Phase Sensitive Amplifier Systems and Optical Regenerators and their applications

Micro- and nano-structures in optical fibres

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13th February 2009 Concentration Meeting - Nano-Photonics, Florence

University of Southampton Optoelectronics Research Centre

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

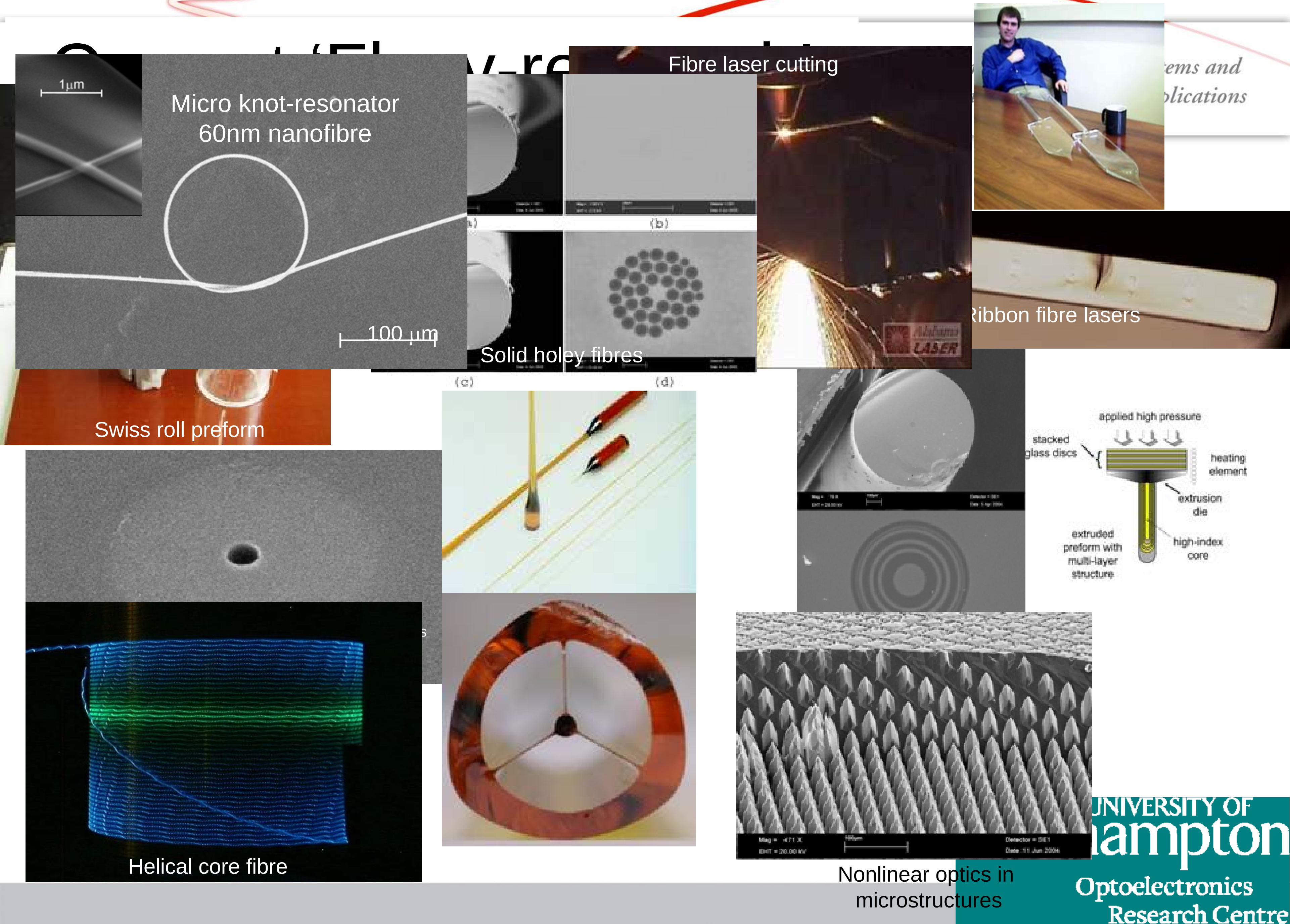
Largest photonics group in UK (160 staff / PhD students, 65 labs)

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

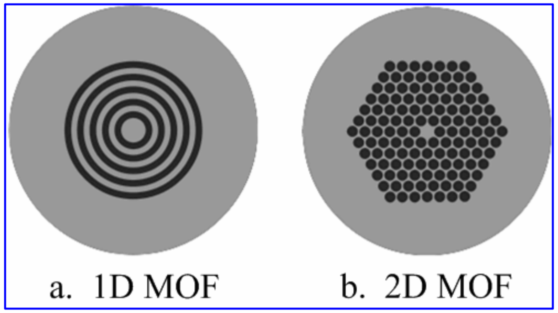
A clear focus on the market needs of cost reduction, integration and increased functionality

Leveraging the vast investment in telecoms photonics into other markets



Micro knot-resonator
60nm nanofibre
1µm
100 µm
Fibre laser cutting
Ribbon fibre lasers
Solid holey fibres
(b)
(c)
(d)
Swiss roll preform
applied high pressure
stacked glass discs
heating element
extrusion die
extruded preform with multi-layer structure
high-index core
Helical core fibre
Nonlinear optics in microstructures
Optoelectronics Research Centre

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.

$$\gamma = \frac{2\pi}{\lambda} \cdot \frac{n_2}{A_{eff}}$$

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

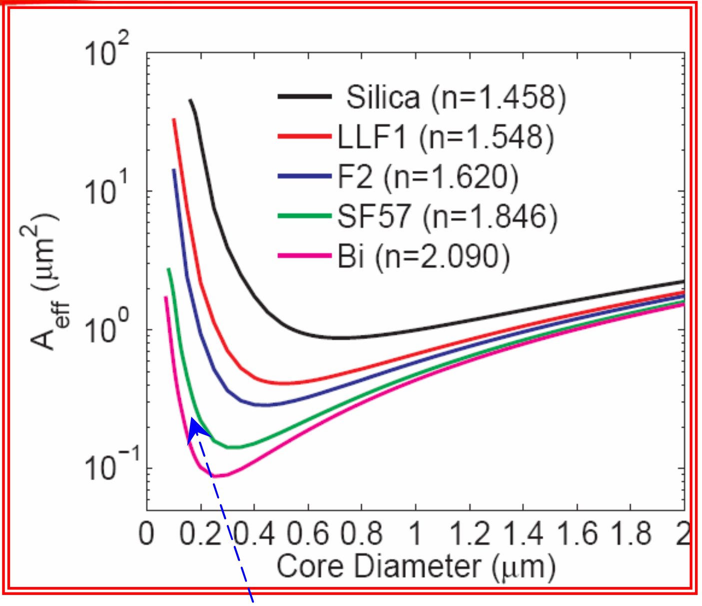
2.2 New opportunities from MOF-tech

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

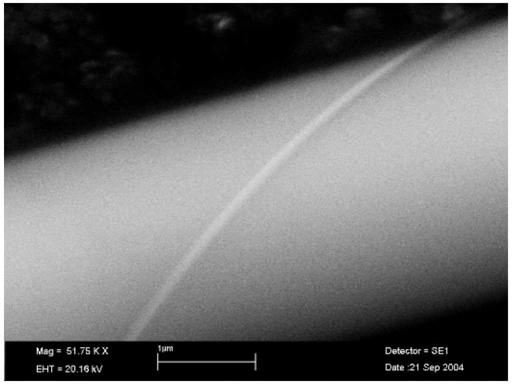
b. Using holes inside fibre as the carrier filling various materials (gas, liquid, solid) for novel fibre with multiple functions (photonic function + others), as long as we can fill them into the small holes.

etc

Example 1. fibre sensor using enhanced evanescent field



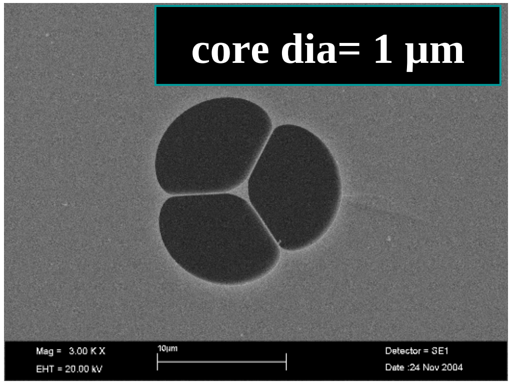
Nanowires



Silica, dia: ~60nm

Courtesy of Dr. Brambilla, ORC

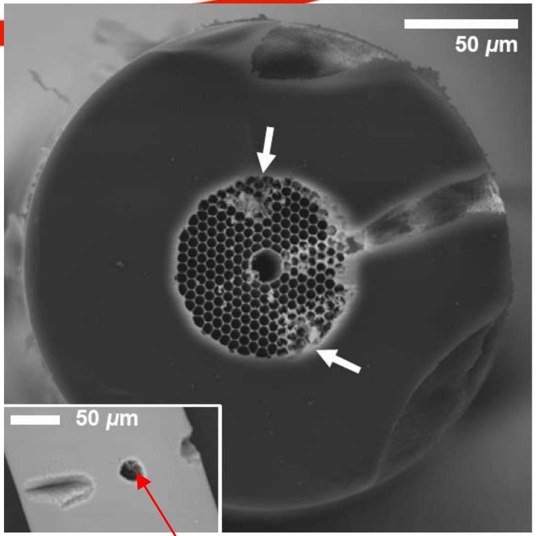
Holey fibre with an air-suspending core (Schott SF57 glass), by ORC

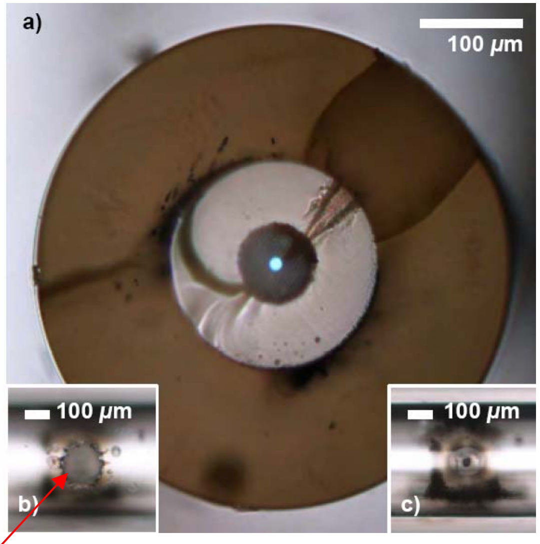


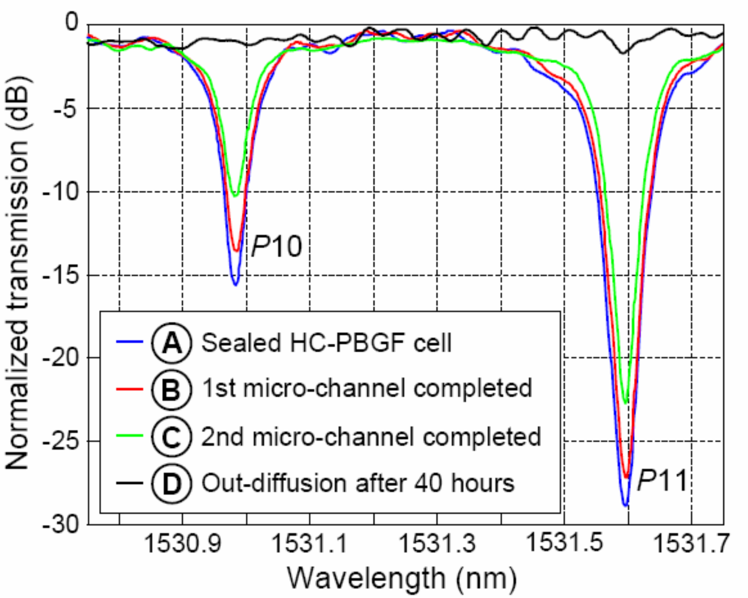
* Evanescent field largely expands out of the core when the core is with micron or submicron size.

* Chemical information of liquid can be detected by immersing the core/nanowire inside the liquid.

Example 2. gas/liquid sensing using photonic bandgap fibre





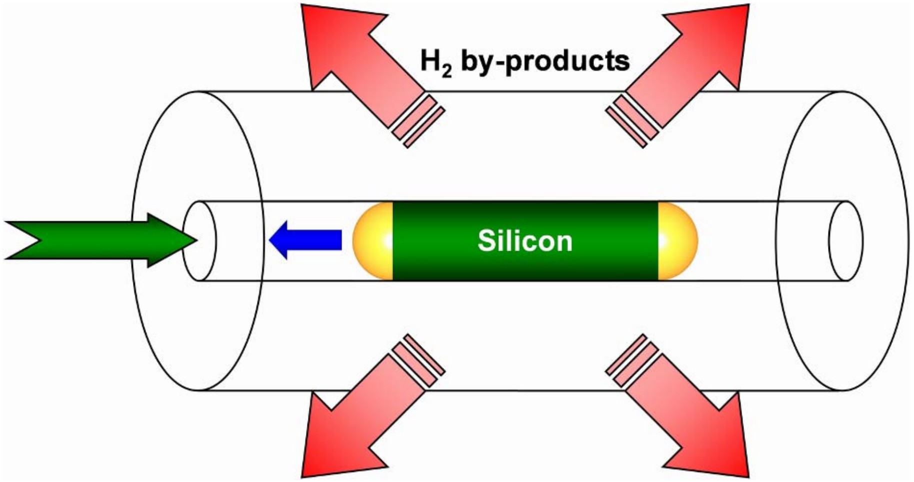


Holes drilled by femtosecond laser

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

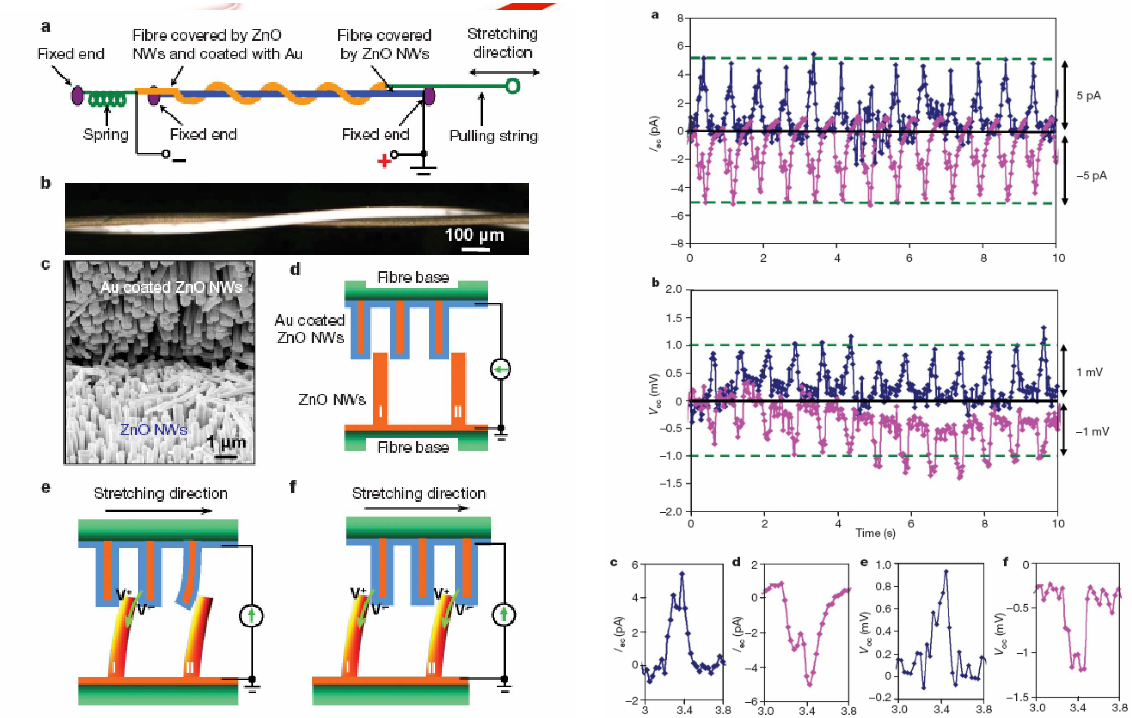
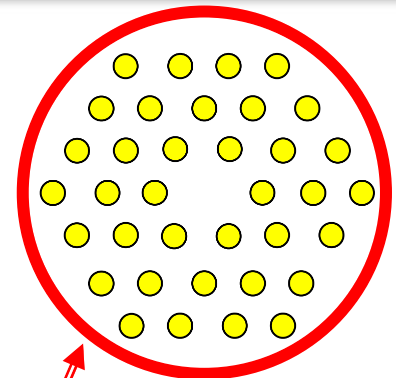


Figure 2 | Design and electricity-generating mechanism of the fibre-based nanogenerator driven by a low-frequency, external pulling force.

Growing piezoelectric ZnO nanowires on **Kevlar fibre** for energy scavenging. After Qin, et al, GIT, NATURE(2008)

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

This is not optical fibre.



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?

3. PHASORS project

http://www.eu-phasors.eu/

PHASORS: **PH**ase sensitive **A**mplifier **S**ystems and **O**ptical **R**egenerators and their application**S** **(1st Jul. 2008 – 30th June 2011)**

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 γ:
low loss α at 1.55μm:
near zero dispersion (D) at 1.55μm:
near zero dispersion slope (DS) at 1.55μm:

	Commercial silica dispersion flattening fibre (DFF) (by OFS)
γ	$11.5 W^{-1}km^{-1}$
α	1 dB/km
D	-1.0 to +1.5 ps/nm/km
DS	0± 0.01 ps/nm/km

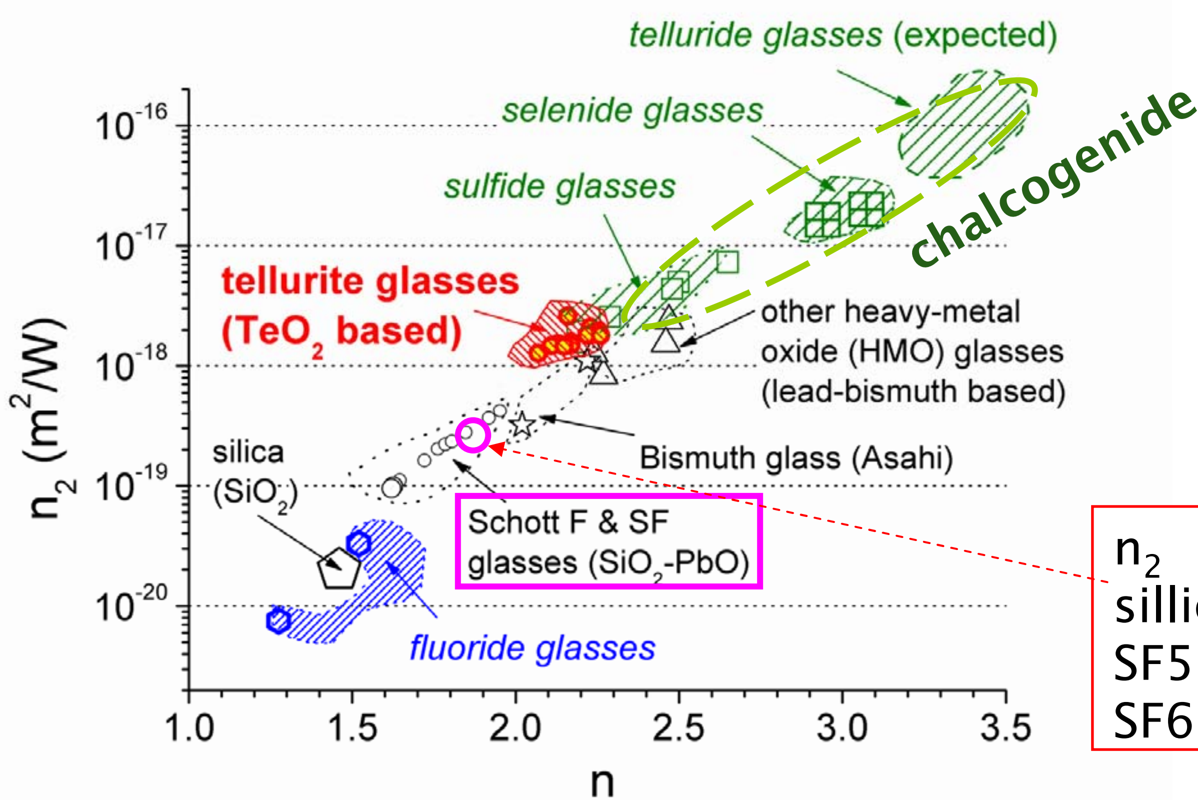
Given fibre with D=0 and DS =0, PHASORS requires $P \times \gamma \times L_{eff} = 1\text{-}10$

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

P: power, $L_{eff}=[1-\exp(-\alpha^{*}L)]/\alpha$, 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



$$\gamma = \frac{2\pi}{\lambda} \cdot \frac{n_2}{A_{eff}}$$

n_2

sillica:	2.5 $\times 10^{-20}$ m^2/W
SF57:	41 $\times 10^{-20}$ m^2/W
SF6:	22 $\times 10^{-20}$ m^2/W

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

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

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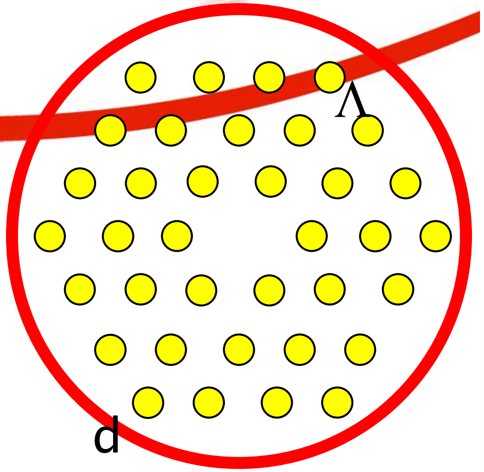
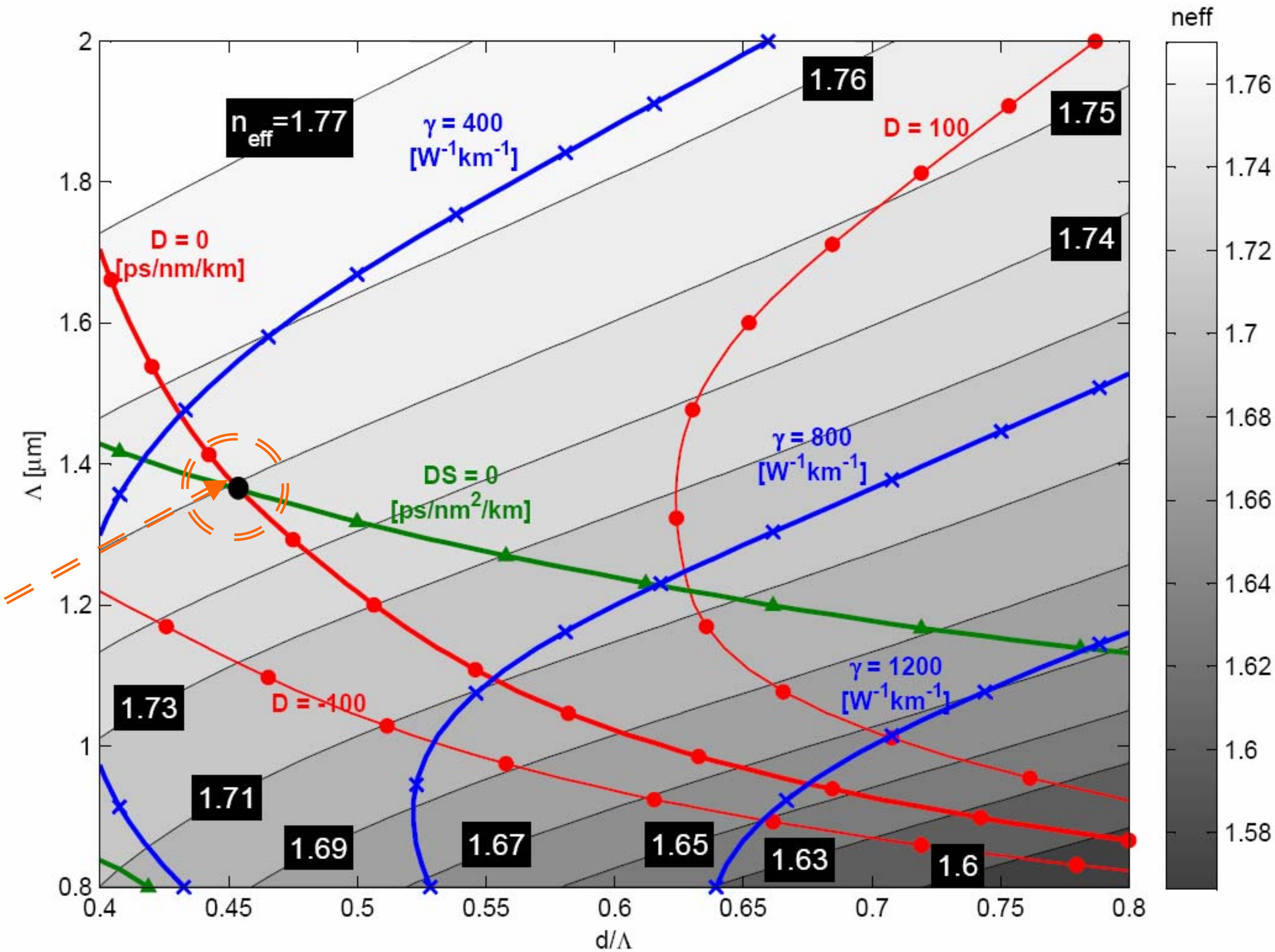
Fibre #1: single-material holey fibre, using Schott SF57 glass (n=1.80, n_2: 41 x10^{-20} m^2/W)



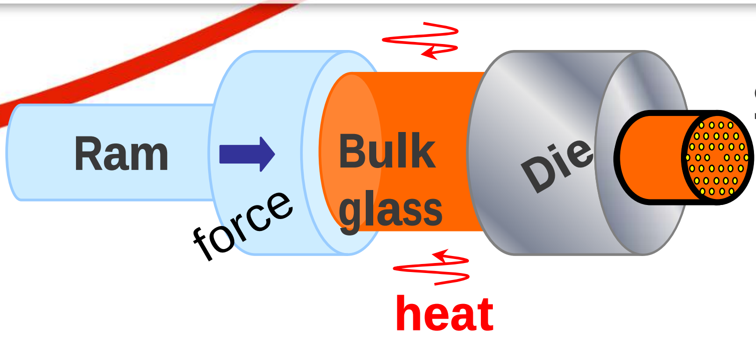
Optimum design:
Λ=1.36μm,
d=620nm,
d/Λ=0.455

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

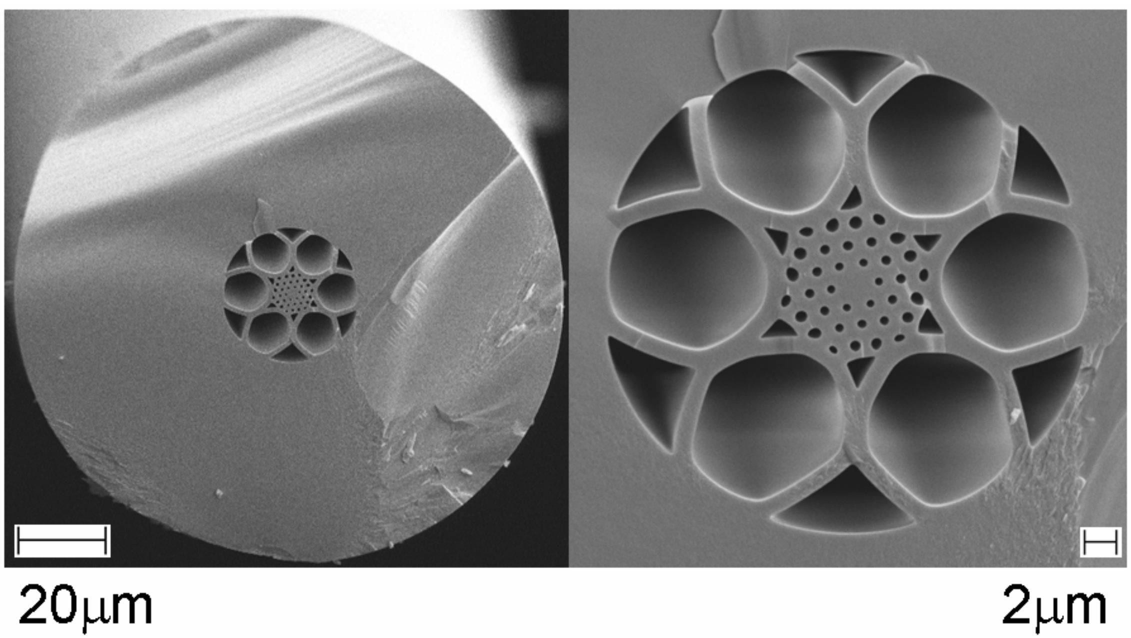


Modelling work by Dr. Poletti, ORC

Fibre #1: holey fibre, using Schott SF57 glass (n=1.80)



Extrusion



Microstructure parameters:
average hole spacing Λ=1.60µm,
hole dia on the first ring: d_1=560nm,
D=17ps/nm/km,
DS=0.10ps/nm²/km,
α=3.0dB/m,
$\gamma=270W^{-1}/km^{-1}$

P x γ x L_{eff}=0.3 (optimum design gives 1.7 (given 1.0dB/m loss)

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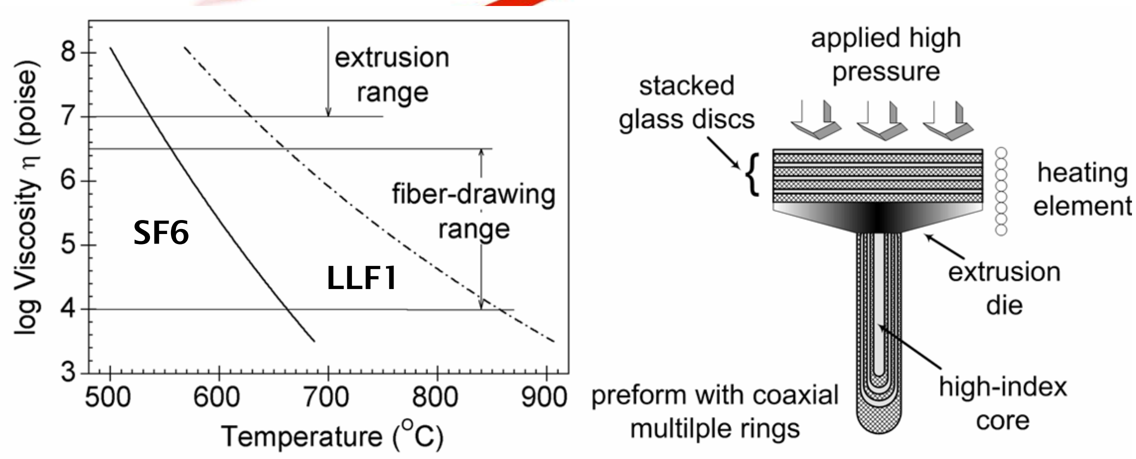
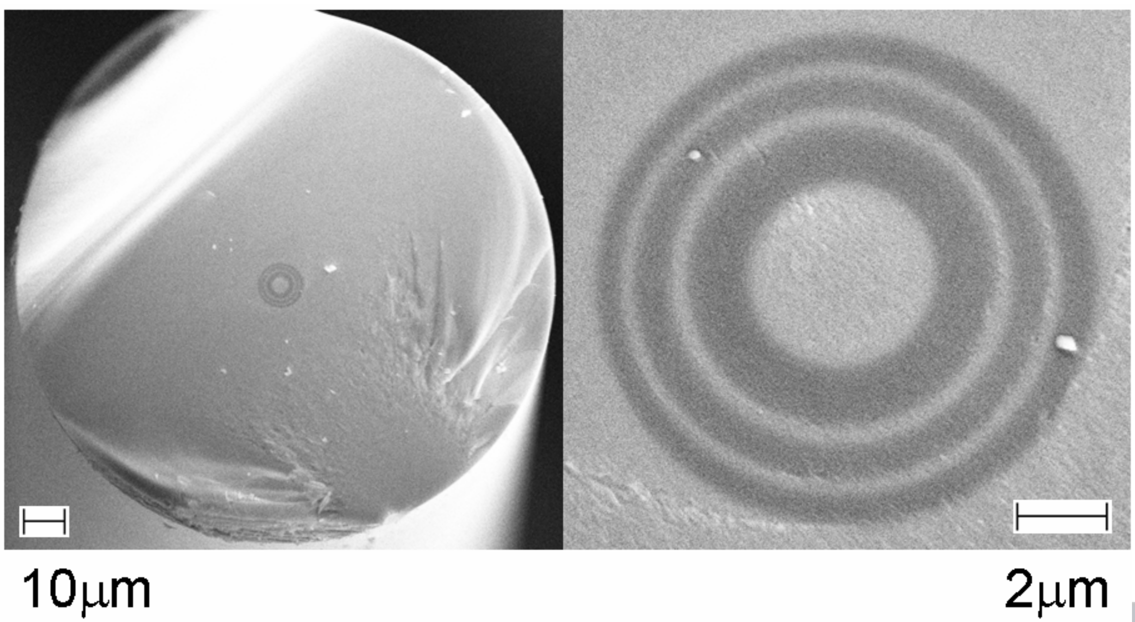
Fibre #2: All-solid MOF, using Schott SF6 glass (n=1.76) & LLF1 (n=1.53)





Microstructure parameters:

core dia: 3.7μm
1st LLF1 ring thickness d_1=1.1μm;
1st SF6 ring thickness Λ_1-d_1=400nm;
2nd LLF1 ring thickness d_2=600nm;
2nd SF6 ring thickness Λ_2-d_2=260nm;

D=12.5ps/nm/km,
DS=0.15ps/nm^2/km,
γ=120W^{-1}km^{-1},
α=0.8dB/m,

P x γ x L_{eff}=0.6 (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!