Microstructured fibers and fiber based microprobes for optofluidic applications:

research activities in ITME & contribution to COST MP1205

Ryszard Buczynski
Dep. of Glass, Institute of Electronic Materials Technology, Warsaw, Poland

www.itme.edu.pl
Department of Glass, Institute of Electronic Materials Technology

Department of Glass (ITME)
R. Buczyński (UW/ITME) – design, characterization, head of research
R. Stępień (ITME) – head of department, glass synthesis
M. Kimczak (FNP TEAM) – design, characterization,
D. Pysz (ITME) – researcher development of fiber optics
I. Kujawa (ITME) – researcher, development of fiber optics
J. Cimek (UW/ITME) – PhD student
B. Siwicki (UW/ITME) – PhD student
G. Stepniewski (UW/ITME) – PhD student
Technical and technology support staff – 6 members

www.itme.edu.pl
Main activity – development of photonic crystal fibers
Supercontinuum generation in photonic crystal fibers

[Graphene mode-locked seed]

[Chirped Pulse Amplification (CPA)]
- Pulse stretcher
- Fiber amplifiers
- Pulse compressor

[Optical spectrum analyzer]

[Supercontinuum generation]

[Normalised Intensity vs Wavelength graph]

[Photonic Crystal Fiber]

[Graph showing the supercontinuum generation process]

www.itme.edu.pl
Use of fiber optics technology for development of nano-size elements

Drawing of preform elements (rods, capillaries)

Assembly of preform from basic capillaries

Subpreform drawing

Integration with tube

Fiber drawing

400 nm diameter

100 nm diameter

All-dielectric volumetric photonic crystal 2D

GRIN elliptical lens

Metal-dielectric structure d=0.8-2 µm

Λ= 5.1 µm

D. Pysz et al., 2004.

Metal-dielectric d=5 µm

Microhole fiber structures

460 nm diameter

www.itme.edu.pl
Glass and polymer synthesis facility

Glass development and modification
- electrical resistance furnaces for optical quality glass melting (up to 2.5 kg.),
- Furnace for heat and computer controlled cooling of melt and formed glass (glass relaxation),
- Induction furnace with platinum pot for glass melting in large volumes
- Polishing equipment
Heavy metal oxide glass for midIR transmission with good rheological properties

Spectral transmission of the glasses for a 2 mm sample

Curves of differential scanning calorimetry of the considered glasses
Fiber drawing facility – Glass Laboratory (ITME)

Fiber development
- Setup for glass tubes development
- „Small towers” - setups for glass tubes shaping and calibration
- Three fiber drawing towers for microtubes, microrods and fibers development
- Double fiber furnace for tube development based on bulky glass.
- Clean room (Class 100) integrated with fiber drawing tower

www.itme.edu.pl
Measurement equipment – Microoptics Laboratory (UW)

- Femtosecond oscillator Ti:Sapphire tuneable 780-850 nm,
- Nanosecond laser 1064 nm
- Tuneable fiber lasers 1420-1560 nm,
- Superluminescent Er based fiber source, and semiconductor lasers 830-860 nm, 1300-1350 nm, 1470-1580 nm,
- Non-contact surface profiler - white-light interferometer VECCO WYKO NT2200,
- Beam analyser 2D,
- Optical spectrum analyser, spectrometers, - 600–1700 nm, 400-1000 nm
- Setups for phase and group refractive index measurements,
- Laser sources (Ar laser, He-Ne, semiconductor lasers – 1300 nm, 1550 nm, 850 nm, oraz Nd:YVO4 Verdi 5 W).
- Mid IR detector with amplifier 2-10 µm of Vigo Systems
Integration of electrodes with optical fiber

Glass fiber

Metal wire

Air holes
PCF infiltrated with liquid crystals

Collaboration with Faculty of Physics, Warsaw University of Technology, Poland

Poincare sphere traces recorded for two different PLCFs described in the paper showing electrically tunable retardation (a) and electrically tunable polarization dependent losses

PCF-18 Schott F2 glass
n= 1.62; d=5 µm, Λ=8.2 µm

PCF-14 PBG08 glass
n= 1.95 d= 5.2 µm, Λ= 7.6 µm

ERTMAN et al.: INDEX GUIDING PHOTONIC LIQUID CRYSTAL FIBERS, JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 30, NO. 8, APRIL 15, 2012

www.itme.edu.pl
Nanostructured microoptical components for fiber microprobes

- GRIN spherical, aspherical, elliptical lens
- GRIN axicons
- Polarization sensitive artificial materials
- DOE – diffractive optical elements

www.itme.edu.pl
Concept of nanostructured microoptical elements

- Focus on dielectric materials only
- Use Maxwell-Garnett concept to fabricate nanostructured material with arbitrary refractive index distribution in XY plane.

For elements with a statistically distribute refractive index distribution and feature sizes much smaller then the incident wavelength it is possible to calculate an effective index distribution based on the Maxwell Garnett mixing formula:

\[
eff = \langle \varepsilon \rangle - f(\varepsilon_1 - \langle \varepsilon \rangle) \frac{\varepsilon_1 - \langle \varepsilon \rangle}{3 \langle \varepsilon \rangle} \approx \langle \varepsilon \rangle
\]

- We have developed algorithm to replace continuous refractive index profile with two discrete materials

Distribution of the two different glasses  
Effective index calculated with the equation below  
Ideal index distribution of a graded index lens
Development of nanostructured GRIN microcomponents

Initial preform

Intermediate preform

Final component

Technological process

60mm

30mm

100µm

www.itme.edu.pl
Results of simulation of ideal continuous microlens with a diameter of 40 µm (a), focal length is 155.8 µm (b), diameter of the beam at focus 5 µm (c)

Results of simulation of nanostructured microlens with a diameter of 40 µm (a), focal length is 155.8 µm (b), diameter of the beam at focus 5 µm (c)
Effective parameters of nGRIN lenses

nGRIN lens LEL3
size: 190um x 125um
Quater pitch: Z_{RX}=445um  Z_{RY}=293 um
Effective focal length for ZR:
\[ f_{\text{effX}}=175 \text{ um} \quad f_{\text{effY}}=115 \text{ um} \]
For lens thickness 260 um
Fractional Pitch \( t_x=0.15 \quad t_y=0.22 \)
Effective focal length \( f_{\text{effX}}=220 \text{ um} \quad f_{\text{effY}}=116 \text{ um} \)
Working distance \( d_x=134 \text{ um} \quad d_y=20 \text{ um} \)

nGRIN lens LEL5
size: 118um x 78um
Quater pitch: Z_{RX}=276um  Z_{RY}=182 um
Effective focal length for ZR:
\[ f_{\text{effX}}=108 \text{ um} \quad f_{\text{effY}}=72 \text{ um} \]
For lens thickness 260 um
Fractional Pitch \( t_x=0.235 \quad t_y=0.356 \)
Effective focal length \( f_{\text{effX}}=109 \text{ um} \quad f_{\text{effY}}=91 \text{ um} \)
Working distance \( d_x=10 \text{ um} \quad d_y=-56 \text{ um} \)
Development of optical tweezers using nanostructured approach

- SM fiber with nanostructured components mounted at the end of the fiber (glue) – currently under test

- Axicon structure – under development with ALBA Photonics

- Spherical and elliptical lens – developed

- DOE - developed
Our goals in COST MP1205

- Development of fiber based optical tweezers with complex functionality – axicon, multifocus, spot array generator

- Experimental study of integration electrodes with hollow channel or with PCF

- Nonlinear phenomena in liquid infiltrated photonic crystal fibers

Activity in WP1 or WP3?

www.itme.edu.pl