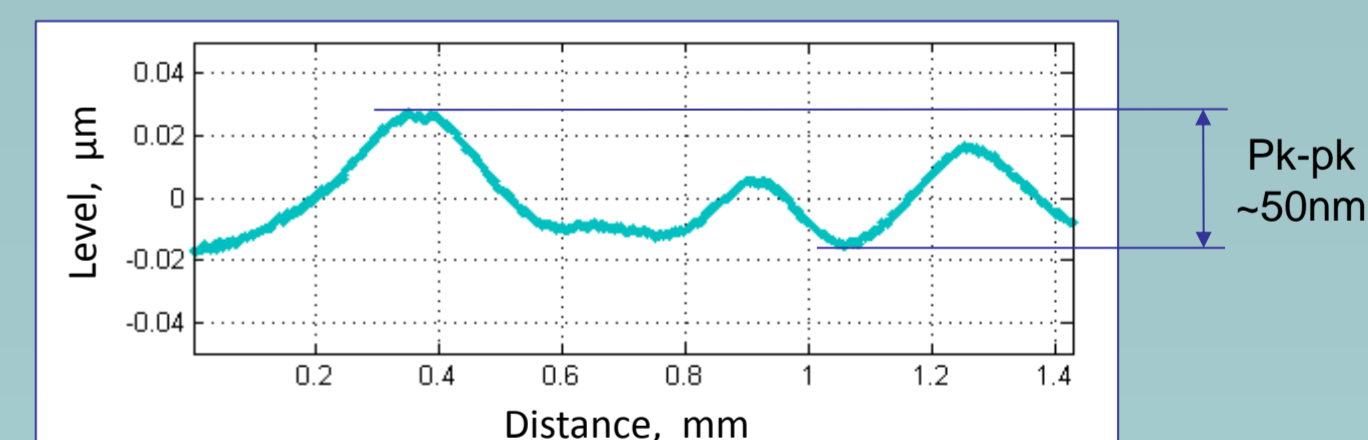
High order modes suppressed in the transverse direction!

Laser fabrication of toroidal mirrors

- Conventional polished cylindrical lens with 230mm RoC used as a substrate.
- Shapes generated by 5 linear laser scans overlapped with a $46\mu\text{m}$ pitch and different laser powers.



Surface quality of the machined mirror



Surface waviness is $\sim \lambda/10$
First time machined on a curved substrate!

Conclusion & Future work

- Localized vaporization provides a tool to fabricate sub-millimetre scale mirrors.
- A radius of curvature controlled by selection of the laser spot size used, the laser power, the number of scans and the raster pitch between them.
- Our mirror successfully used as a resonator mirror for a $150\mu\text{m}$ core Yb:YAG planar waveguide laser.
- We are planning to test the fabricated toroidal mirrors and to improve the power stability of CO_2 laser system in the near future.

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