IOCN 2020 2nd International Online-Conference on Nanomaterials 15–30 NOVEMBER 2020 | ONLINE

# Waveguides in nanoporous glass for optofluidic purposes

ITMO UNIVERSITY

OUR LABORATORY RESEARCH GATE


Zhong Lijing[1,2] , Zakoldaev R.A.[1,*]

1 - ITMO University, Russia, St. Petersburg, Kronverksky Pr. 49

2 - School of Optical and Electronic Information, Huazhong University of Science & Technology, Luoyu Road 1037, Wuhan 430074, China

*e-mail: zakoldaev@gmail.com


Background

## 1. INTRODUCTION

Bulk waveguides (BWGs) in nanoporous materials are promising to be applied in photonics and sensors industries. Such light guiding components interrogate the internal conditions of nanoporous material and are able to detect chemical or physical reactions occurred inside nanopores especially with small molecules, which represent a separate class for sensing technologies [1].

Porous glass (PG) is an attractive platform for laser-induced inscription of photonics elements. Up to day, only PG-based sensors have been demonstrated to detect dangerous components from environment. However, the analysis is usually carried out by spectra investigation of the entire PG plate that limits integration perspectives [3].

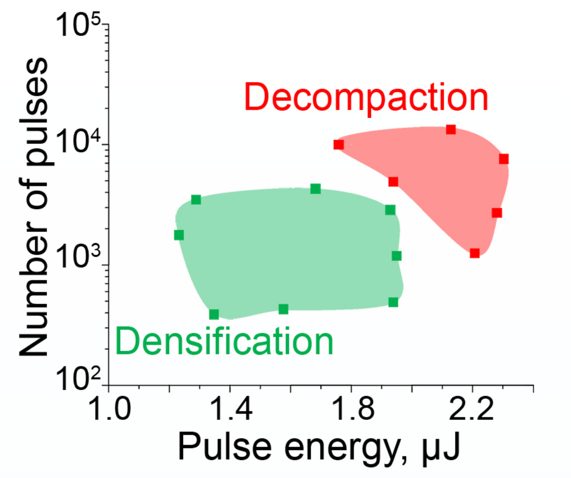
## 2. PURPOSE

**THE AIM OF THIS WORK** is the development of laser technology for BWGs with sensitive cladding inscription in PG.

- PG laser-induced densification to form BWGs
- Testing of BWGs
- Demonstration of BWGs sensor ability to detect small molecules

## 3. EXPERIMENTAL

### FS- LASER DENSIFICATION

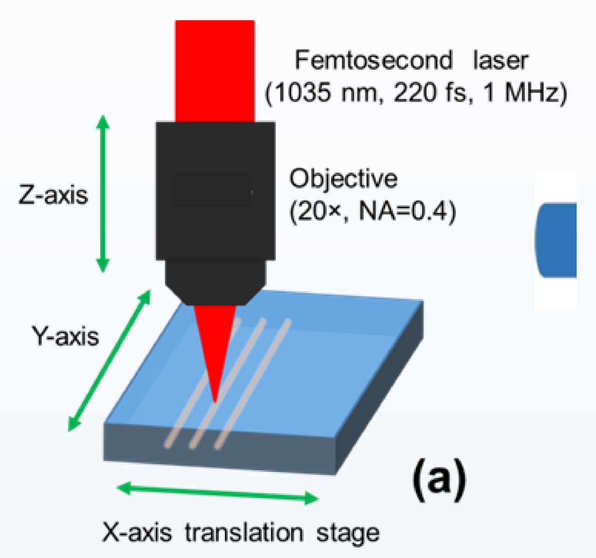



Regimes of structural modification inside the PG plate

The observed local densification of the PG network within the laser beam waist apparently proceeded via heat accumulation from multiple ultrashort laser pulses, enabling the local temperature to reach thousands of Celsius degree, inducing the local pore collapse.

In contrast, the increasing number of the laser pulses (N > 4000) and their energy ($E_p$ > 2.2 μJ) resulted in decompaction of the PG structure in the form of the dark spherical foam-like regions [4].

### BWGs FABRICATION

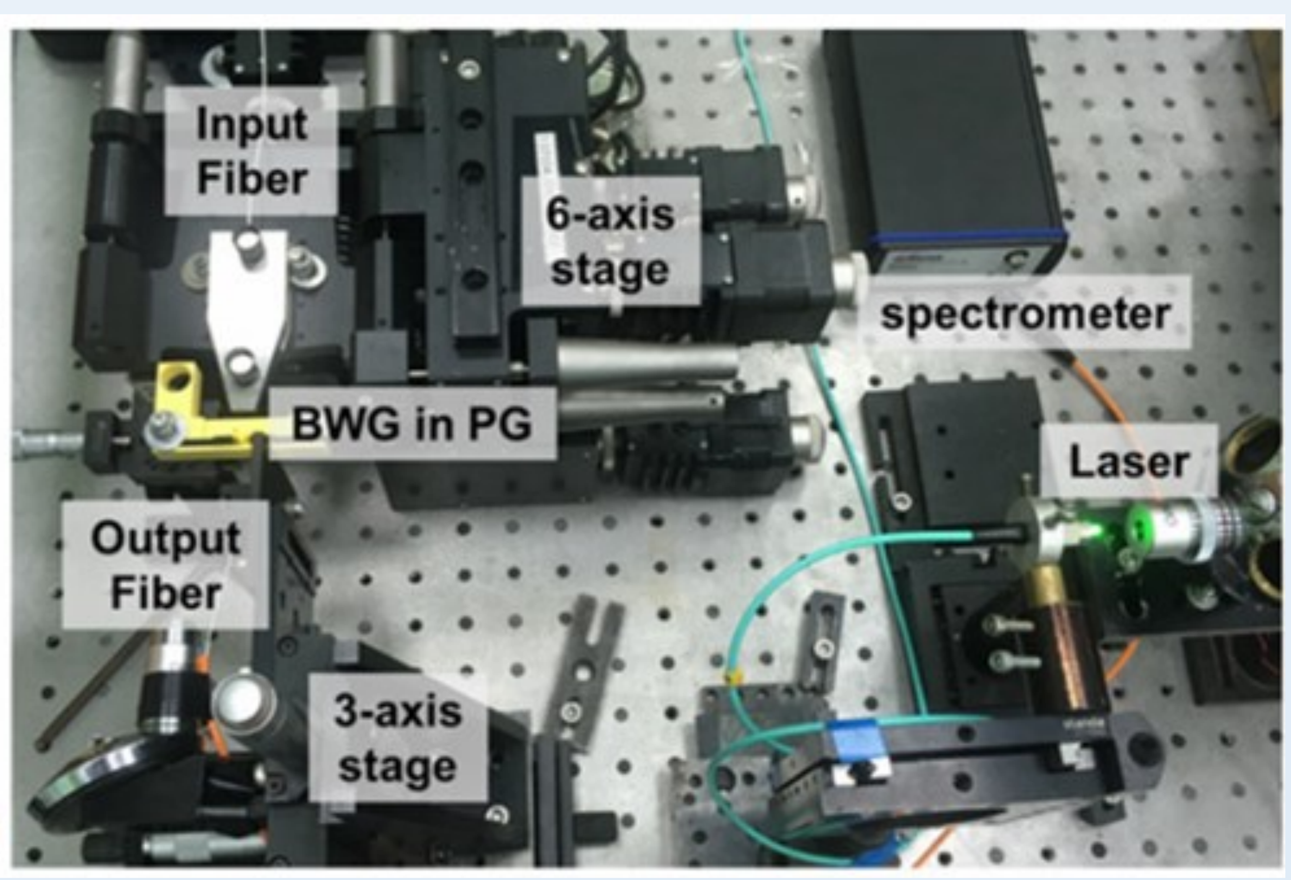



Single step approach to form BWG inside the PG plate:

a) a typical direct laser writing station based on a Yb-doped fiber laser (Avesta ANTAUS-20W-20u/1M, City Avesta, Moscow, Russia);

b) Material: PG plates with the content of 0.30 Na2O, 3.14 B2O3, 96.45 SiO2, and 0.11 Al2O3 (wt.%);

### BWGs TESTING

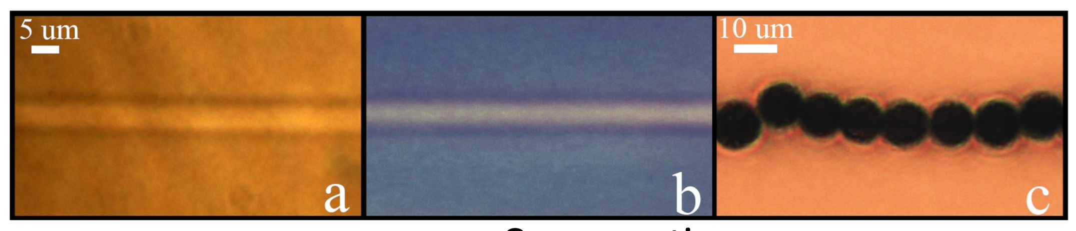



Experimental setup for testing the BWG transducer and the inserted photo of laser radiation coupling into the BWG by fiber–-sample–-fiber connection.

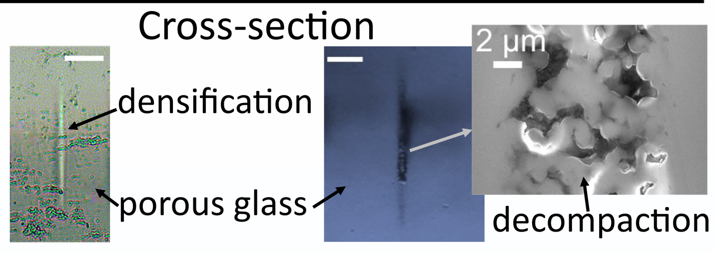
## 4. RESULTS & DISCUSSION

### DENSIFIED REGIONS—BWGs

→ Densified tracks with the increased refractive index were fabricated at Ep > 1.5 μJ and 400 – 4000 laser pulses per spot (a).



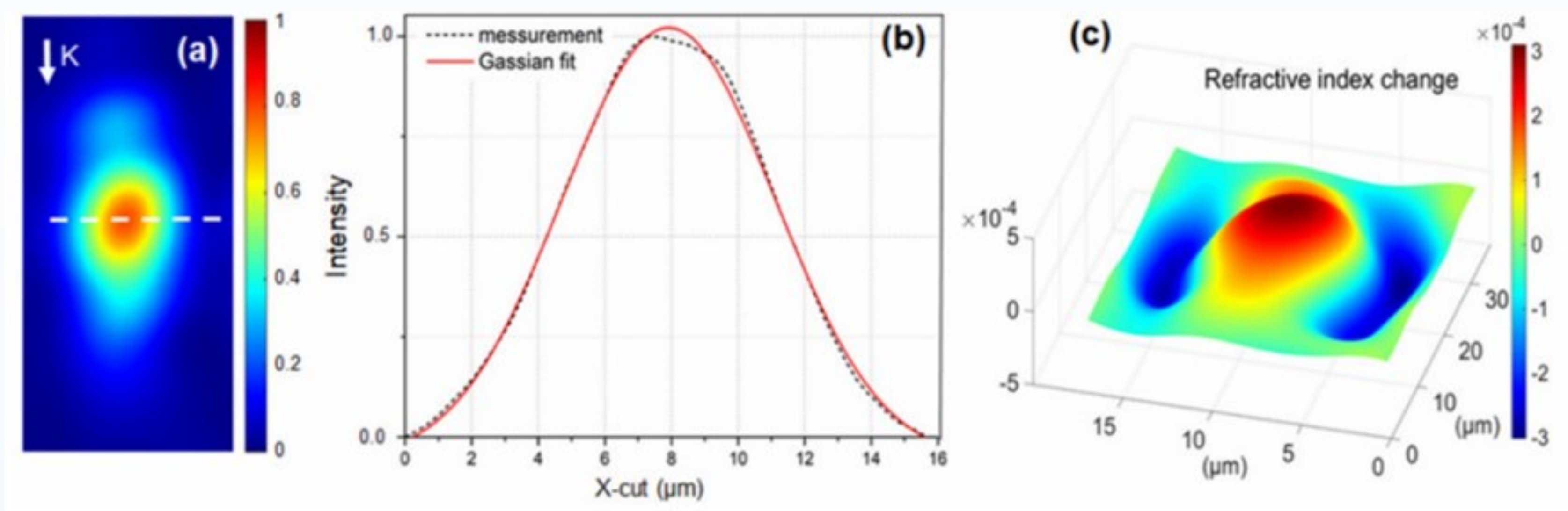

Cross-section



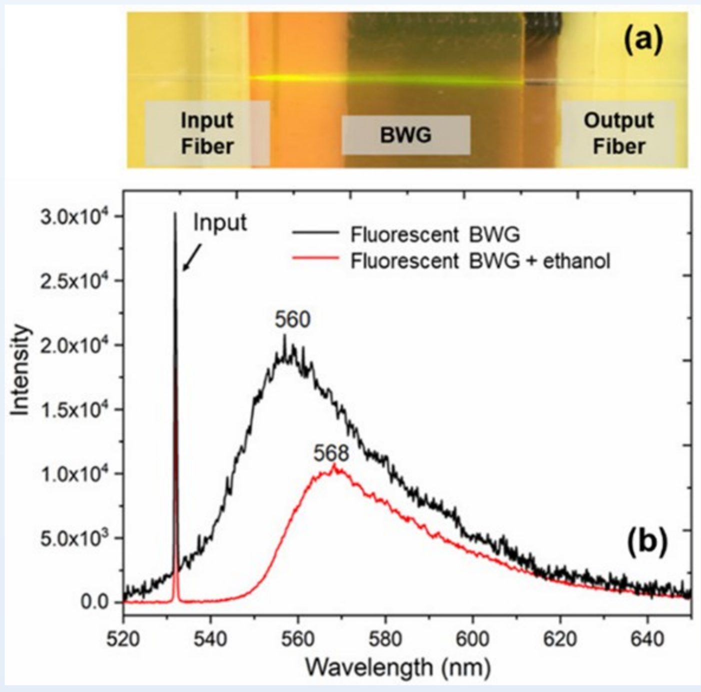

→ Photos in linearly polarized light indicates the absence of micro-cracks and residual stresses (b).

→ In comparison with the densified tracks, the lateral size of such decompaction tracks increased twofold (c).

### BWGs properties




The distribution replicates the waveguide shape—an elongated ellipse (a). The full-width-at-half-maximum (FWHM) of the mode field diameter equals 7.0 × 11.0 μm. The Gaussian function fits well with the captured X-axis distribution with divination of ~6% (b). The averaged insertion losses are ~1.2 dB/cm at a wavelength of 975 nm. Based on the mode profile, a numerical method, known as the refracted near-field method, is used to estimate the refractive index profile (Δn) of the BWG (c).



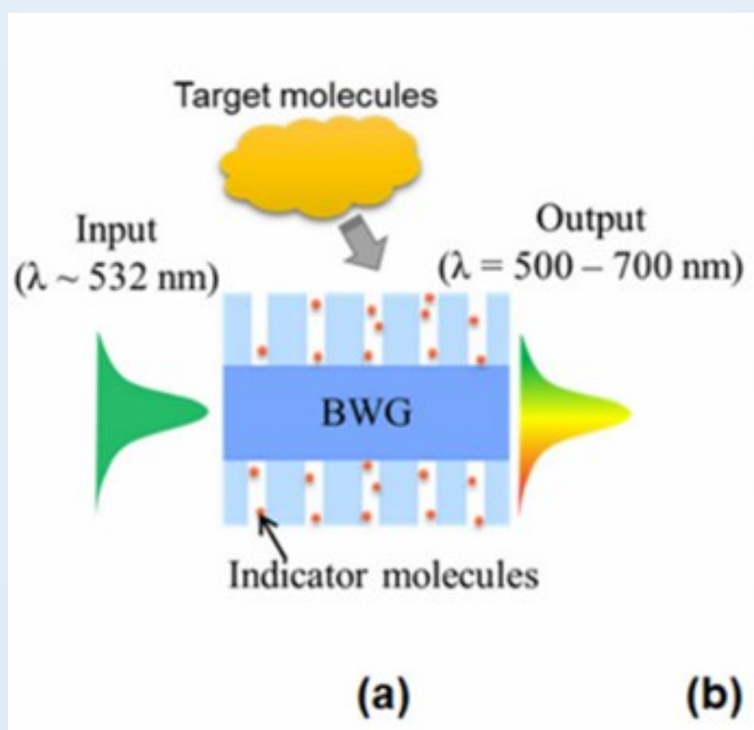

The image of laser radiation coupling into the BWG by the fiber–sample–fiber connection (a). The spectra curves of laser radiation transmitted through the BWG (b): black curve corresponds to the signal captured from the BWG in PG impregnated with rhodamine 6G and dried in the furnace (100 °C, 15 min), while the red curve demonstrates the same BWG after ethanol molecules (100%) captured by the nanoporous framework. Input radiation is 531.7 nm of the diode laser with power ~1.5 mW.

### Sensing of small molecules

Concept:

a) BWGs captures the indicator by cladding and is sensitive to changes happened in the nanoporous framework;

b) For example, 532 nm laser radiation excites the indicator molecules generating fluorescence in the range of 500–700 nm, which can be registered at the waveguide output.. The concentration of the captured ethanol molecules affects the shift and intensity of the fluorescence peak.




## 5. CONCLUSION

In this study, we have designed, fabricated, and tested the novel configuration of a PG-based sensor. Specifically, we inscribed an optical micro-sized channel—a BWG—in PG, which functions as the primary transducer of the sensor interrogating the internal conditions of the nanoporous material, and detects the chemical reactions occurring inside nanopores. The transducer showed the principal ability to detect target small molecules, such as ethanol, which were deposited on the PG surface. The detection threshold of volume concentration is equal to 1%.


*The study is funded by the grant of Russian Science Foundation (project № 20-71-10103).*