Micro- and nano-structures in optical fibres

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Outlines

1. A brief introduction of our Optoelectronics Research Centre (ORC)

2. Microstructured optical fibre (MOF) technology & new opportunities from MOF-tech

3. Using MOF technology for nonlinear fibre optics in the current FP7-funded project, the PHASORS
1. Brief introduction of ORC

Largest photonics group in UK (160 staff / PhD students, 65 labs)

New glass and crystal materials, processing and device fabrication, especially in planar and fibre waveguides

Microstructured fibres and crystals, femtosecond laser science and direct write in waveguides

A clear focus on the market needs of cost reduction, integration and increased functionality

Leveraging the vast investment in telecoms photonics into other markets
Current 'Flexy-research'...

Extruded Bragg fibre

Swiss roll preform

Si is transparent at telecoms wavelengths

Silicon-filled waveguides

Nonlinear glass preform

Ribbon fibre lasers

Nonlinear optics in microstructures

100 μm

Micro knot-resonator 60nm nanofibre

Solid holey fibres

Helical core fibre

Fibre laser cutting

Micro knot-resonator 60nm nanofibre

Swiss roll preform

Solid holey fibres

Helical core fibre

Nonlinear optics in microstructures
2.1 Microstructured optical fibre (MOF) technology

MOF technology: i.e., engineering the fibre cladding with
(1) fine structure at the optical-wavelength scale
   (i.e., hundreds nanometers to tens of microns);
(2) high index-contrast between the structured regions and the background.

Novel optical performance:
(1) enhanced nonlinearity due to high index-contrast;
(2) tailorable dispersion profile with broad bandwidth;
(3) endless single-mode guidance;
(4) photonic bandgap guidance;
   etc

\[ \gamma = \frac{2\pi n_2}{\lambda A_{\text{eff}}} \]
2.2 New opportunities from MOF-tech

a. Using fibre itself,
   e.g., fibre sensor based on evanescent field, etc

b. Using holes inside fibre as the carrier filling various materials
   (gas, liquid, solid) for novel fibre with multiple functions
   (photonic function + others), as long as we can fill them into
   the small holes.

etc
* Evanescent field largely expands out of the core when the core is with micron or submicron size.
* Chemical information of liquid can be detected by immersing the core/nanowire inside the liquid.
Example 2. gas/liquid sensing using photonic bandgap fibre

Holes drilled by femtosecond laser

sensing acetylene

Courtesy of Dr. Petrovich, ORC
Example 3. solid (single-crystal silicon) filled holey fibre

growing single-crystal silicon wire in MOF by fluid-liquid-solid (FLS) approach, for fibres with multiple opto-electronic functions

Co-work of Prof. Badding (Penn. State University) and Dr. Sazio (ORC), Adv. Mater. 2008
One of our current interests: growing piezoelectric nanowires in microstructured optical fibre for energy scavenging.


Key selling point: converting very small mechanical energy to electric energy (concept of nanogenerator)

We are going to do it on MOF, to have the extra function of energy-scavenging in optical fibre.

And, ZnO is similar to GaN, a good semiconductor material (maybe a fibre LED?)

Join us?

This is not optical fibre.
3. PHASORS project
http://www.eu-phasors.eu/


Partners:
1. ORC, University of Southampton (UK): Coordinator, (working on soft-glass MOF and fibre device);
2. OFS (DEN);
3. Chalmers University (SWE);
4. Onefive GmbH (CH);
5. National and Kapodestrian, University of Athens (GRE);
6. University of Cork (IRE);
7. Eblana Photonics (IRE)

Project target:
developing fibre-based phase sensitive amplifier with lower noise figure than the existing optical amplifiers, to improve the transmission capacity and energy efficiency of optical fibre communication networks.
Two new key components in PHASORS

1. High power laser source with narrow width (i.e., single-frequency)
2. Nonlinear fibre gain medium:

| high nonlinearity $\gamma$: |
| low loss $\alpha$ at 1.55$\mu$m: |
| near zero dispersion (D) at 1.55$\mu$m: |
| near zero dispersion slope (DS) at 1.55$\mu$m: |

<table>
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<th>Commercial silica dispersion flattening fibre (DFF) (by OFS)</th>
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<tr>
<td>$\gamma$</td>
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Given fibre with D=0 and DS =0, PHASORS requires $P \times \gamma \times L_{eff} = 1 - 10$

Note that with 1W pump, silica DFF need to be 100m to 1km long.)

$P$: power, $L_{eff} = \frac{1 - \exp(-\alpha L)}{\alpha}$, L: fibre length
Silica fibre is so good. Why still need soft-glass fibre?

Relation of refractive index \( n \) and nonlinear refractive index \( n_2 \) of various glasses

![Graph showing the relationship between refractive index (n) and nonlinear refractive index (n2) for various glasses.]

\[ \gamma = \frac{2\pi}{\lambda} \cdot \frac{n_2}{A_{\text{eff}}} \]

Soft glass with high \( n \) and \( n_2 \) provides \( \gamma \) 100-10000 higher than commercial silica fibre SMF-28 (\( \gamma = 1\text{W}^{-1}\text{km}^{-1} \)).

Benefit: short-length (1-10m length) fibre-based compact device. But low loss 0.5-1.0dB/m required.

- Silica: \( n_2 \approx 2.5 \times 10^{-20} \text{m}^2/\text{W} \)
- SF57: \( n_2 = 41 \times 10^{-20} \text{m}^2/\text{W} \)
- SF6: \( n_2 = 22 \times 10^{-20} \text{m}^2/\text{W} \)
Fibre #1: single-material holey fibre, using Schott SF57 glass ($n=1.80$, $n_2: 41 \times 10^{-20} \text{ m}^2/\text{W}$)

Optimum design: $
\Lambda = 1.36 \mu\text{m},
\text{d}=620\text{nm},
\text{d/}\Lambda=0.455$

At 1550nm,
$D=0$
$DS=0$
$\gamma=470\text{W}^{-1}\text{km}^{-1}$

Modelling work by Dr. Poletti, ORC
Fibre #1: holey fibre, using Schott SF57 glass (n=1.80)

Microstructure parameters:
- average hole spacing $\Lambda=1.60\mu m$,
- hole dia on the first ring: $d_1=560nm$,
- $D=17ps/nm/km$,
- $DS=0.10ps/nm^2/km$,
- $\alpha=3.0dB/m$,
- $\gamma=270W^{-1}/km^{-1}$

$P \times \gamma \times L_{\text{eff}}=0.3$ (optimum design gives 1.7 (given 1.0dB/m loss))
Fibre #2: All-solid MOF, using Schott SF6 glass (n=1.76) & LLF1 (n=1.53)

Microstructure parameters:

- **core dia**: 3.7 μm
- **1st LLF1 ring thickness**: \( d_1 = 1.1 \mu m \)
- **1st SF6 ring thickness**: \( \Lambda_1 - d_1 = 400 \text{nm} \)
- **2nd LLF1 ring thickness**: \( d_2 = 600 \text{nm} \)
- **2nd SF6 ring thickness**: \( \Lambda_2 - d_2 = 260 \text{nm} \)

- **\( D = 12.5 \text{ps/nm/km} \)**
- **\( DS = 0.15 \text{ps/nm}^2/\text{km} \)**
- **\( \gamma = 120 \text{W}^{-1}\text{km}^{-1} \)**
- **\( \alpha = 0.8 \text{dB/m} \)**

\[ P \times \gamma \times L_{\text{eff}} = 0.6 \text{ (optimum design gives 3.5 given 0.5dB/m loss)} \]
Summary

1. Microstructured optical fibre (MOF) technology & new opportunities from MOF-tech
2. Our progress on using MOF technology for nonlinear fibre optics in the current FP7-funded project PHASORS.

Thank you!