Centre for Photonics and Photonic Materials

UNIVERSITY OF BATH

High-power Acetylene Hollow Fiber Laser At 3 μm Wavelength

Fei Yu, Mengrong Xu and Jonathan C. Knight

Centre for Photonics and Photonic Materials

Department of Physics, University of Bath

Bath, BA2 7AY, UK

June 16th, 2017

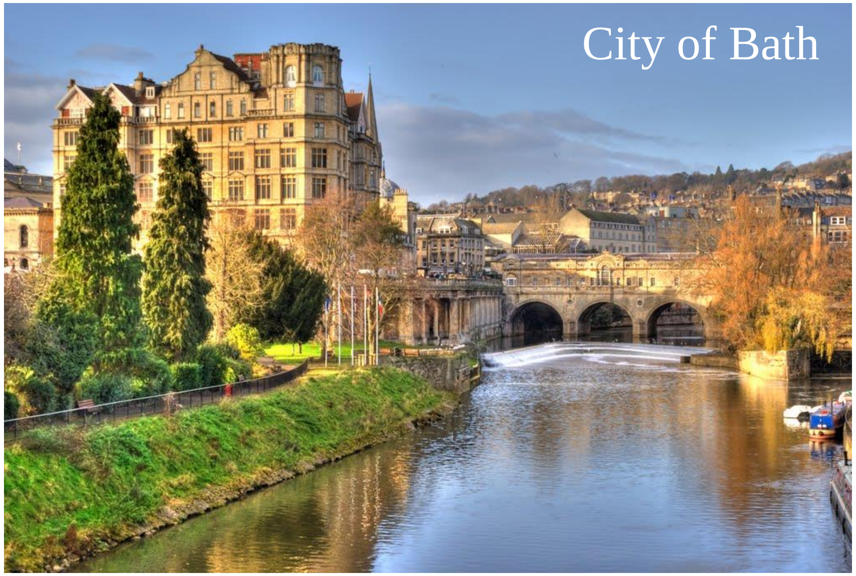
EPSRC

Engineering and Physical Sciences Research Council

Centre for Photonics and Photonic Materials

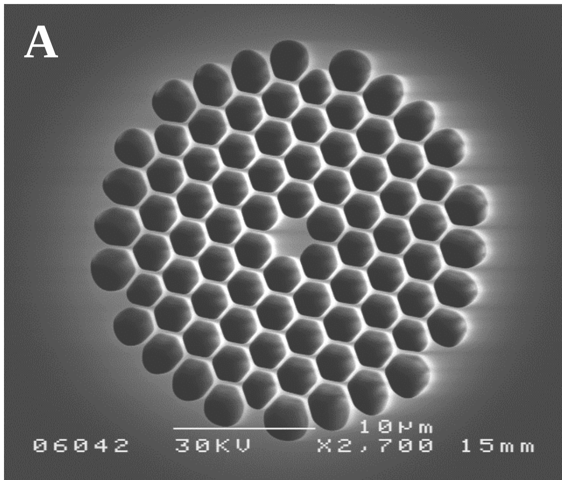
UNIVERSITY OF BATH

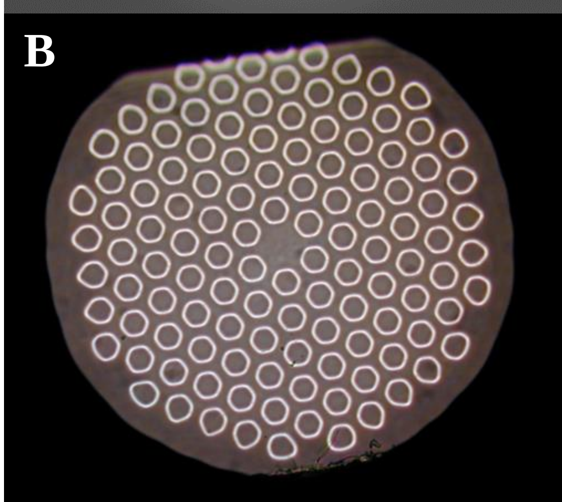
Prof. Jonathan C. Knight



Ms. Mengrong Xu

Fibre Optics in CPPM

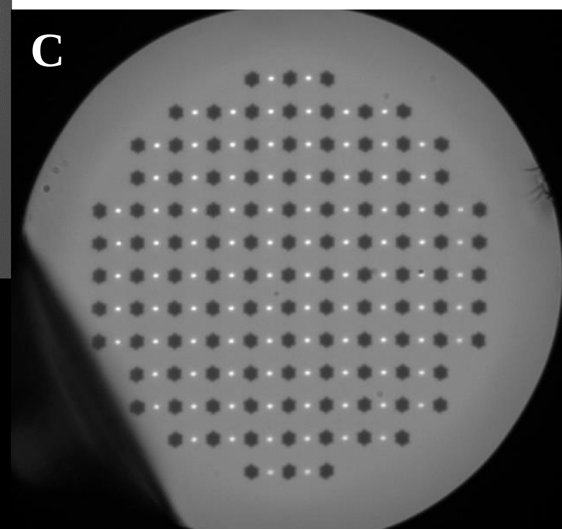




A. photonic crystal fibre

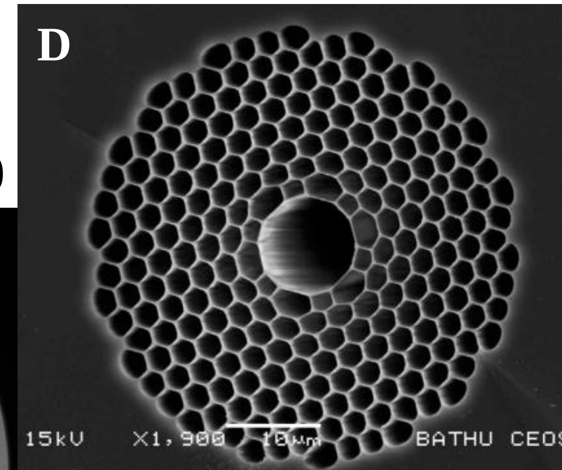
B. all solid bandgap fibre

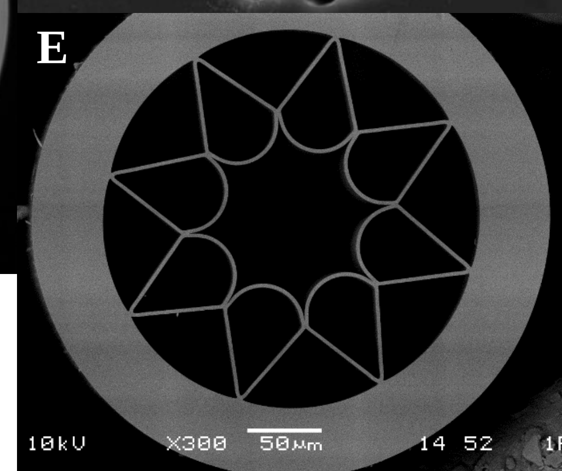
C. multicore fibre (98 cores)



D. hollow core phtonic bandgap fibre

E. hollow core negative curvature fibre





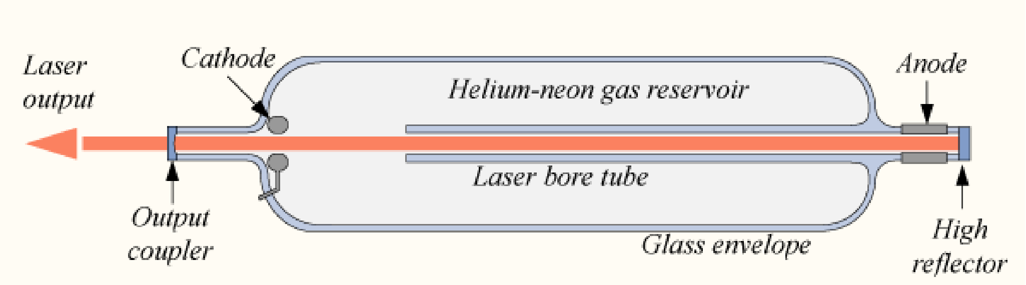
Outline

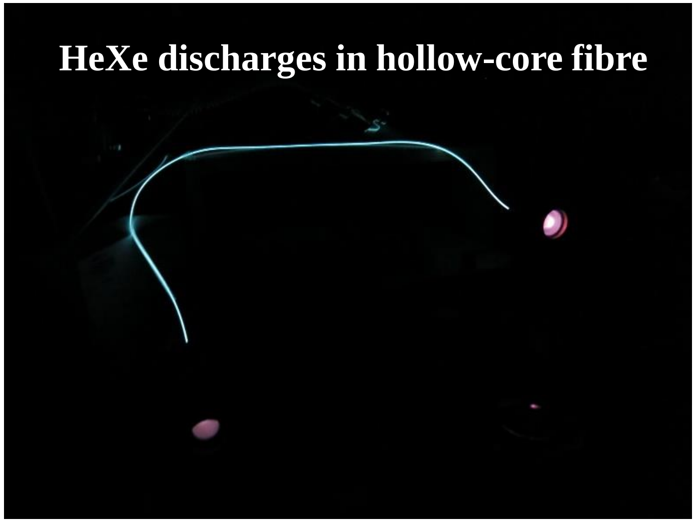
1. Introduction to waveguide gas laser
2. Low-loss anti-resonant hollow-core fibre (AR-HCF)
3. High-power acetylene fibre laser at 3 μm
4. Summary

1. Waveguide gas lasers

- ***Gain medium***
  - Atom/molecule gas
  - Metal vapour
- ***Pump scheme***
  - Electric discharge
  - Optical pump
- ***Advantages***
  - Rich laser lines
  - Free of host material
  - Ideal for high power lasing
- ***Disadvantages***
  - Waveguide loss
  - Low pump efficiency

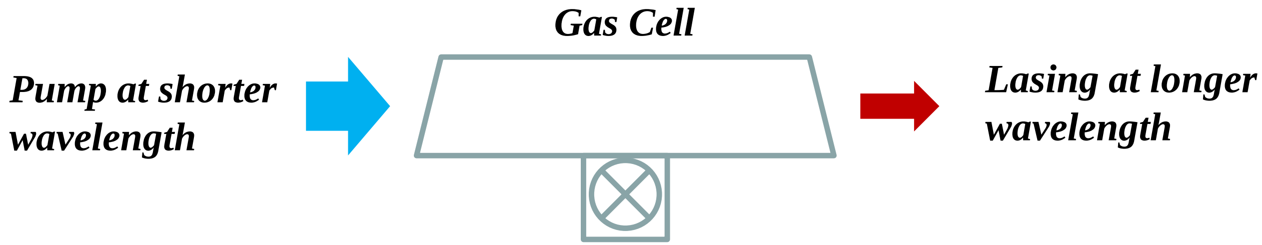
† *Image from Wikipedia*





by courtesy of Adrian Love

Optical-pump scheme for waveguide gas laser



✓ ***Most efficient***
✓ ***Simplest***

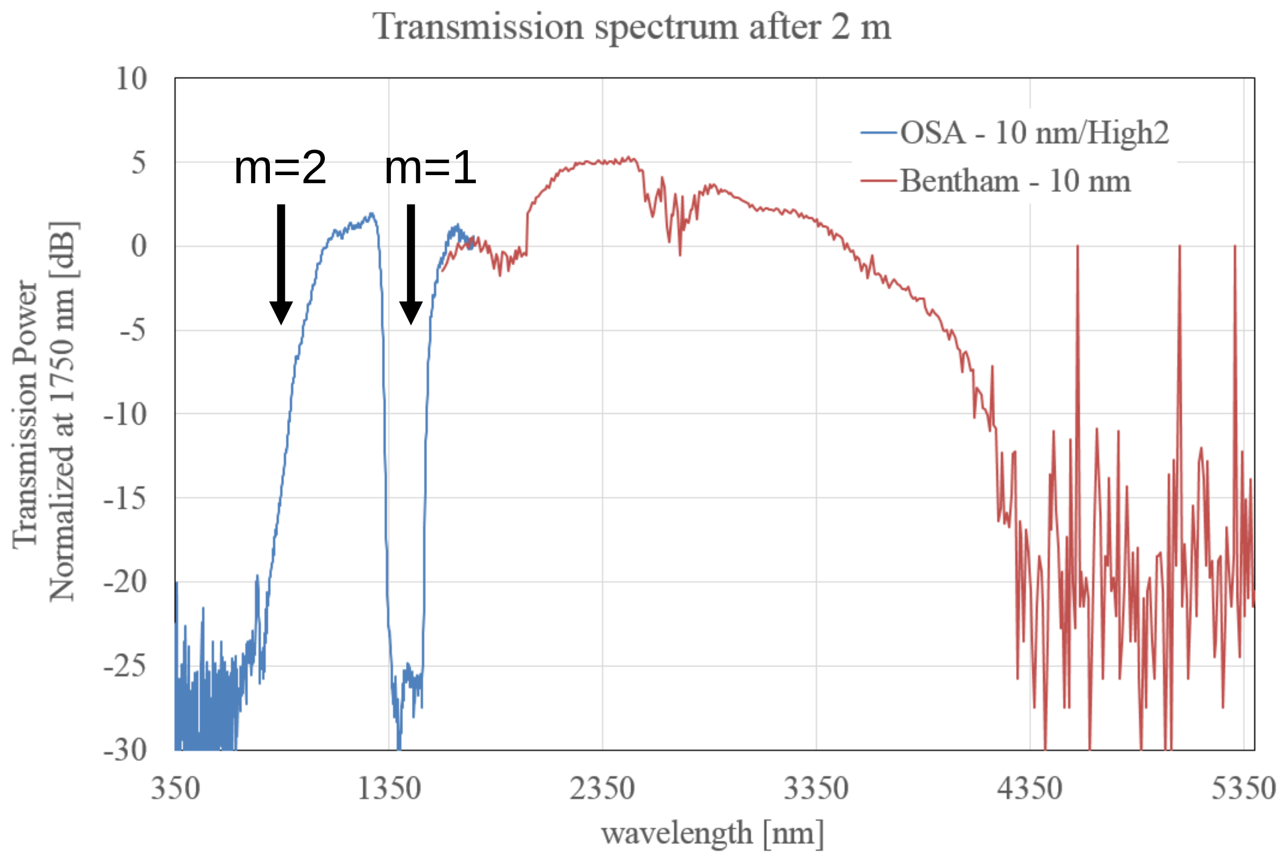
} pump scheme for gas laser

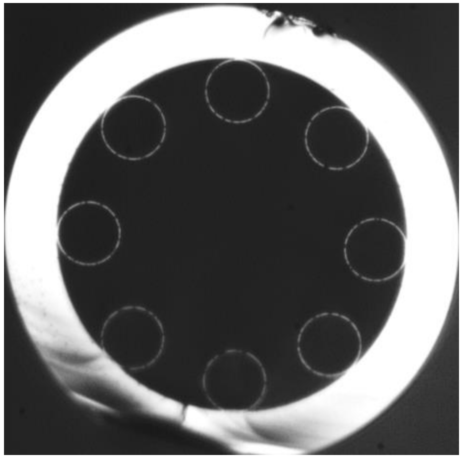
× ***High-power, narrow linewidth, fine-tunable*** pump source!?

× ***Loss control*** of hollow-core waveguide at dual wavelengths

- ~ Higher-order mode excitation
- ~ Restriction of bending

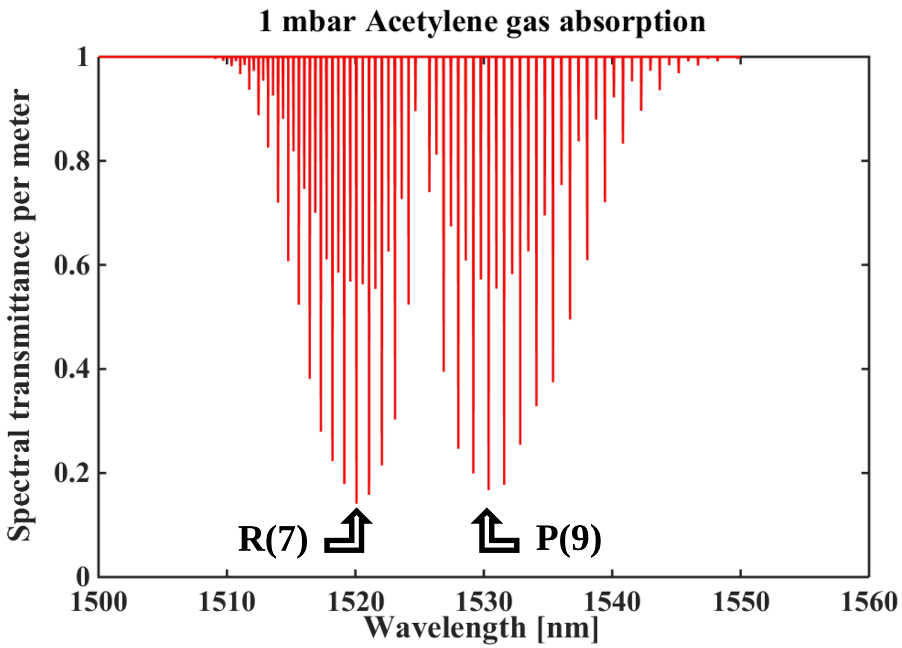
2. Anti-resonant hollow-core fibre (AR-HCF) – *the smallest gas cell ever!*

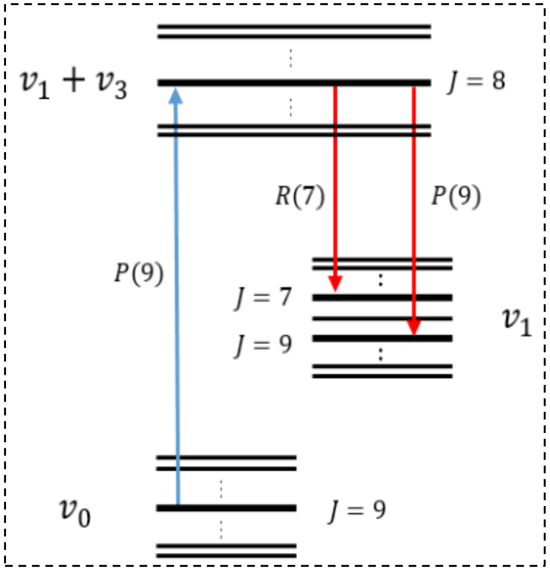




On resonance condition: $m = \frac{2d}{\lambda}\sqrt{n^2 - 1}$

3. Acetylene fibre laser at 3 µm





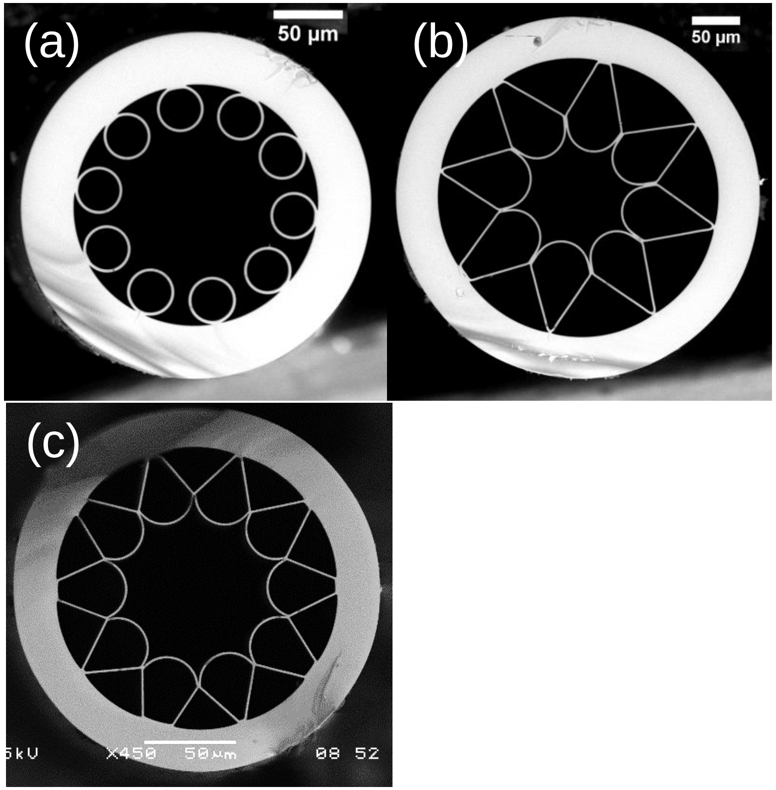
† To be published in *Optics Letter*

AR-HCFs developed for optical pump scheme

- Made of fused silica glass
- Fabricated by Stack-and-draw method
- Pressurization in fabrication to achieve the cladding structure

Best AR-HCFs so far		
Fibre type	Loss at 1.53 μm	Loss at 3.16 μm
(a)	~ 0.1 dB/m	~0.1 dB/m
(b)	> 0.1 dB/m	0.025 dB/m
(c)	0.037 dB/m	< 0.07 dB/m
Kagome	~ 0.08 dB/m	> 1.1 dB/m

†(a) (b) and (c) are all designed and fabricated in Bath



Study of acetylene fibre laser in Bath since 2014

❖ *Pulsed lasing*

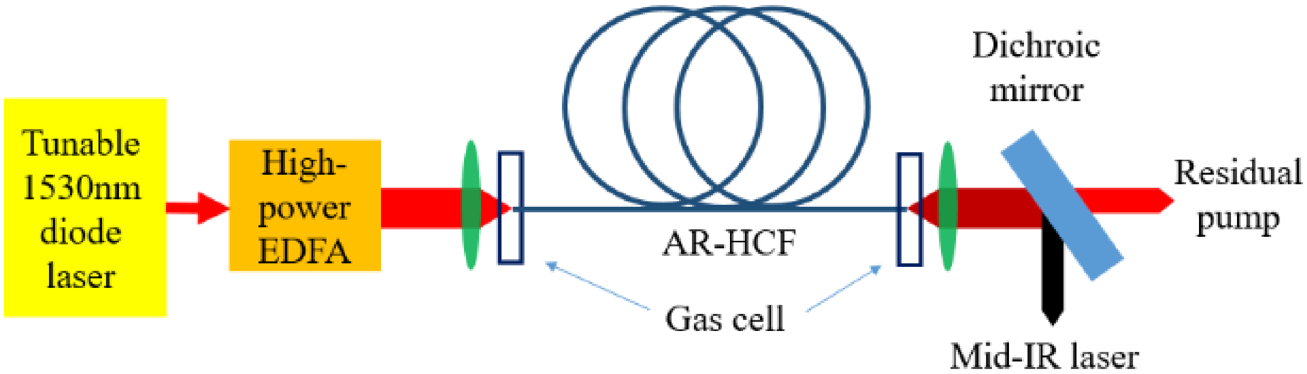
- ❑ Single-pass: 0.76 μJ pulse energy, 30 % slope efficiency [1] (***2014***)
- ❑ Ring cavity: >1.54 nJ pulse energy in the forward direction, 8.8 % slope efficiency [2] (***2016***)

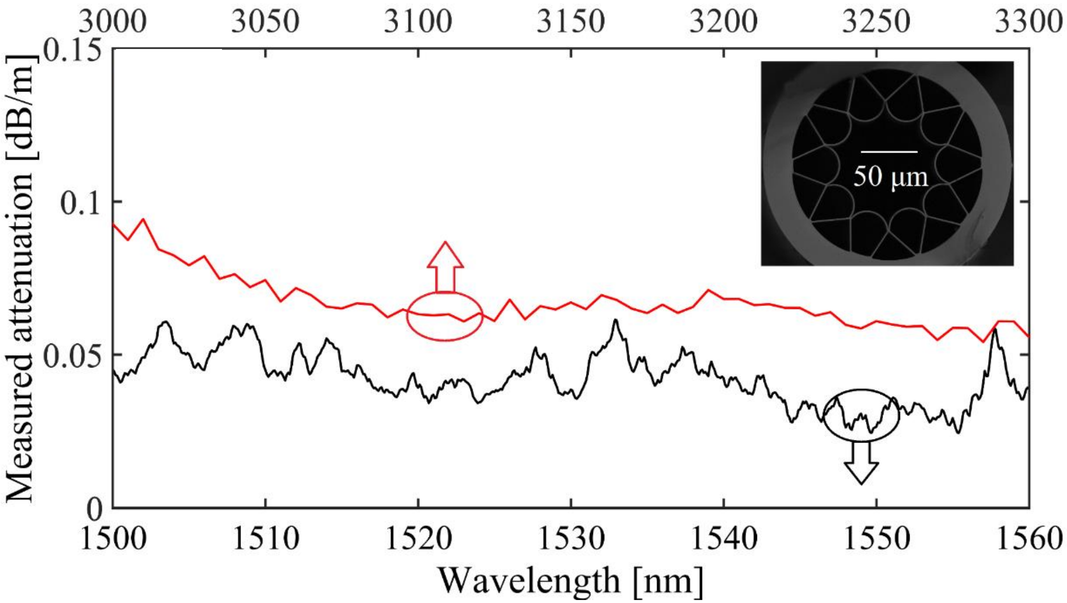
❖ *CW lasing*

- ❑ Ring cavity:
  - >2.5 mW in the forward direction, 6.7 % slope efficiency [2] (***2016***) – **First observation of CW acetylene lasing**
  - 0.31 W with 70 % output coupler, 17.2 % slope efficiency [3] (***2017***)
- ❑ Single-pass:
  - 0.47 W output, 18.6 % slope efficiency [3] (***2017***).
  - 1.12 W output, 33.3 % slope efficiency [4] (***recently***).

[1] Z. Wang, W. Belardi, F. Yu, W. J. Wadsworth, and J. C. Knight, Opt. Express **22**, 21872 (2014).
[2] M. R. Abu Hassan, F. Yu, W. J. Wadsworth, and J. C. Knight, Optica **3**, 218 (2016)
[3] M. Xu, F. Yu, M. R. Hassan, and J. Knight, in CLEO 2017, p. SF2K.4.
[4] To be published in *Optics Letter*.

Single-pass configuration for high-power CW lasing





† To be published in *Optics Letter*

Pump source

Seed laser:

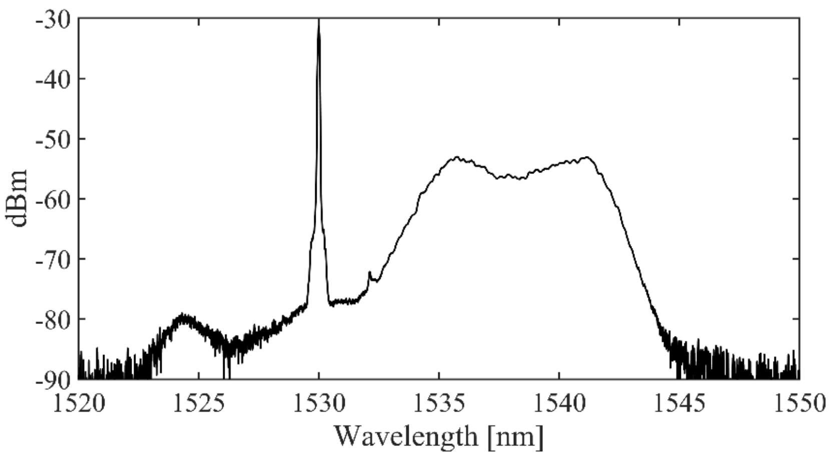
Tunable DBR diode laser (ID Photonics GMBH, CoBrite DX1)

- ❑ Maxiumum output ~ 40 mW
- ❑ Linewidth ~ 100 kHz.

High-power EDFA:

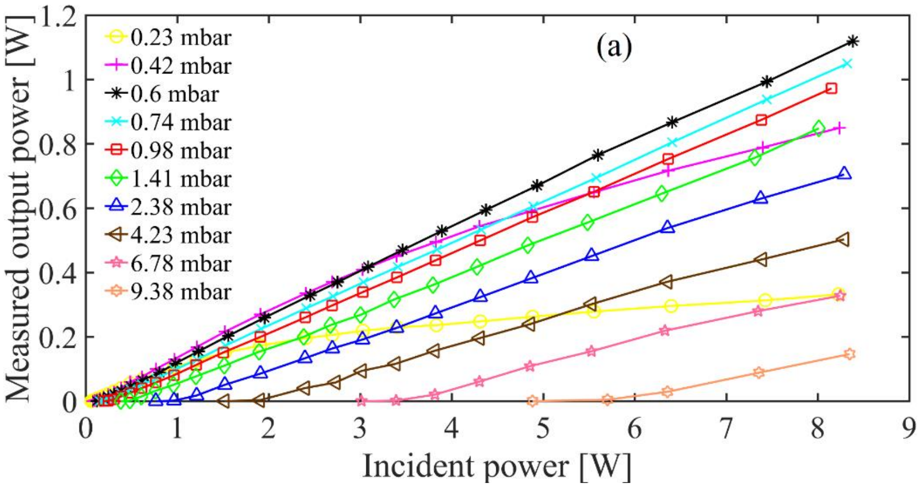
Bktel Photonics, HPOA-S370ac

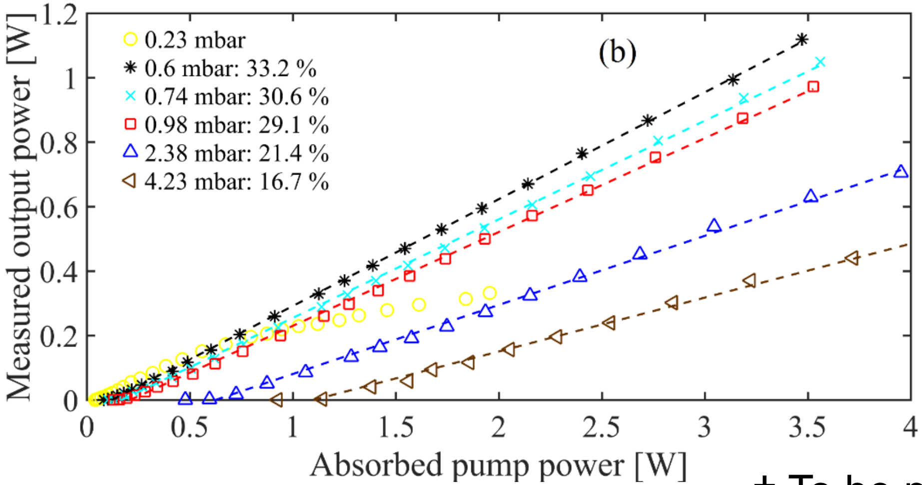
- ❑ Maximum output ~ 9.6 W
- ❑ Maximum effective power at P(9) ~ 4.8 W.



† To be published in *Optics Letter*

Power scaling – *15 m fibre length*

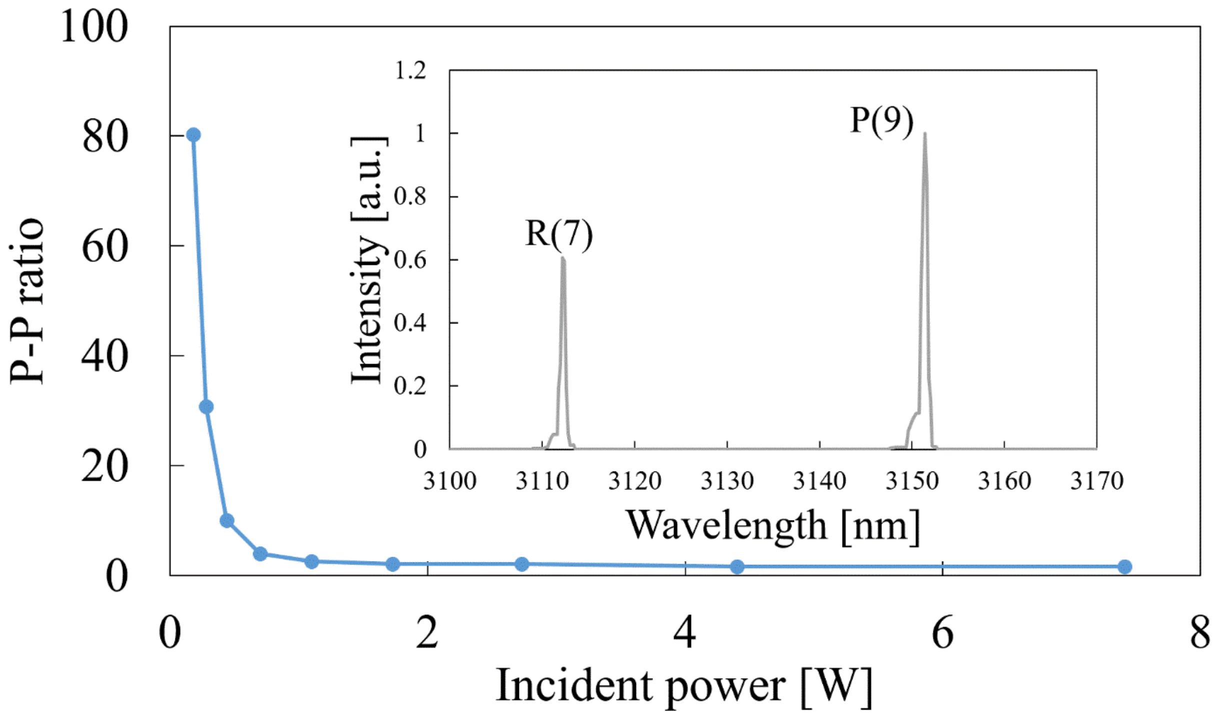




† To be published in *Optics Letter*

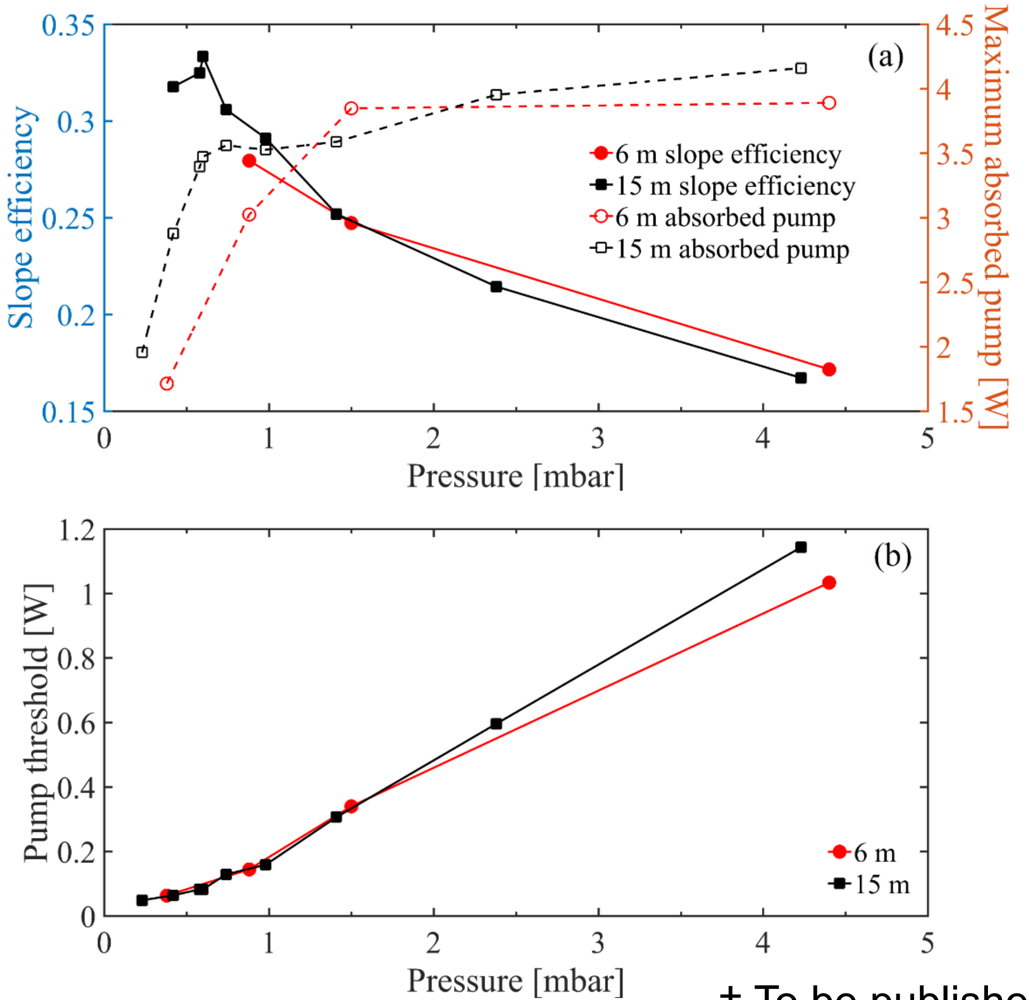
Centre for Photonics and Photonic Materials | UNIVERSITY OF BATH

Output spectrum – *competition between P(9) and R(7)*



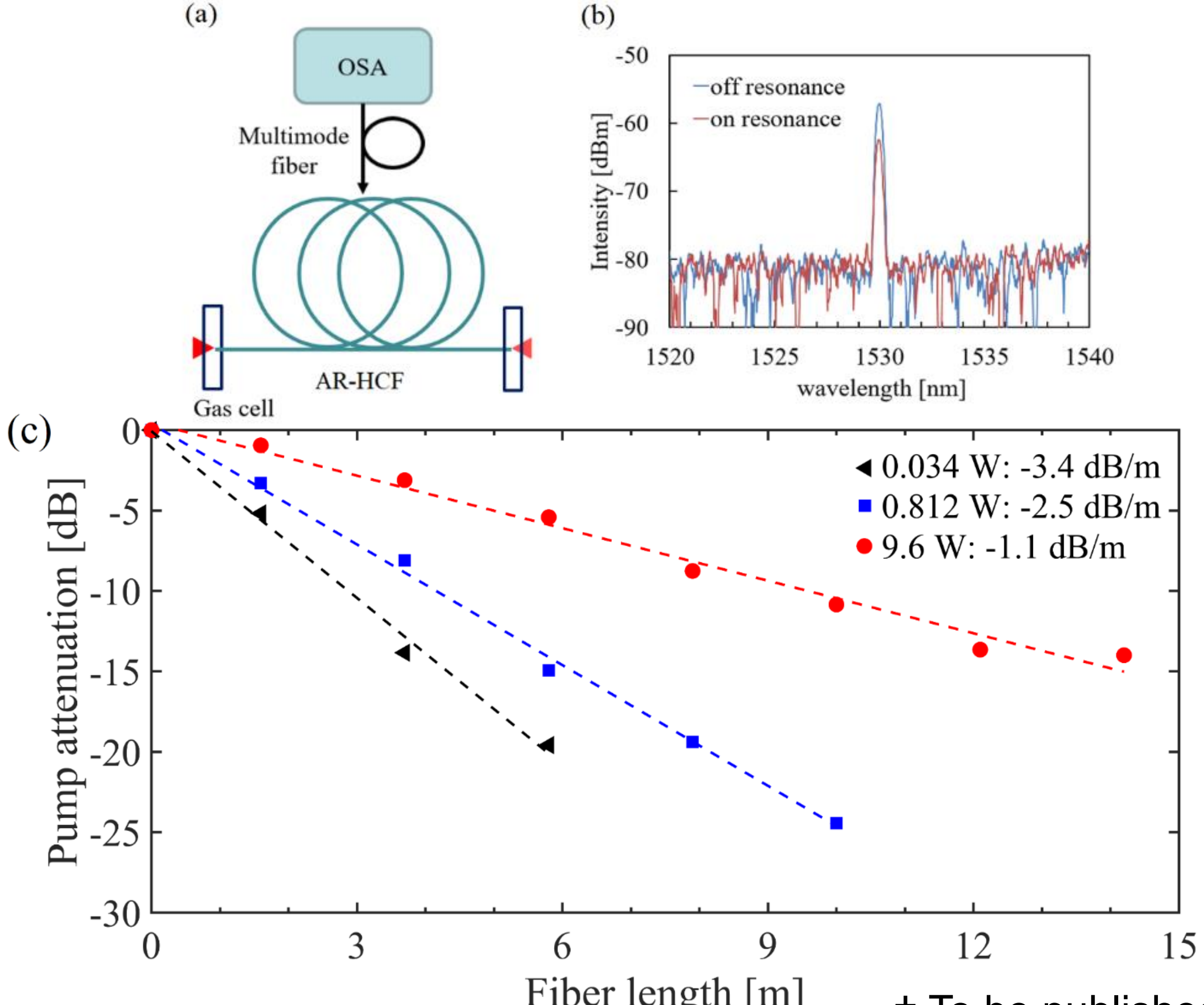
† Submitted to *JSTQE*

Fibre length dependence



† To be published in *Optics Letter*

Utilization of pump



† To be published in *Optics Letter*

Summary

1. Low-loss anti-resonant hollow-core fibres have been developed for acetylene fibre laser
   - ❑ Attenuations at both pump and laser wavelengths have been reduced to less than 0.1 dB/m.
2. 1.12 W laser power was demonstrated at 3 μm with 33 % slope efficiency.
3. 15 m fibre length and 0.6 mbar acetylene gas were found optimized for current pump source.

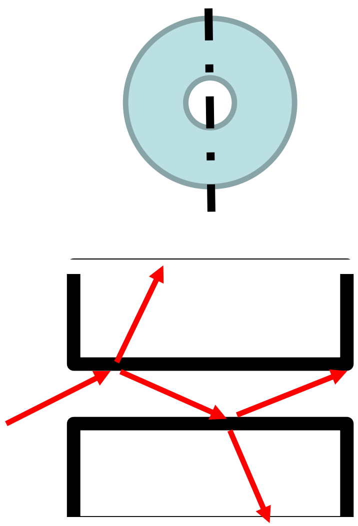
Centre for Photonics and Photonic Materials

UNIVERSITY OF BATH

Acknowledge

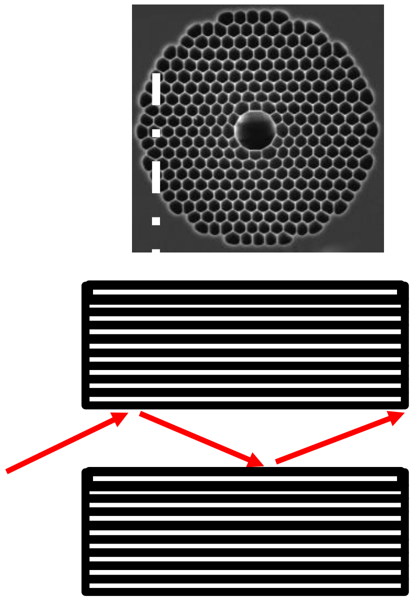
We acknowledge support from The Engineering and Physical Sciences Research Council (EPSRC) (EP/M025381/1).

Comparison of hollow-core fibres



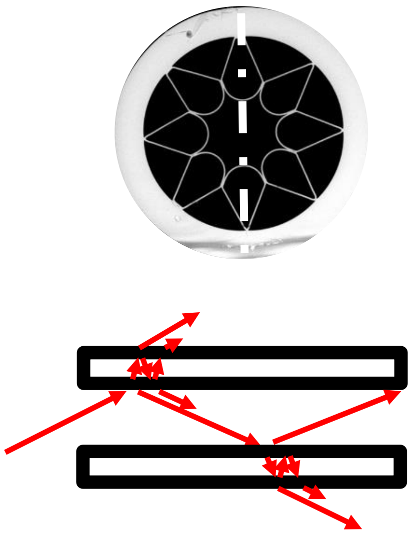
Capillary HCF

High loss
&
Broadband



Photonic Bandgap HCF

Low loss
&
Narrow-band



Anti-resonant-HCF

Acceptable loss
&
Broadband