CANDLE Synchrotron
Research Institute

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Department of Physics

Ultrafast laser-induced modification of glass and fabrication of buried phase structures

Ultrafast Beams and Applications

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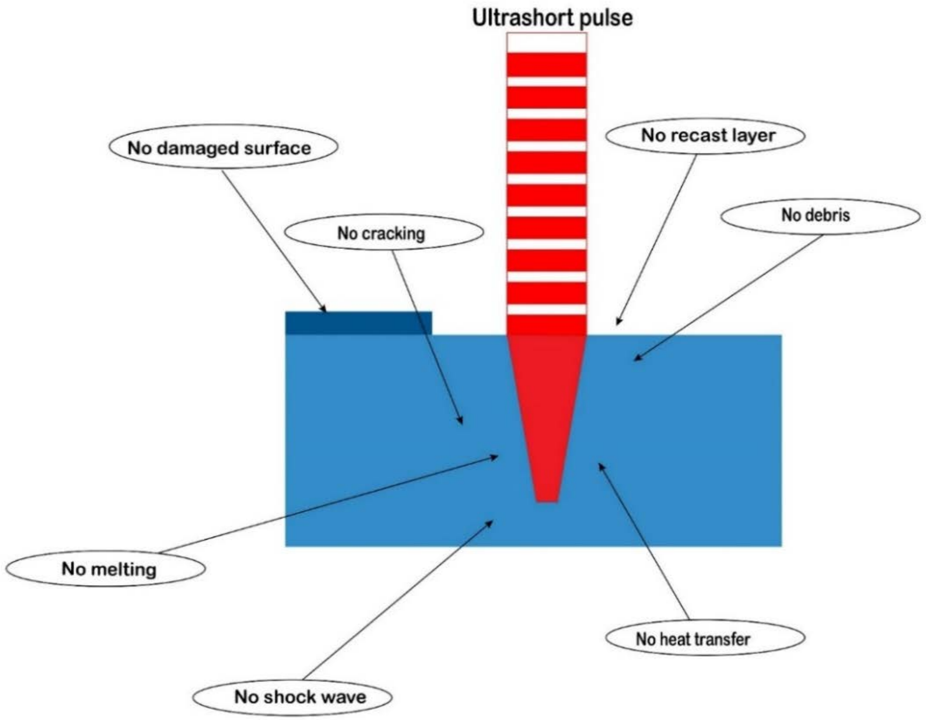
Outline

- Application of ultrashort-pulse lasers for glass processing
  - Advantages and features
- Fabrication of buried structures in glass
  - Potential for high-aspect ratio and large structures
- Application for estimation of the Refractive Index Change
- Summary

Ultrashort laser processing of glass

Features of the femtosecond processing



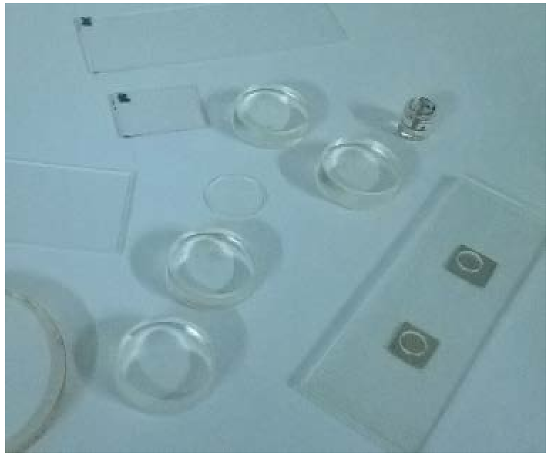
- Ultrafast processing reduces the heat affected zones and improves the quality and resolution of fabrication

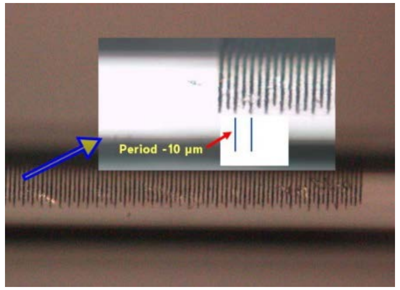
- The high peak intensities of ultrashort pulses increase the probability of multiphoton absorption in transparent materials, so both surface (2D) and volume (3D) writing of micro- and nanostructures becomes feasible

- <u>In particular</u>, refractive index change (RIC) can be induced in the volume of a glass sample at sufficiently high intensities.

Ultrashort laser processing of glass

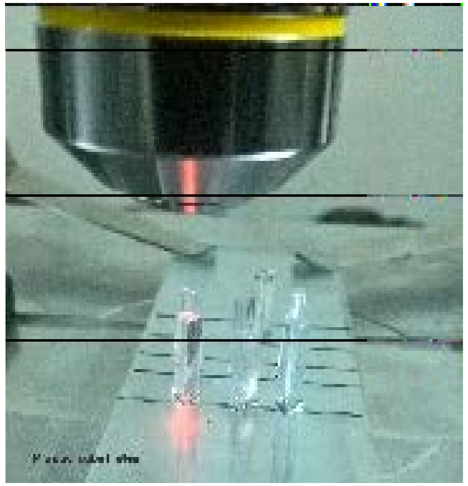
Laser-induced refractive index change in glass





The technique is widely used for fabrication of glass-based components and devices:

Diffraction gratings, phase plates, waveguides, etc.

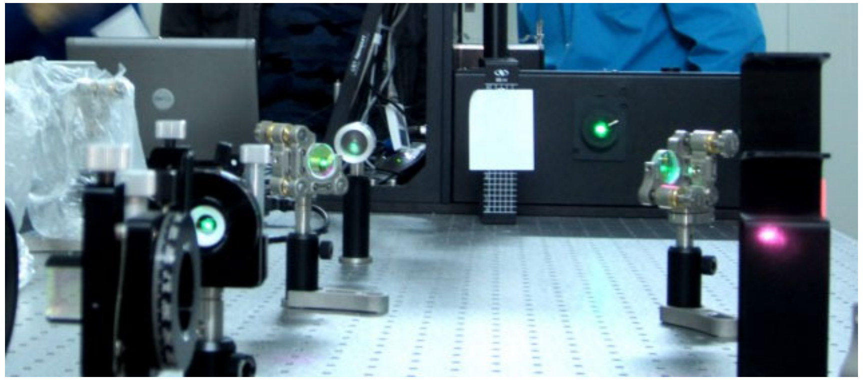


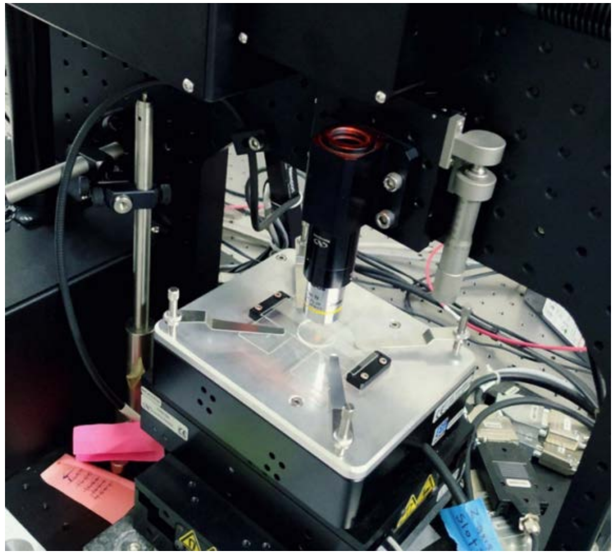
Fabrication of high-aspect ratio and large structures is still a challenge

Quality fabrication requires accurate control of fabrication regimes:

- Laser stability and scanning precision
- Optimized design approaches to reduce the fabrication time

DELTA uFAB station



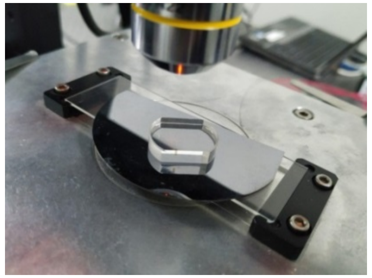


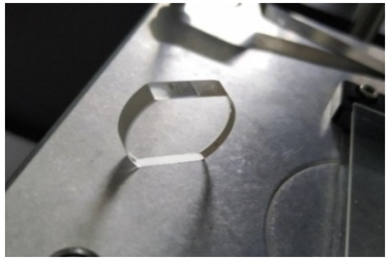
Specifications of laser	
Pulse duration	from 400 fs to 10 ps
Repetition rate	from 1 Hz to 100 kHz
Average power	up to 8 W
Pulse energy	up to 2 mJ (1030 nm) and 1 mJ (515 nm)
Wavelengths	1030 nm, 515 nm

Features of station

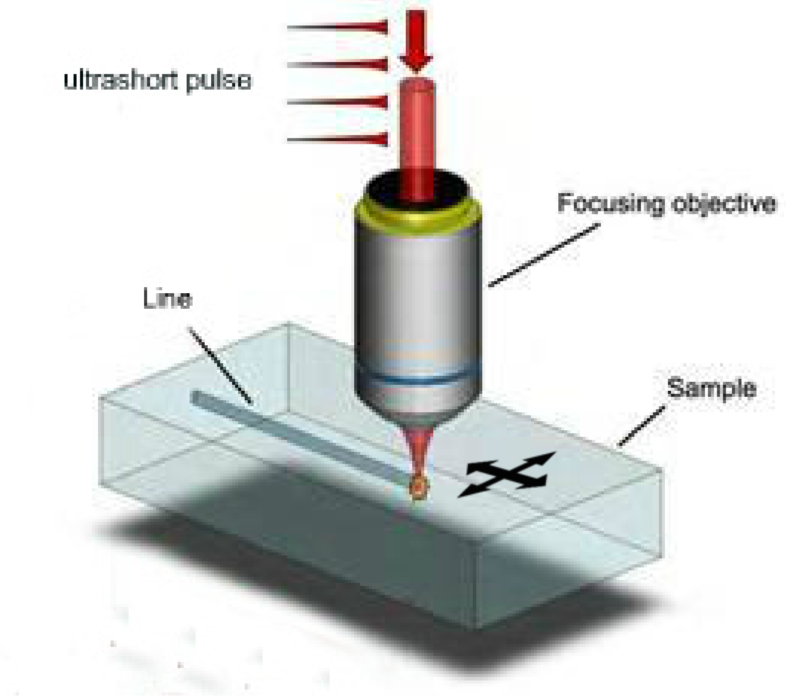
- Travel range:100 x 100 mm (XY), 25 mm (Z)
- Scanning speed: up to 5 mm/sec
- High accuracy of XYZ positioning/motion: ±50 nm
- High-grade optics to achieve nanoscale precision in both 2D and 3D processing
- Software for both visualization of the machining process and direct control of sample motion hardware and pulse parameters

Experimental Details





- BK7 borosilicate optical glasses widely are used in optoelectronics, microwave technology, integrated optics devices and many other areas of diffractive optical elements.

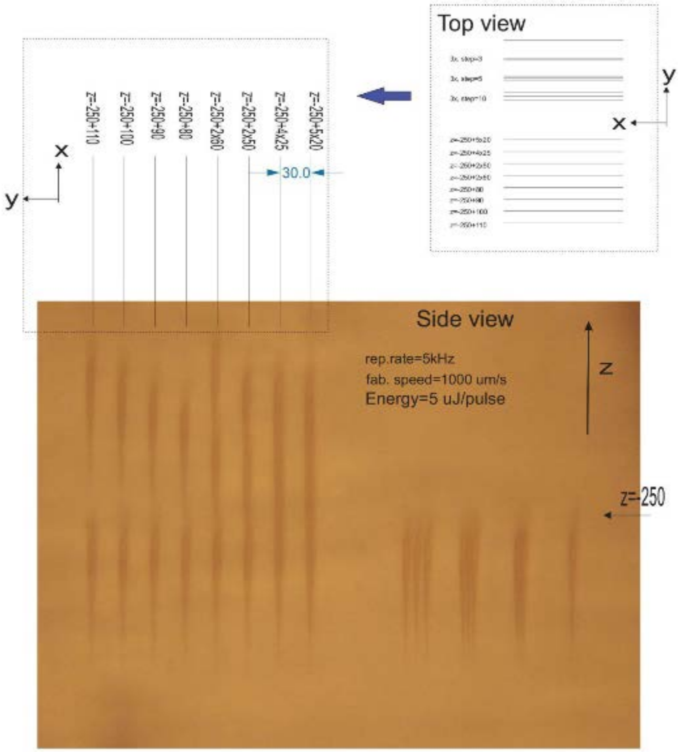


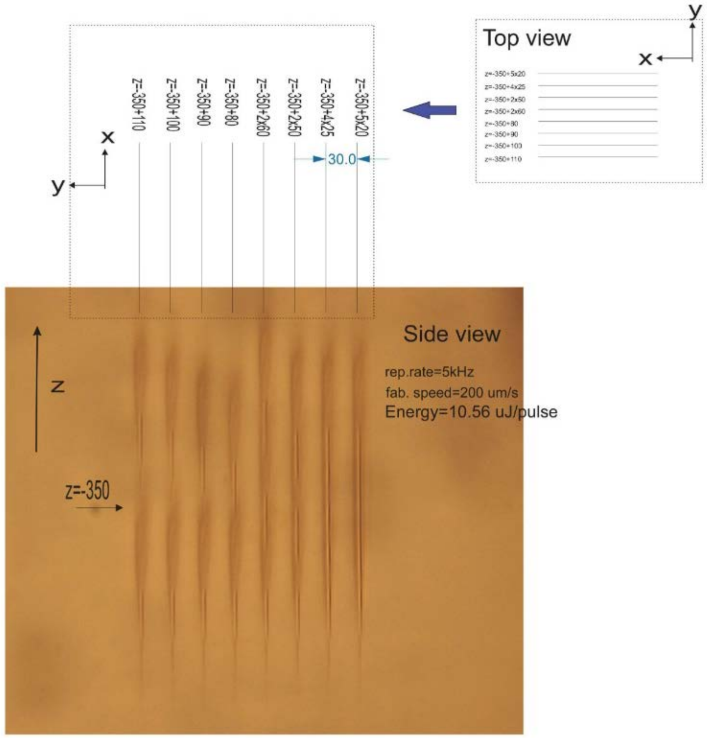
- to study the fabrication regimes horizontal lines are written in glass which are then repeated in different steps in horizontal plane. In order to study the dependence on the depth, the lines are written also at different depths.

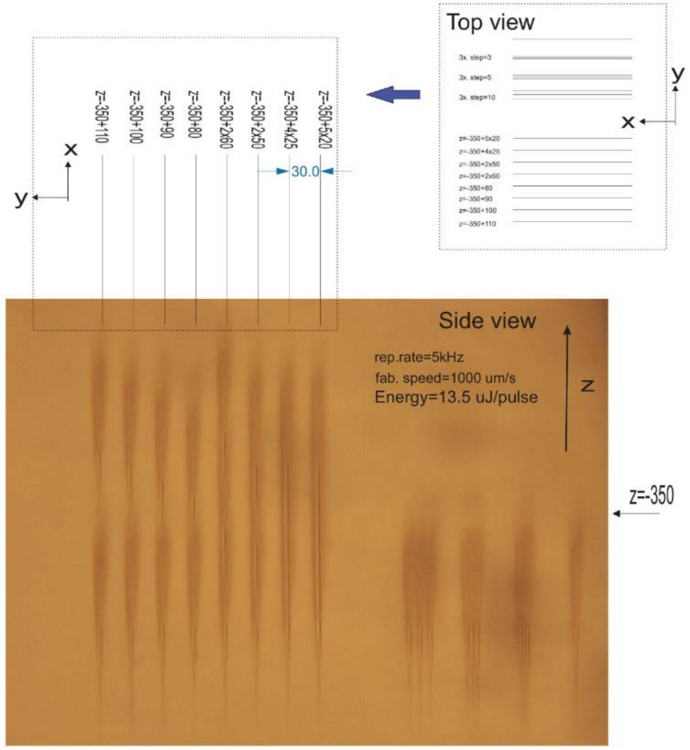
- the sample is cut and polished to make the horizontally formed trace cross-sections visible with a microscope.

Results

Study of fabrication regimes



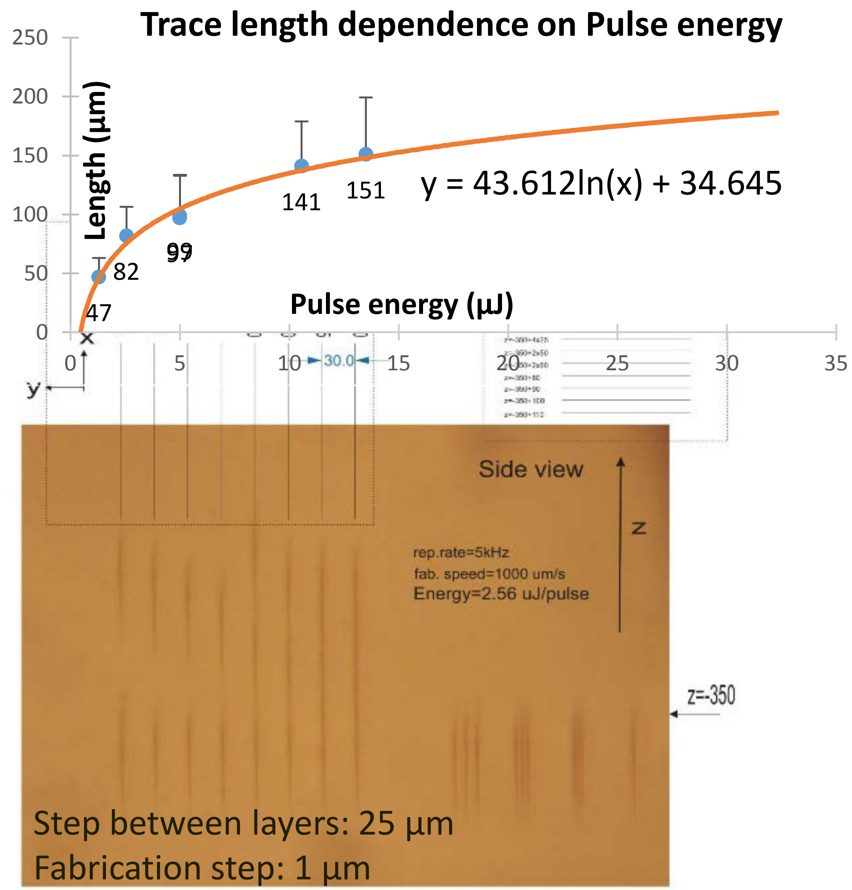




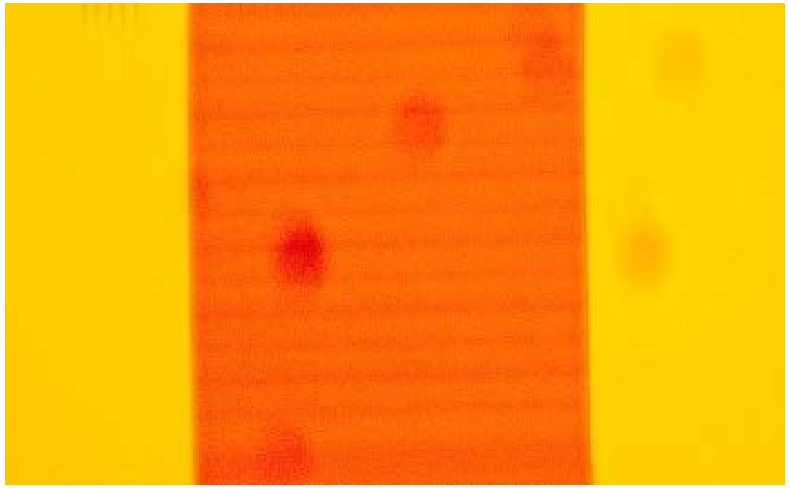
Dependence on pulse energy and fabrication speed

The homogeneity depends on the exposure
i.e. pulse energy and fabrication speed (or repetition rate)

Fabrication of large buried structures



Large structures



buried structure size: 600 µm × 600 µm x1800 µm

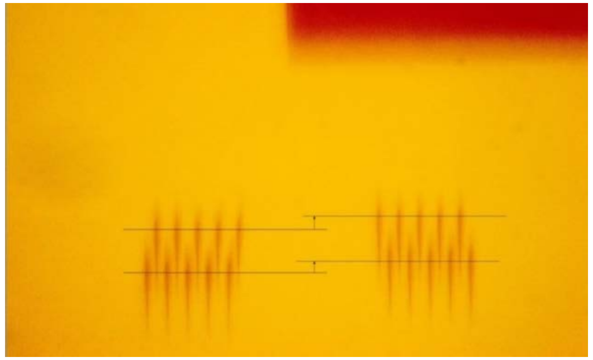
Possible improvements

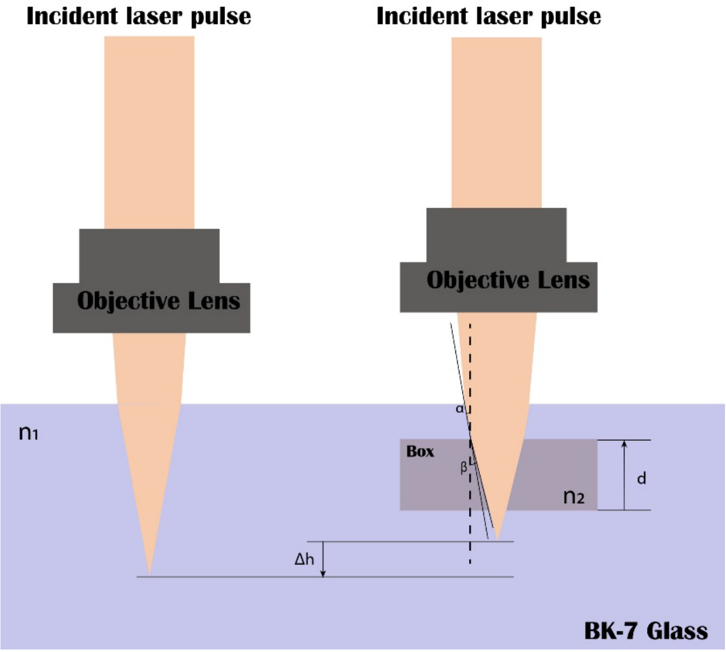
- Fabrication time to be reduced (the sample above took more than 3 hours!)
- Higher speed of fabrication requires the increase of repetition rate and pulse energy—subject to future studies

Estimation of the Refractive Index Change

Large structures can be used for "express" evaluation of RIC during a fabrication process

The idea is to fabricate trace series below the structure and out of it.



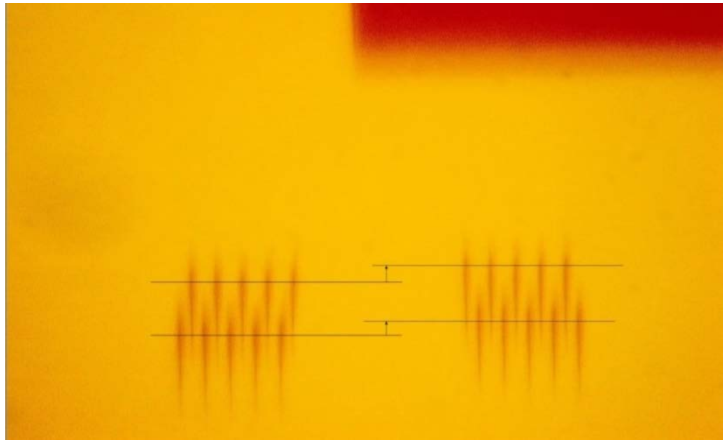


Law of refraction: $n_2 * \sin\beta = n_1 * \sin\alpha$

From some geometric calculations: $\frac{d}{\Delta h} \approx \frac{1}{1-\frac{\sin\alpha}{\sin\beta}}$; ➔ $d = n_1 * (\Delta h/\Delta n)$

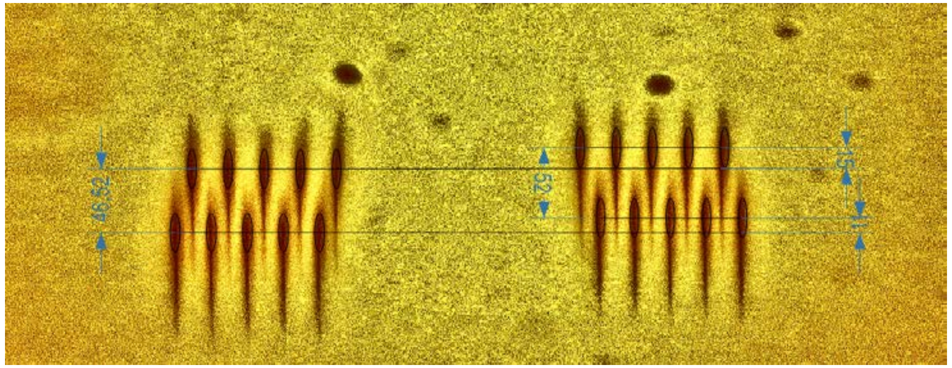
Experiment Results

the qualitative estimation of the sign of the RIC



The sign and magnitude of RIC can be estimated from the relative shift of the trace series.

the qualitative estimation of the value of the RIC using image processing



Negative refractive-index shift of 10^{-2} in this case.

Summary

- optimal regimes for fabrication of buried large structures in glass: smooth edges, good homogeneity can be obtained
- large structures can be fabricated for an “express” qualitative estimation of the sign and the value of the Refractive Index Change in a particular regime of device fabrication
- Quality fabrication requires improvement in control and optimized design approach
- Future studies for high-speed fabrication regimes

Thank You

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