

Ultrafast Laser Inscription of Spatial- Reformatting Components for Astronomical Spectroscopy

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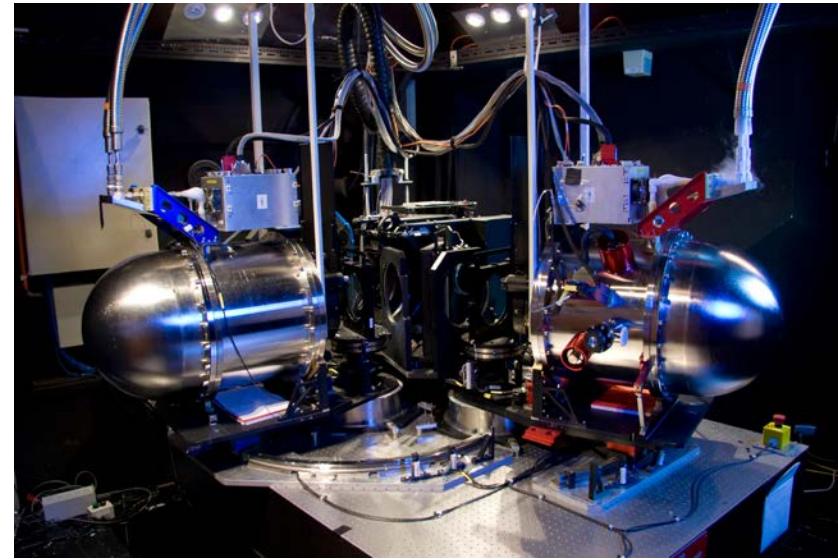
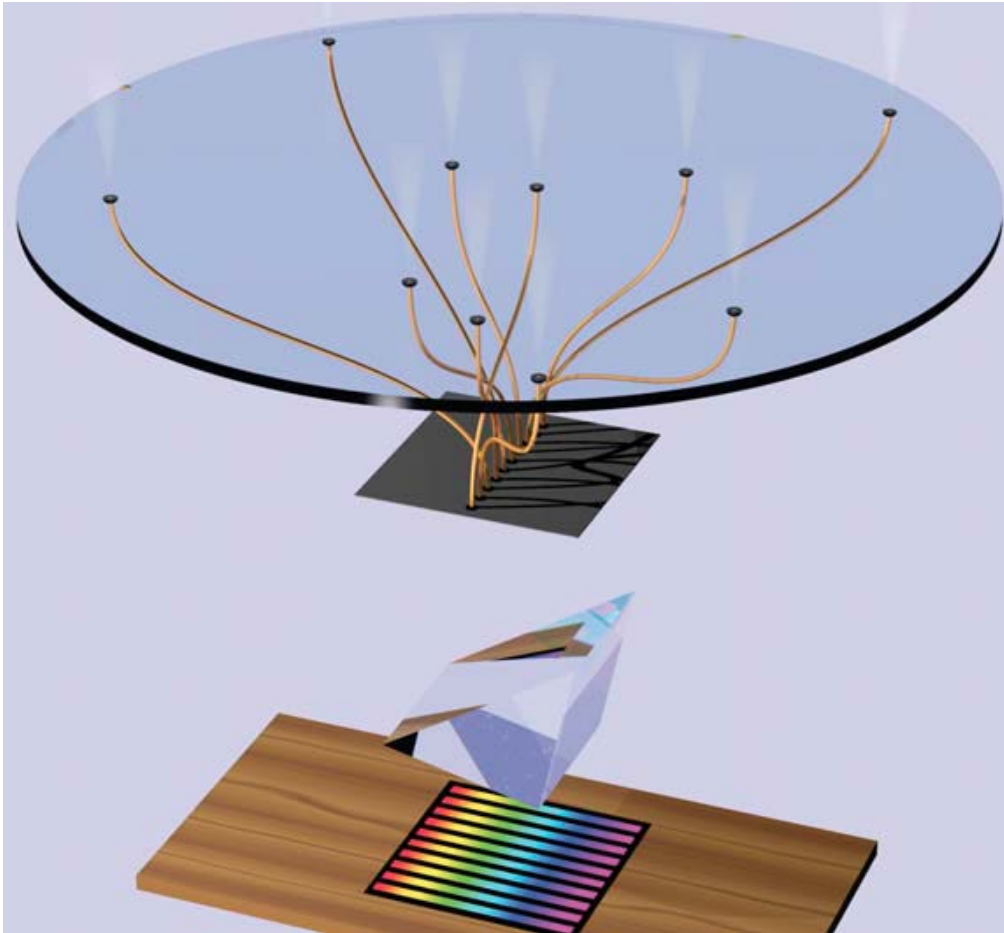
Motivation - Multi-object spectroscopy



The 2df multi-object robotic optical fibre positioner

www.aao.gov.au

Motivation - Multi-object spectroscopy



AAOmega spectrograph
www.aao.gov.au

Bland-Hawthorn et al, Physics Today 65, 31 (2012)

Photonic Multi-object spectroscopy ?

Instruments without optics: an integrated photonic spectrograph

J. Bland-Hawthorn³, A. Horton

Anglo-Australian Observatory, 167 Vimiera Rd, Eastwood, NSW 2122, Australia

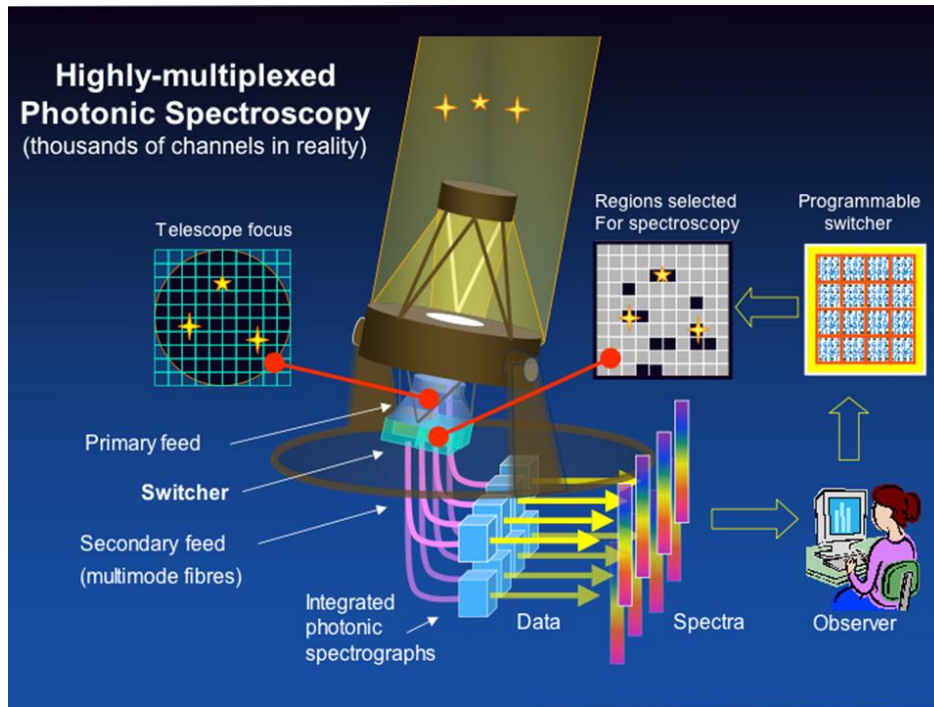
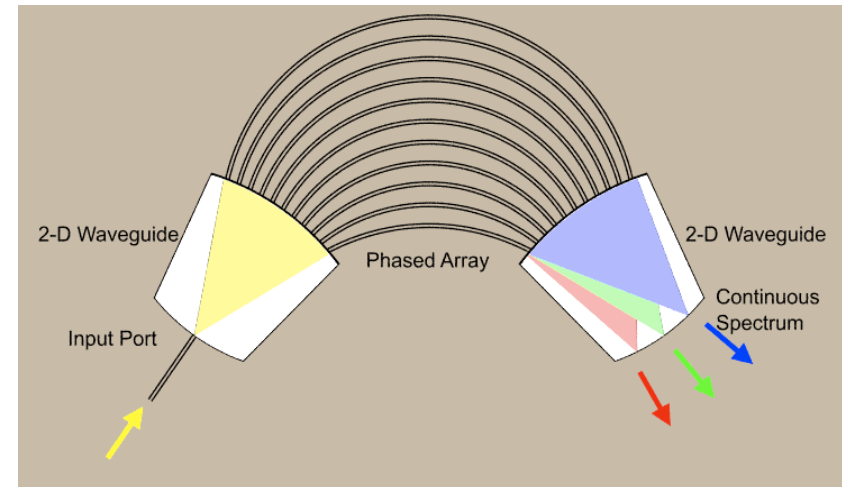
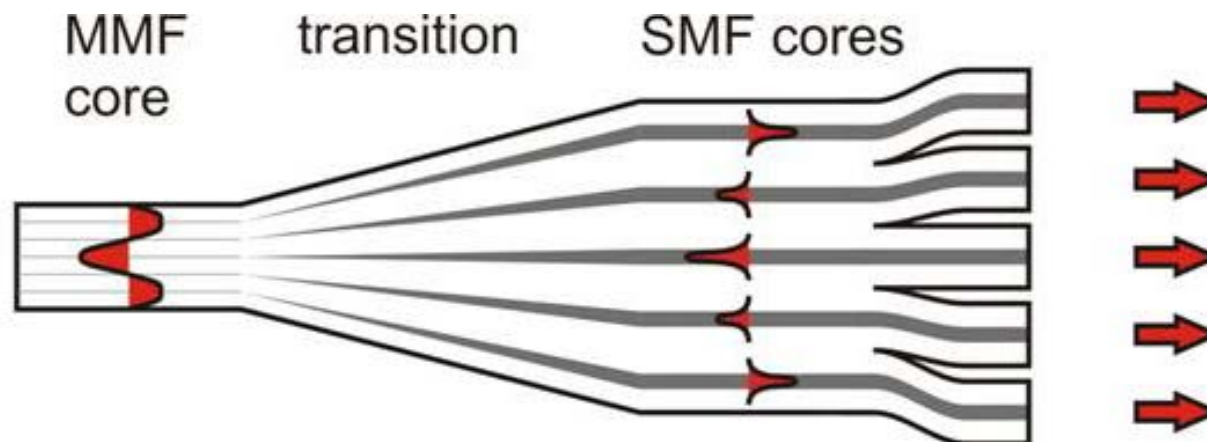


Image courtesy of J. Allington-Smith (CfAI - U. of Durham)



Multimode-to-single mode conversion - The photonic lantern

- Couple light from one MMF to several SMF cores along a gradual taper transition

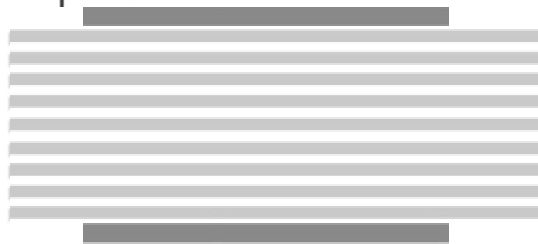


S. G Leon-Saval et al, Opt. Lett. 30, 2545 (2005)

- Low loss: let N (number of single modes) = M (number of MMF modes)
 \Rightarrow conserve no. modes / entropy / brightness / etendue couple light from one MMF to several SMF cores along a gradual taper transition

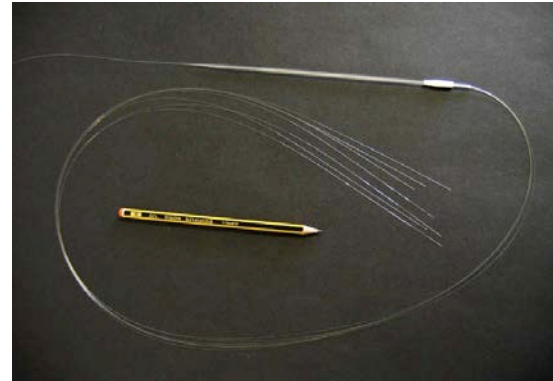
The photonic lantern fabrication

Single-mode fibers

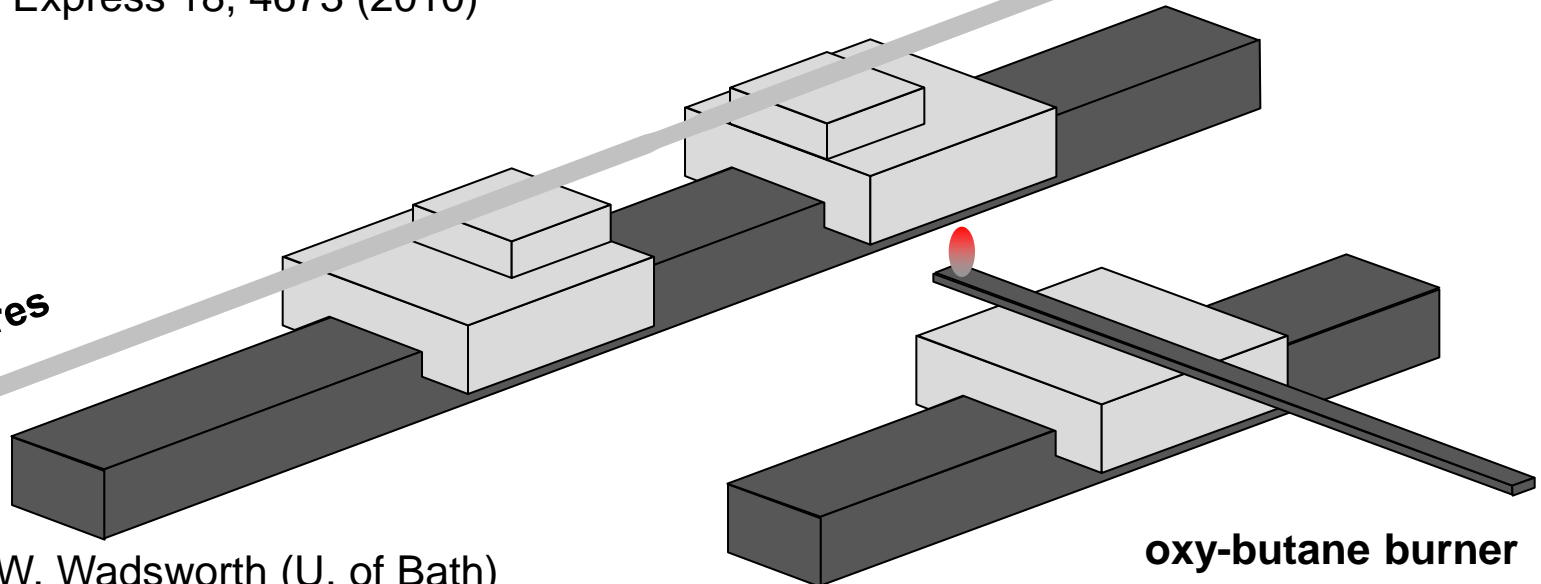


Low index tube

D. Noordegraaf et al,
Opt. Express 18, 4673 (2010)

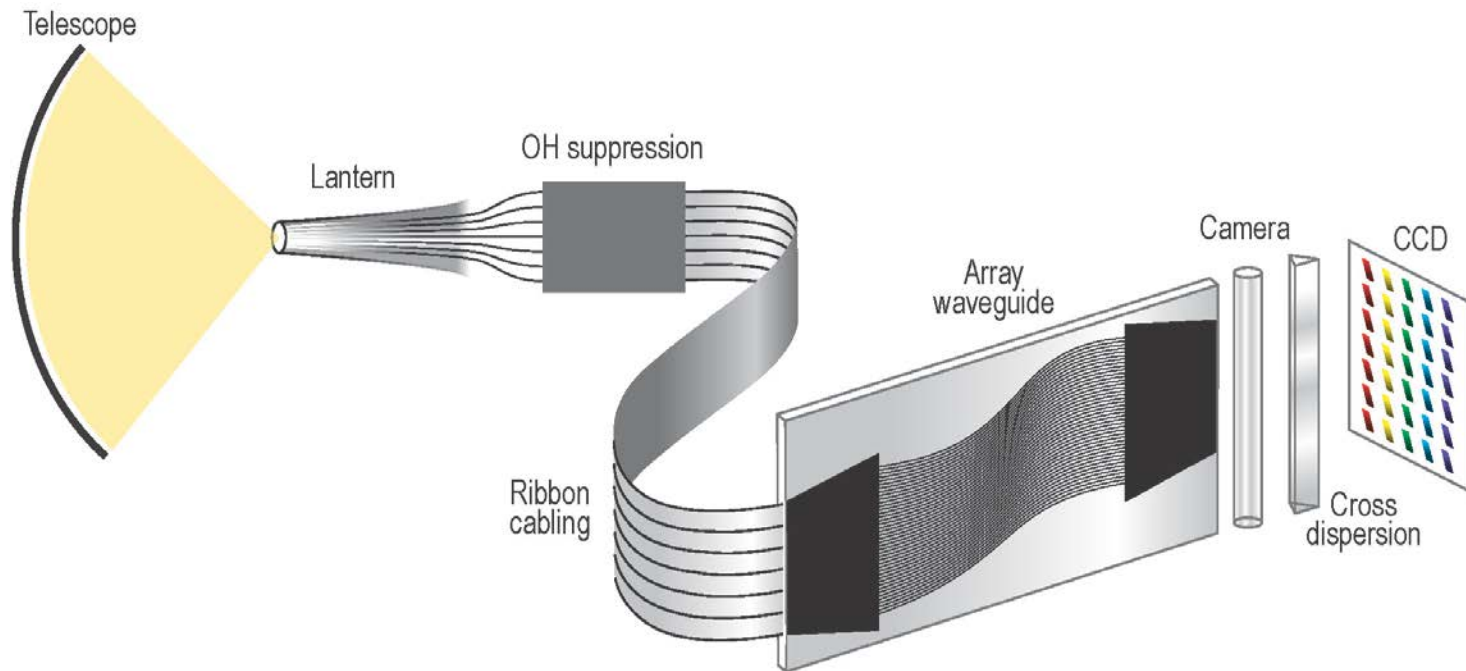


Tube and fibres



oxy-butane burner

The photonic integrated multimode micro-spectrograph (PIMMS)



The PIMMS instrument concept

J. Bland-Hawthorn et al,
Proc. SPIE 7735, 77350N (2010)

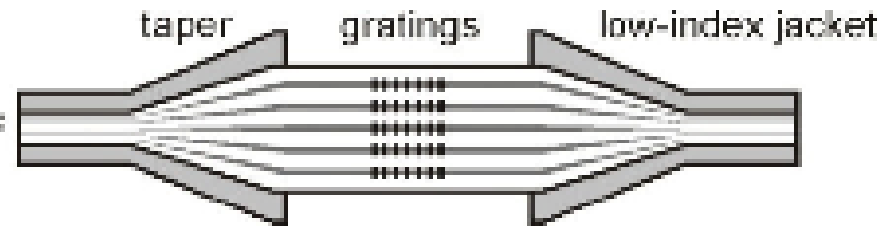
Mass producible photonic lanterns

“Photonic lantern” spectral filters in multi-core fibre

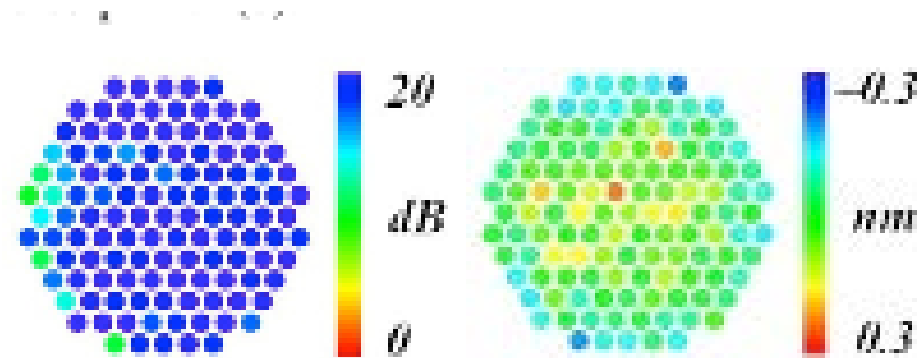
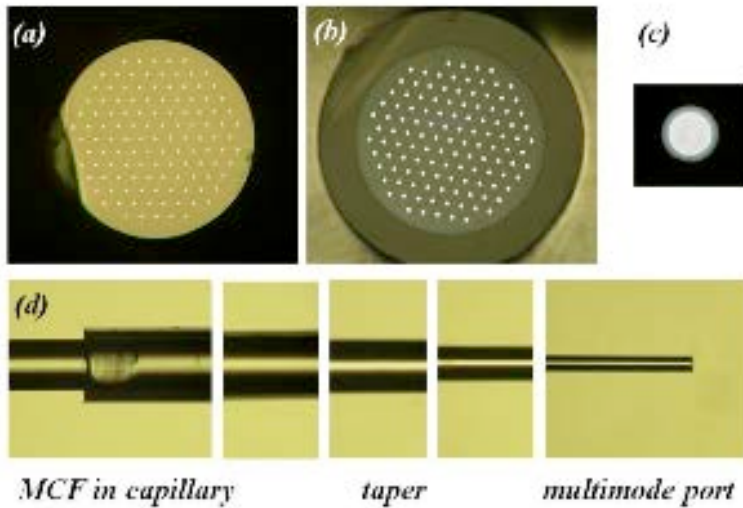
T. A. Birks,^{1*} B. J. Mangan,¹ A. Díez,² J. L. Cruz,² and D. F. Murphy³

18 June 2012 / Vol. 20, No. 13 / OPTICS EXPRESS 13996

MCF



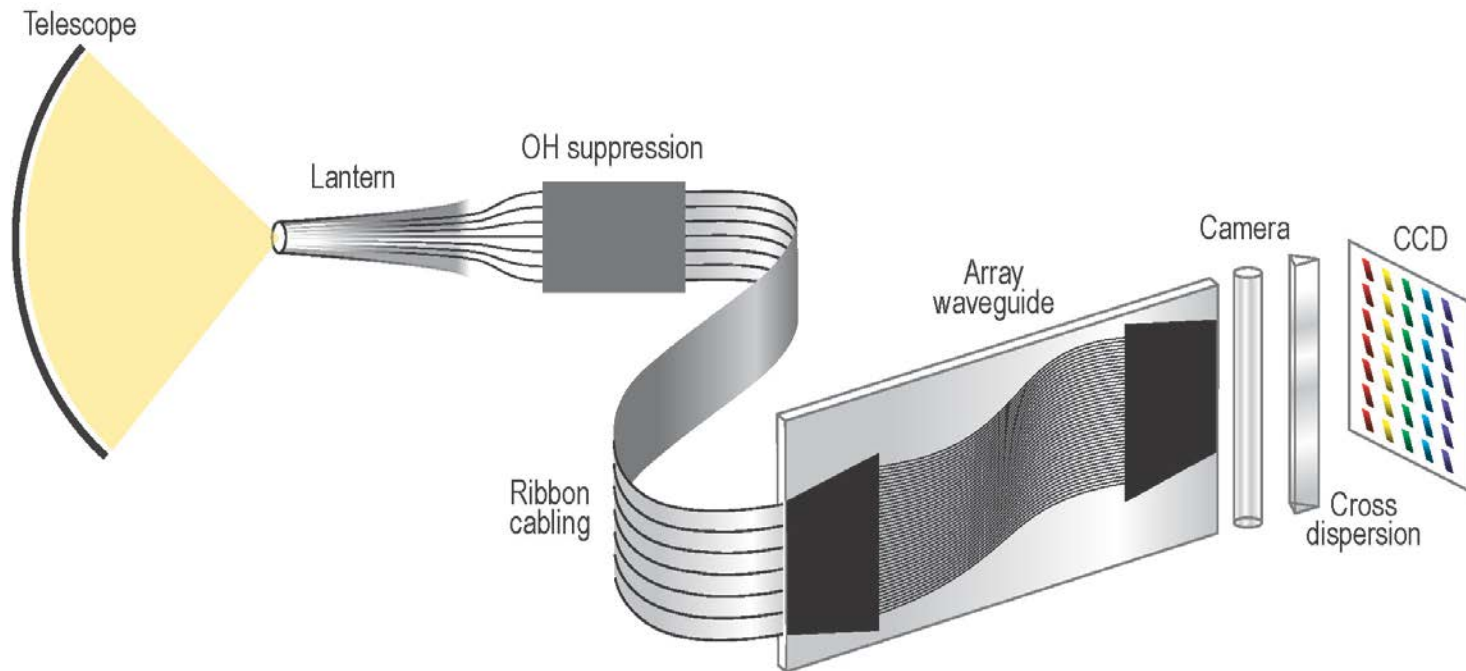
Schematic of a photonic lantern MCF filter



Map of FBG spectral properties

Collage of images of an MCF lantern at various stages

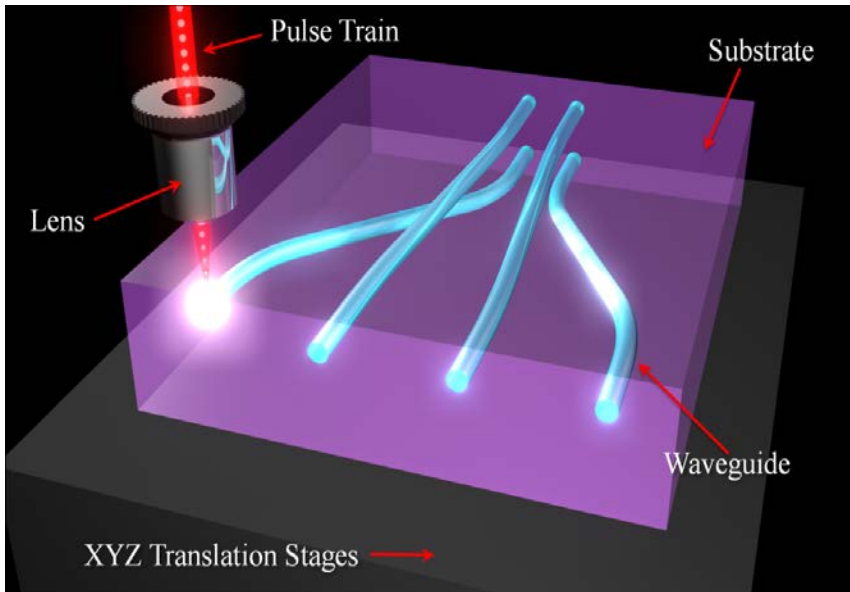
The photonic integrated multimode micro-spectrograph (PIMMS)



The PIMMS instrument concept

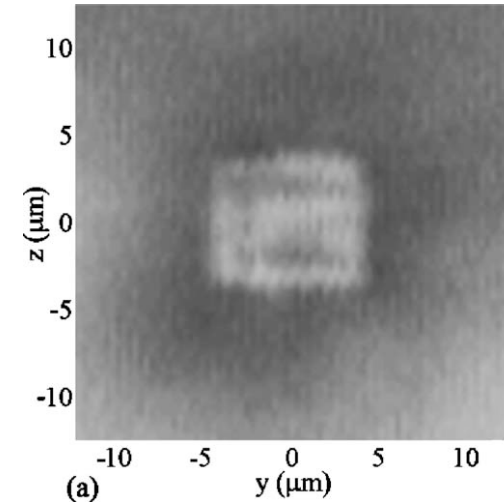
J. Bland-Hawthorn et al,
Proc. SPIE 7735, 77350N (2010)

Ultrafast laser inscription (ULI)

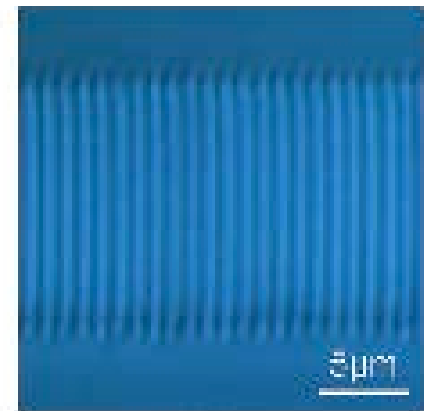
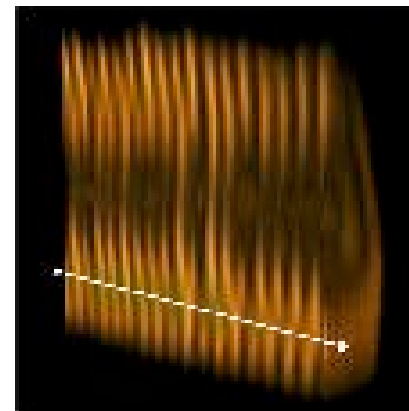


Cartoon of ULI process

- Unique fabrication capabilities:
 - 3D optical waveguides.
 - Micro-optics, -mechanics and -fluidics.
- ULI is material flexible.
- ULI is a direct-write technology.



Psaila et al, *Appl. Phys. Lett.* 90, 131102 (2007)

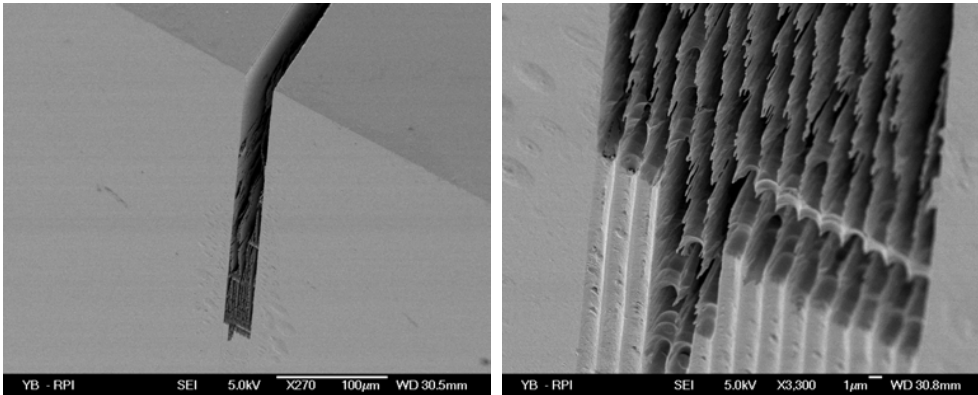


Graham D. Marshall et al, *Opt. Lett.* 36, 695 (2011)

ULI Fabrication capabilities

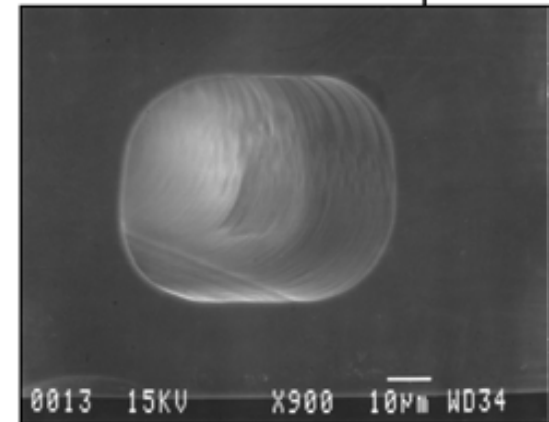
Selective etching

High aspect ratio surface μ -channels



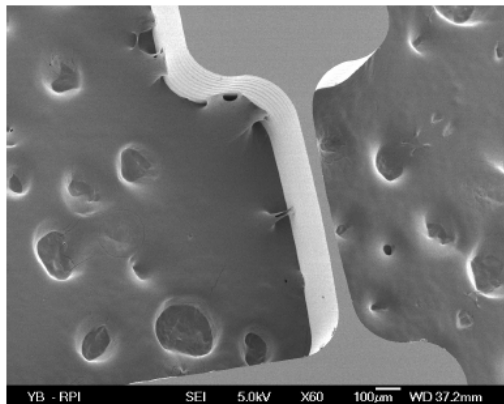
Bellouard et. al., *Opt. Express.* 12, 2120 (2004)

Sub-surface μ -channels

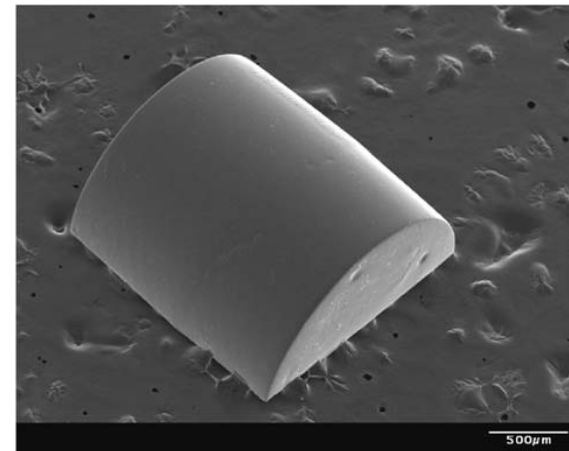


Bellouard et. al., *Opt. Express.* 12, 2120 (2004)

μ -mechanics



Bellouard et. al., *Opt. Express.* 13, 6635 (2005)



Cheng et. al., *Appl. Phys. A.* 85, 11 (2006)

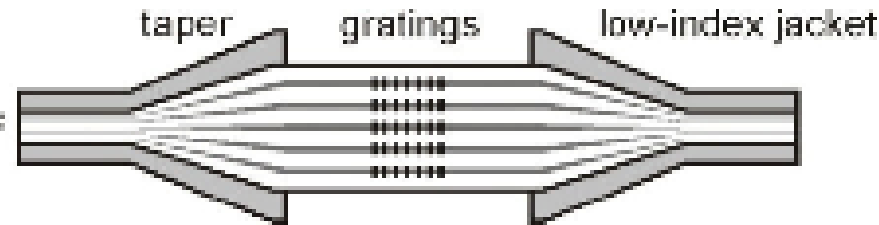
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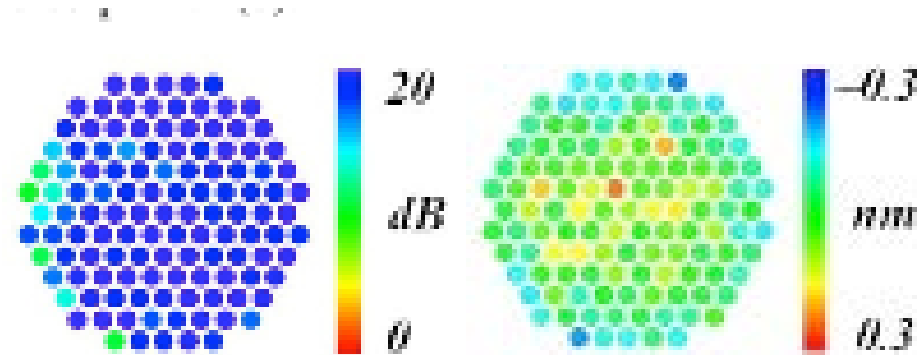
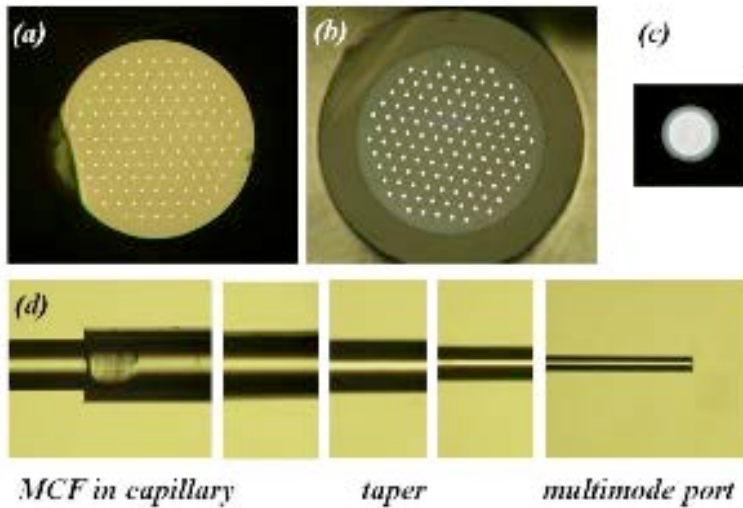
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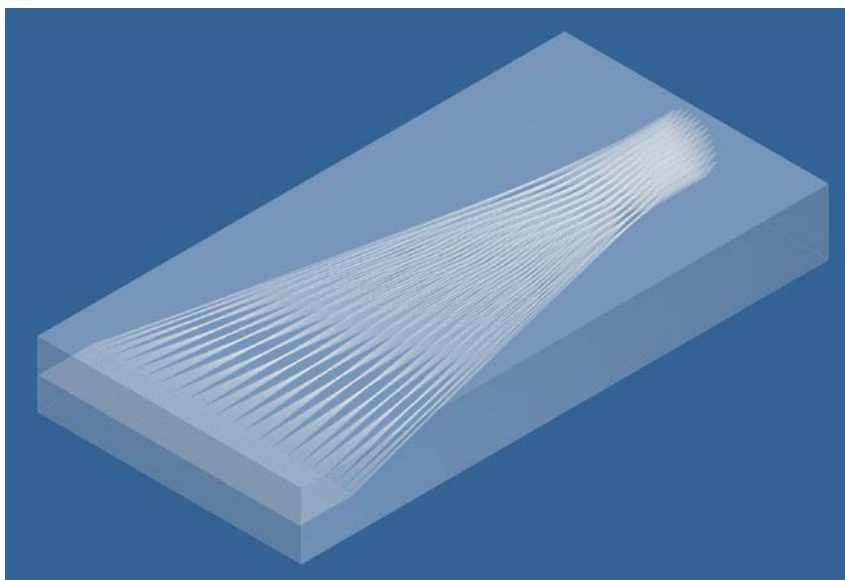
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3D interconnects via ULI

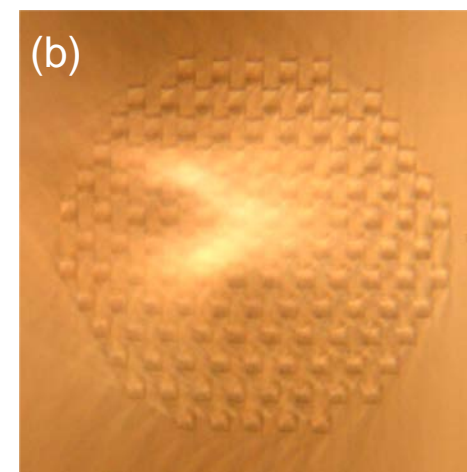
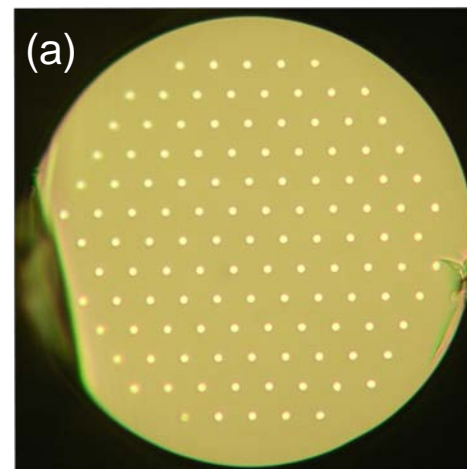


Conceptual diagram of the 3D fan-out device

Prototype throughput loss ~ 5 dB.

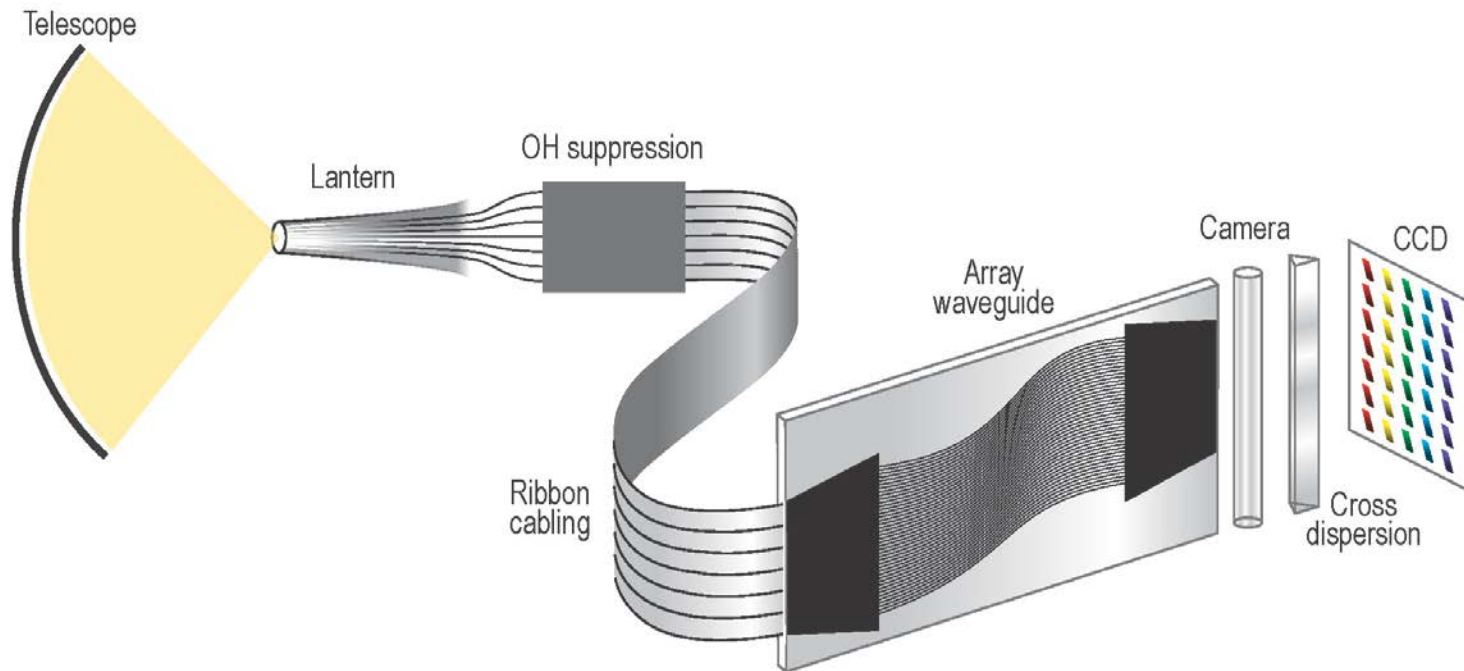
Throughput losses of < 1 dB have now been demonstrated for low core count devices.

For more info, see: R. R. Thomson et al, "Ultrafast laser inscription of a 121-waveguide fan-out for astrophotonics," *Opt. Lett.* **37**, 2331 (2012)



Optical micrograph of (a) the 120 core MCF and (b) the MCF coupling end of the 3D fan-out

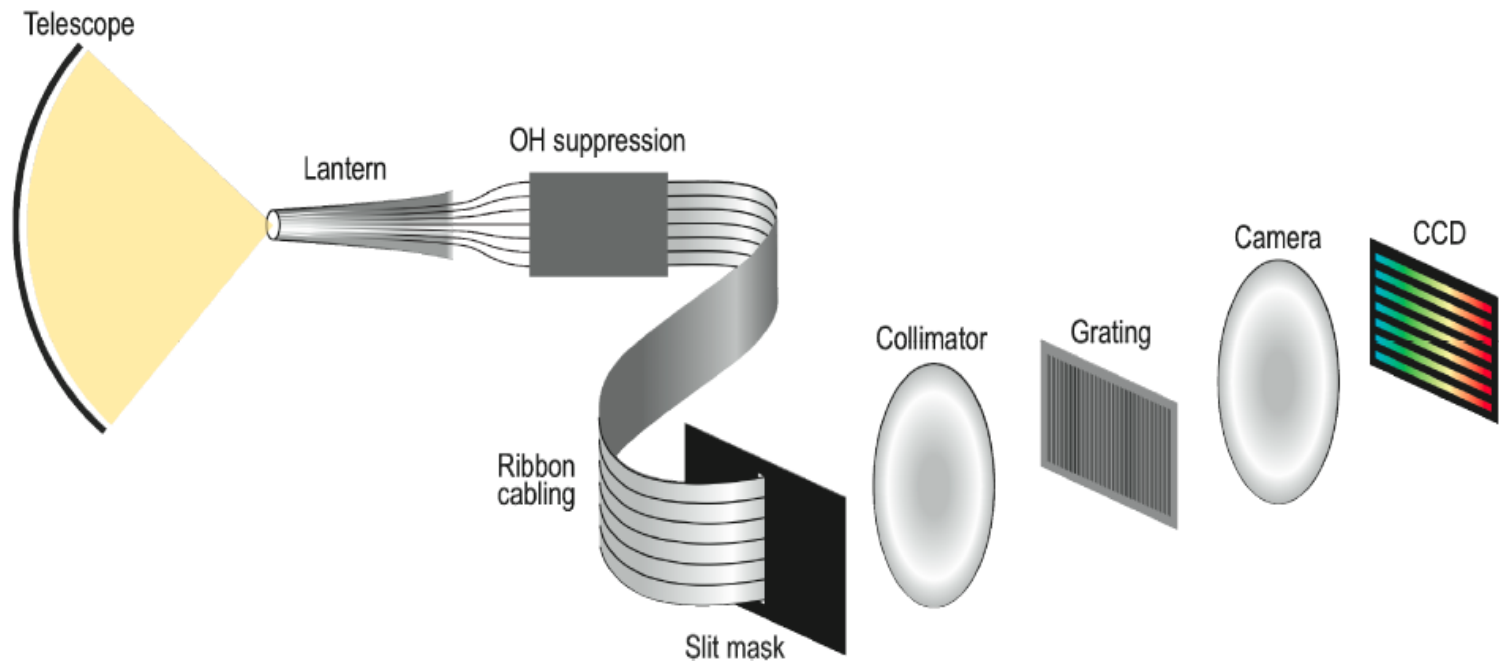
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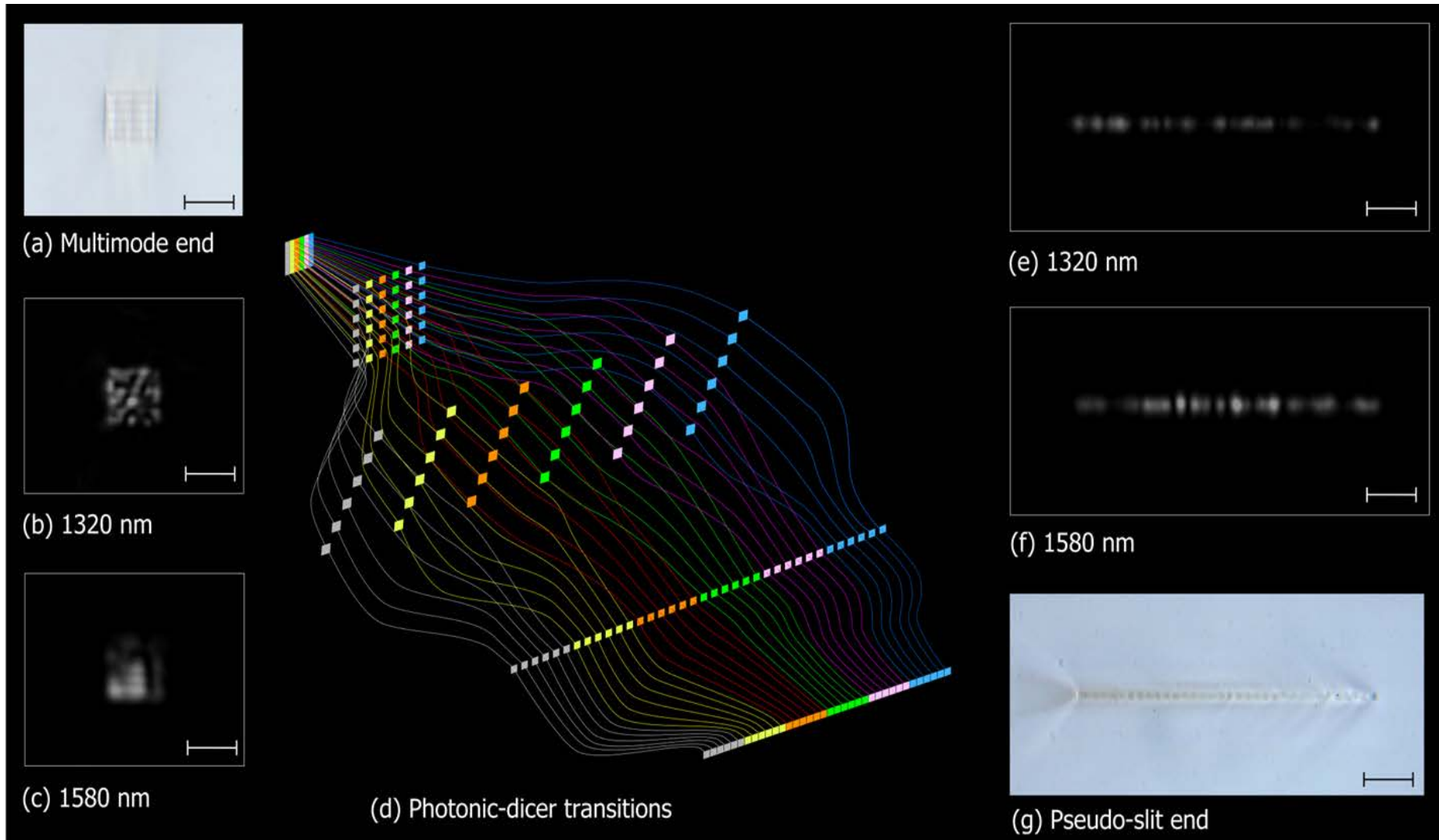
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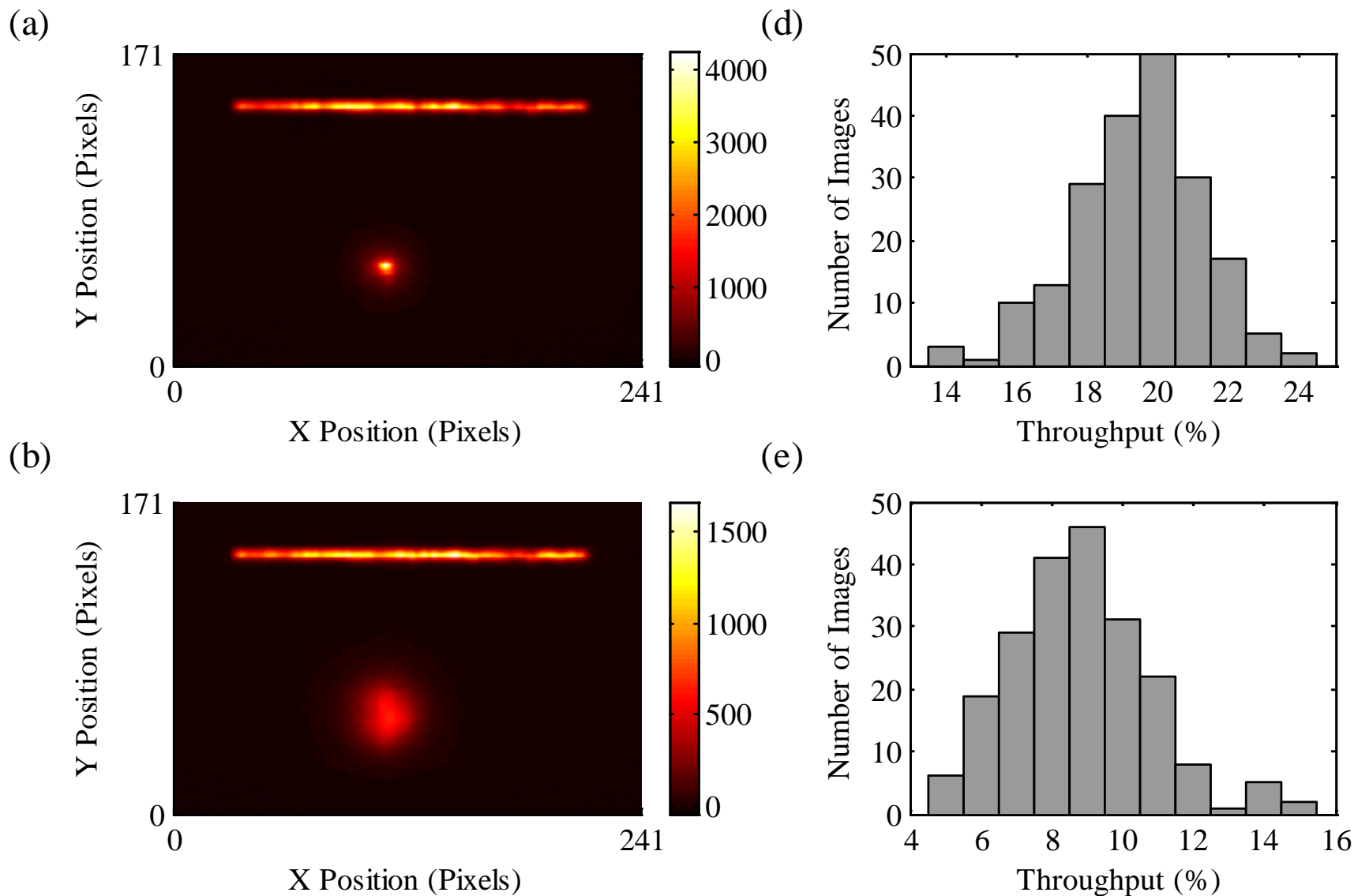
The PIMMS instrument concept

J. Bland-Hawthorn et al,
Proc. SPIE 7735, 77350N (2010)

Integrated spatial photonic reformatters



Integrated spatial photonic reformatters



Conclusions

- Ultrafast laser inscription is a rapidly maturing and unique fabrication technique, which enables a variety of novel optical technologies.
- Astronomy is now driving the development of entirely new guided wave photonic devices and concepts.
- Astrophotonic technologies such as those presented here have the potential to revolutionise astronomy.
- Some astrophotonic technologies are now at the level whereby they can be seriously considered for use in real-world instruments.

Acknowledgements

- C. Cunningham and D. Lee (UK-ATC)
- J. Allington-Smith, R. Harris T. Morris (Durham U.)
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