The evolution and impact of photonics components

David N Payne

Director: ORC Southampton University
Chairman: Southampton Photonics Inc

Optical Fibre Group 1972

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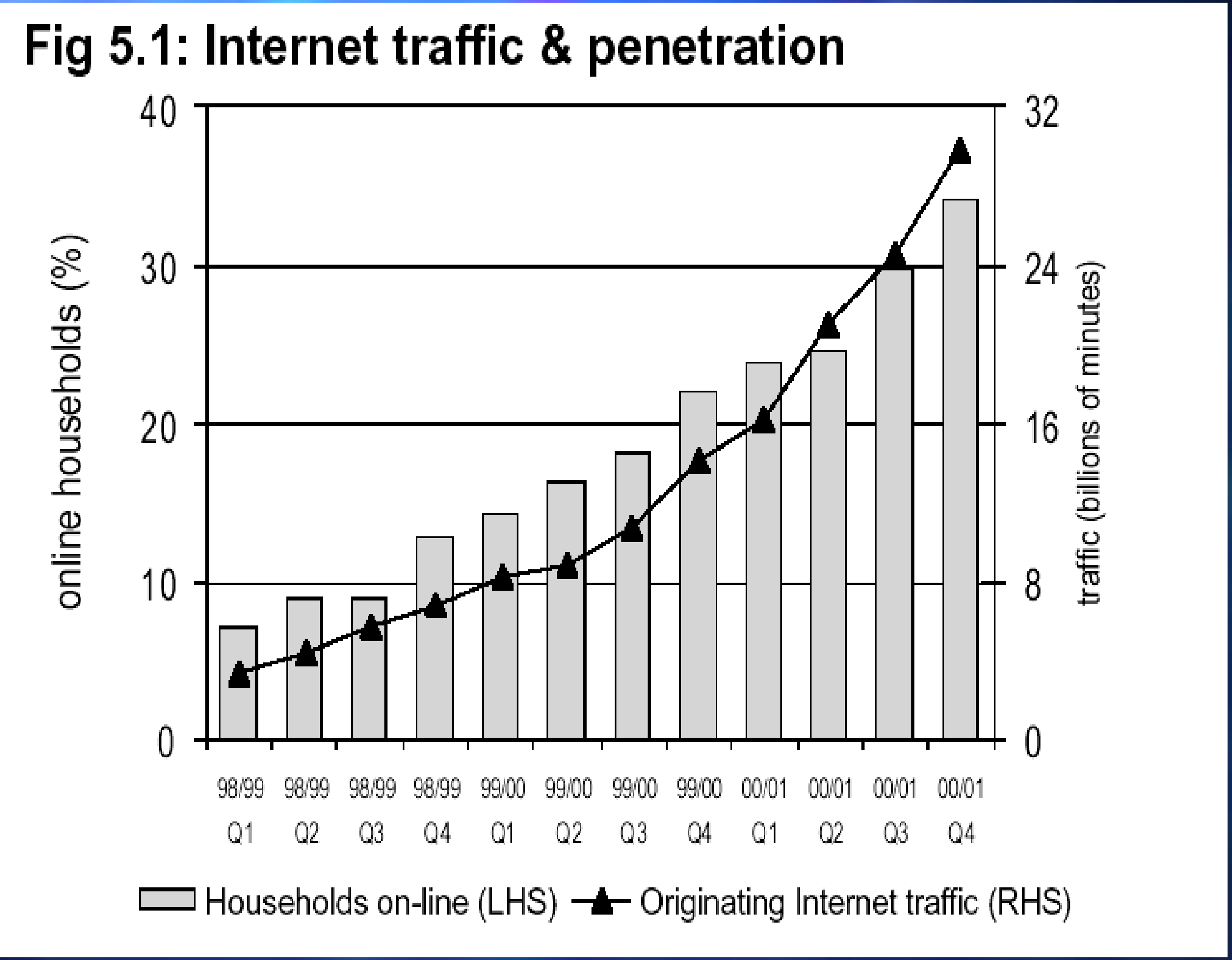
Telecom growth remains healthy – UK Oftel



US internet traffic still growing at x4 per year – Roberts et al. 2001, Caspian Networks

The art of prediction

“Prediction is very difficult, especially about the future”
Niels Bohr, Nobel Laureate

"The future isn't what it used to be !"
IBM PC executive 1992

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Great predictions of the 20th century

- **"Stocks have reached what looks like a permanently high plateau.“**
  -- Irving Fisher, Professor of Economics, Yale University, 1929

- **"Everything that can be invented has been invented."**
  -- Charles H. Duell, Commissioner, U.S. Office of Patents, 1899

- **"The herd instinct among forecasters makes sheep look like independent thinkers.** " --Edgar R. Fiedler

- **“There's no-one who likes the PC who doesn't like Microsoft"**
  --Bill Gates, Free Market and the LA Times

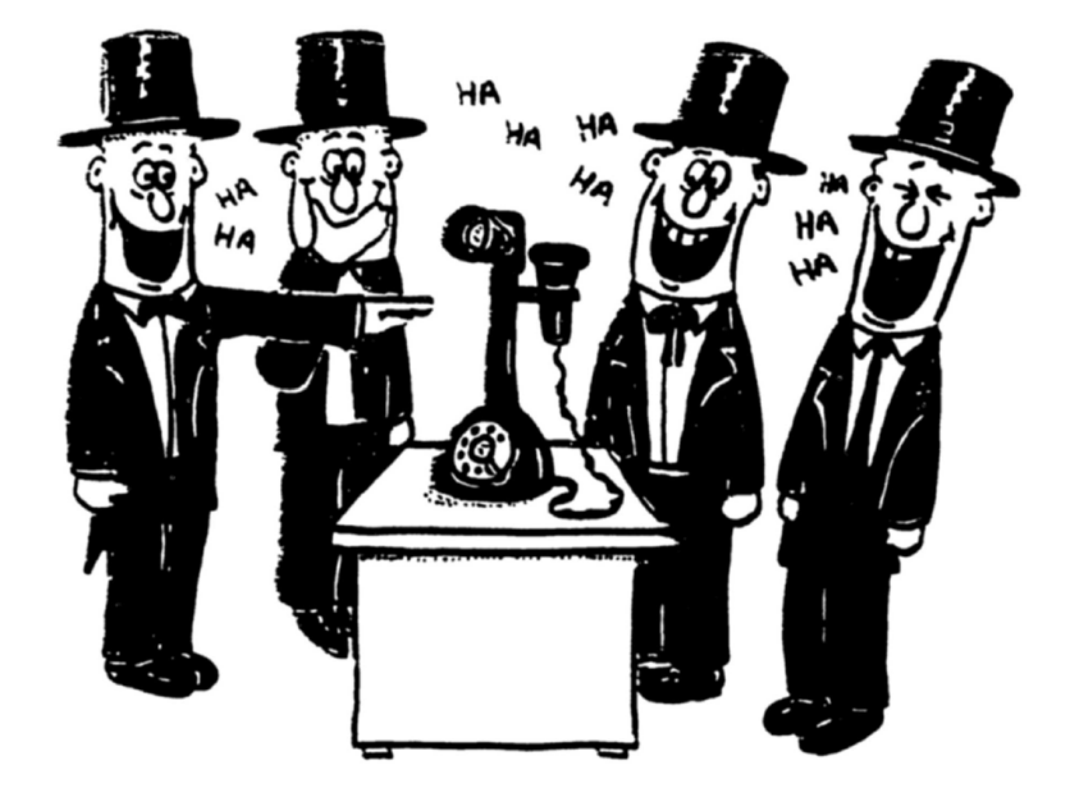
“Bandwidth is like health-care – *you can never have too much*”
-- David Payne ECOC 2000

19th Century technical predictions

Fig. 17.2 A French prediction for the year 2000.

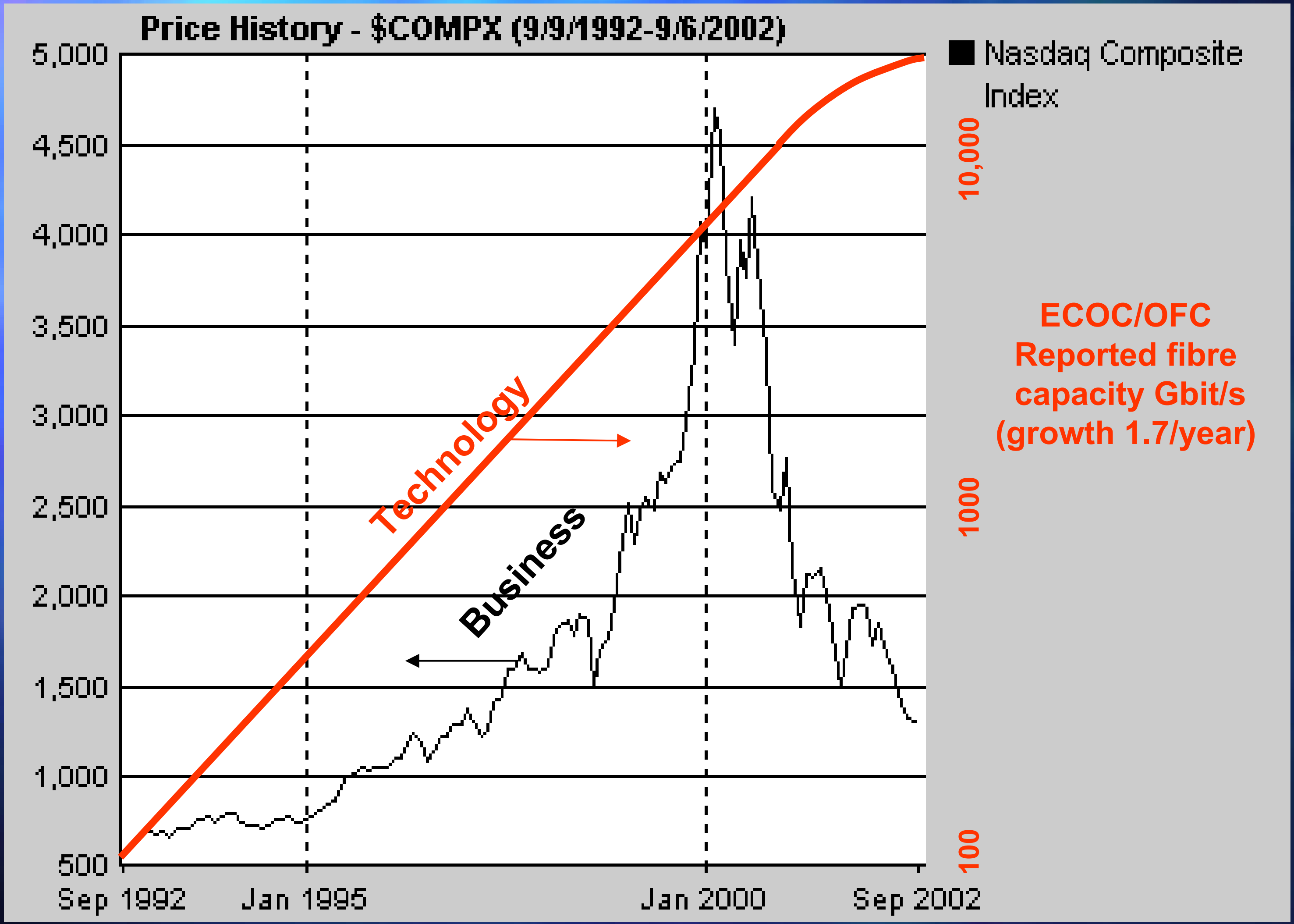
Le photo-telephone

Dubious investments of the twentieth century?



"This 'telephone' has too many shortcomings to be seriously considered as a means of communication. The device is inherently of no value to us."
-- Western Union internal memo, 1876.

Sound investments of the twenty-first century?



Key issues in optical fibre telecommunications

- WDM and TDM - The optimum mix
- Broadband amplifiers for 1.2 – 1.75 μm
- Dispersion and polarization management
- Optical regeneration
- Optical networks
- IP on optics
- Integration and cost reduction

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Optical spectral efficiency

- Fibre transmission window from 1.1µm – 1.7µm
- ~ 90 THz available
- Amplifiers are the limiting technology (Fibre, Raman, Diode?)
- Towards 3 bit/Hz requires better wavelength control

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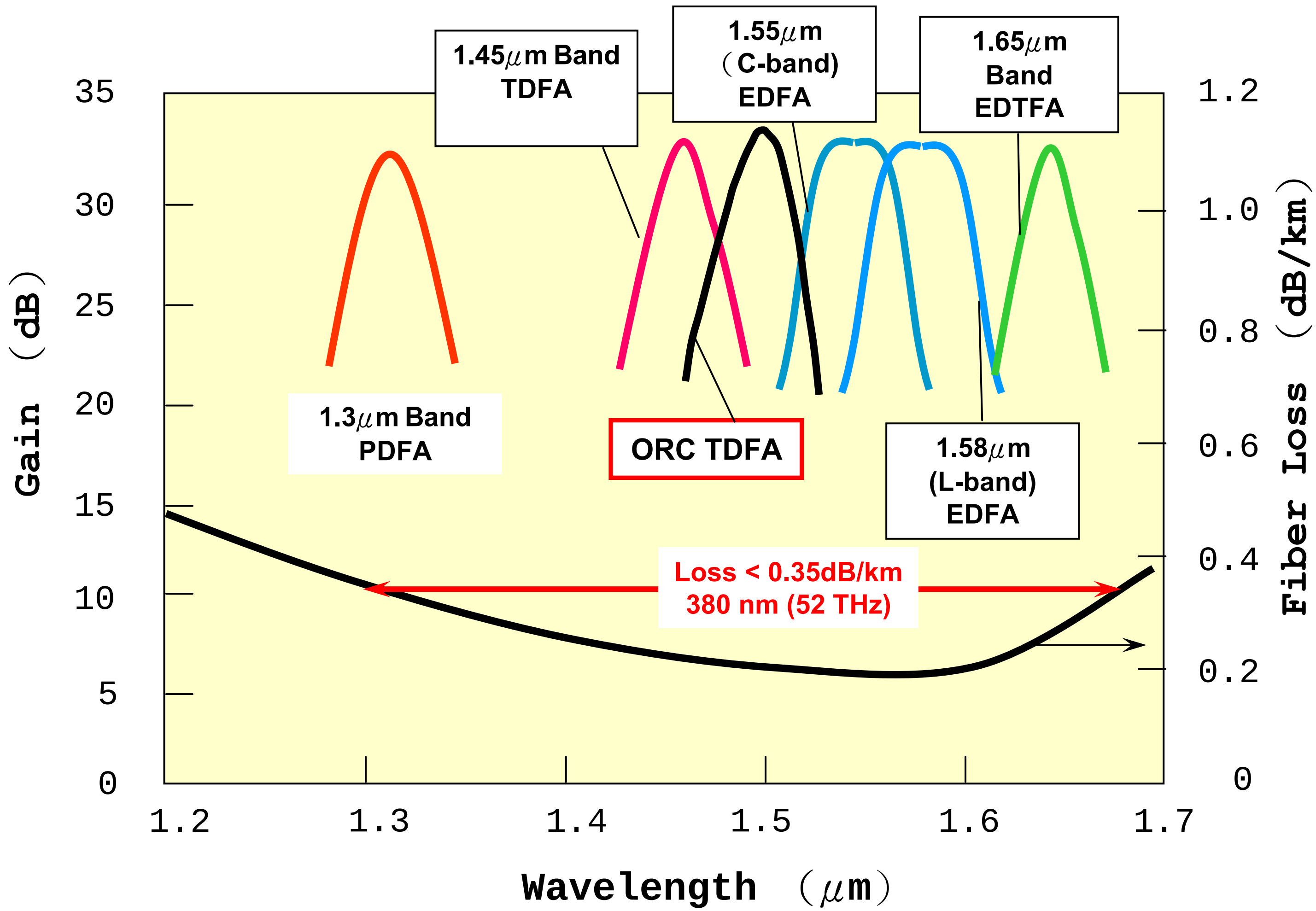
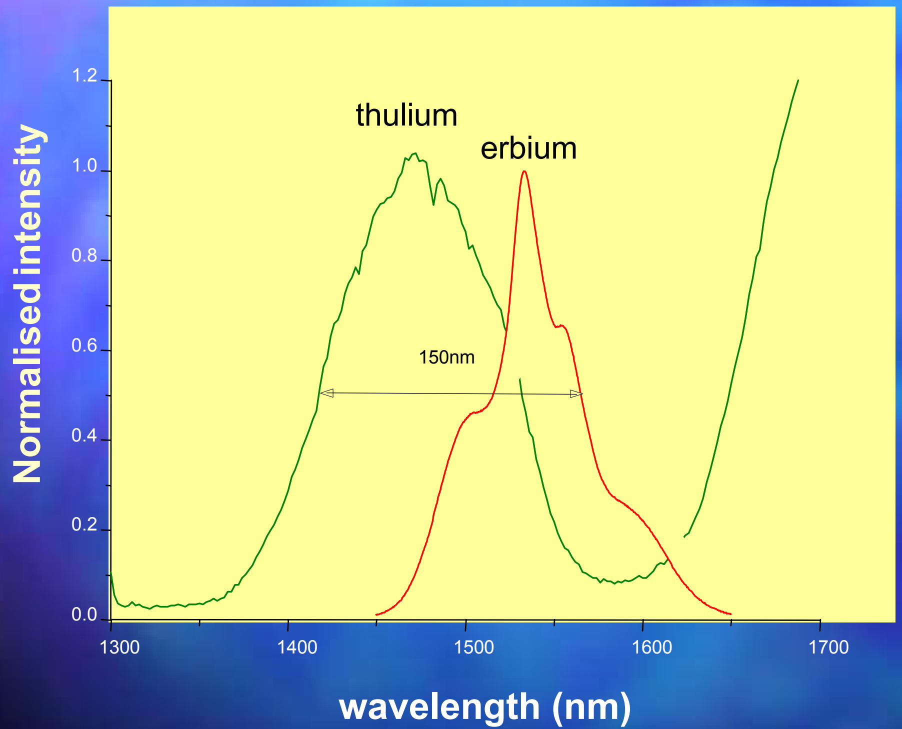
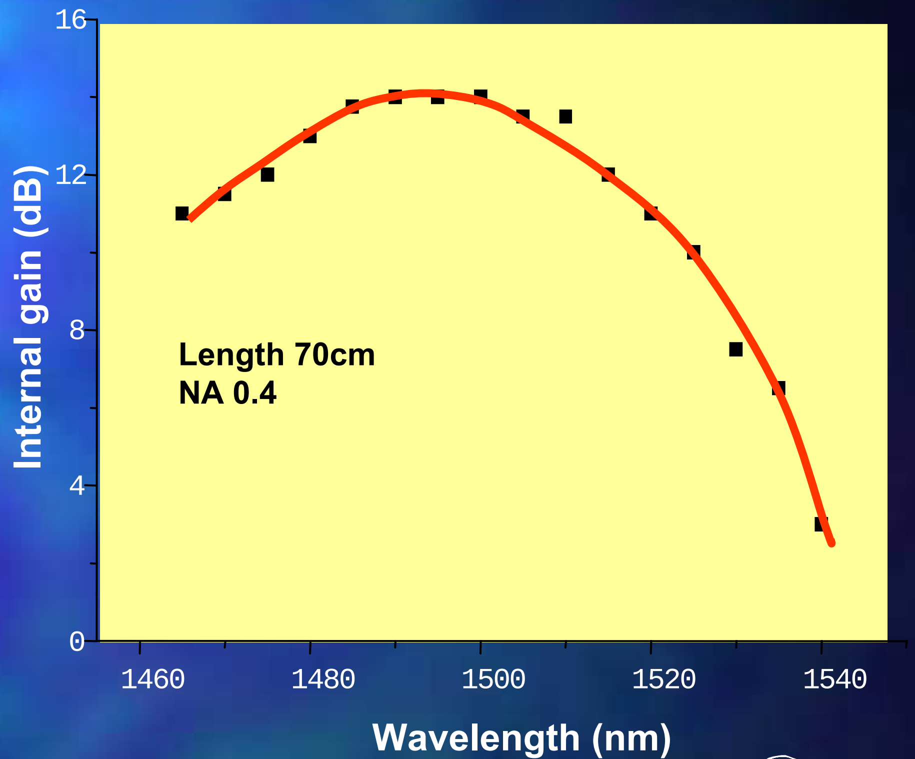
Spectral Region covered by Fiber Amplifiers

PDFA : Praseodymium-doped FA
TDFA : Thulium-doped FA
EDTFA : Erbium-doped Tellurite FA



Thulium-doped fibre amplifier





- Telluride glass fibre
- 800nm/1064 double pump scheme

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The Inventory Problem

The problem

- Components (transmitters, add/drops, routers) are DWDM channel-specific
- Large inventory required for 160-channel systems

The solution

- Make everything tunable (or pre-settable)
- The plug-and-play network?
- New fail-safe component configurations

Remote provisioning?

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Tunable Lasers

- Wide tunability allows wavelength self-routing
- Reduces the need for space switching
- Must be discretely tuned to the ITU grid
- Dark while tracking
- No mode-hopping, drift or increase in noise

- **These are tough requirements!**

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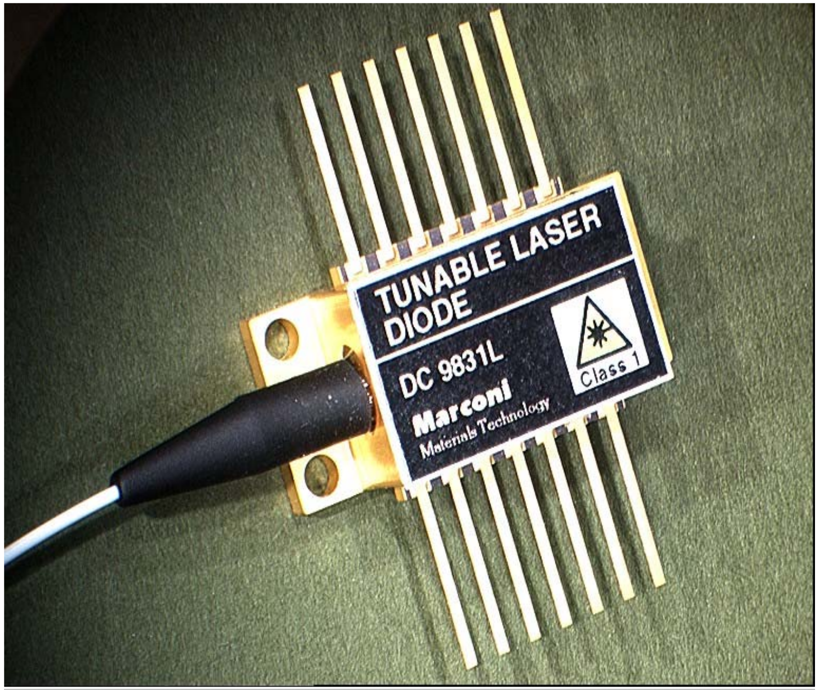
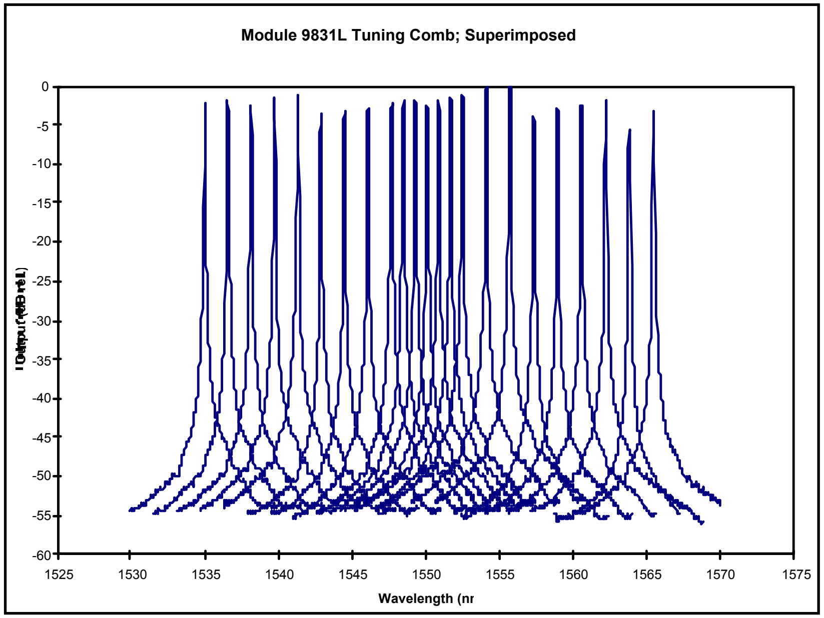
SG-DBR Tunable Laser Source

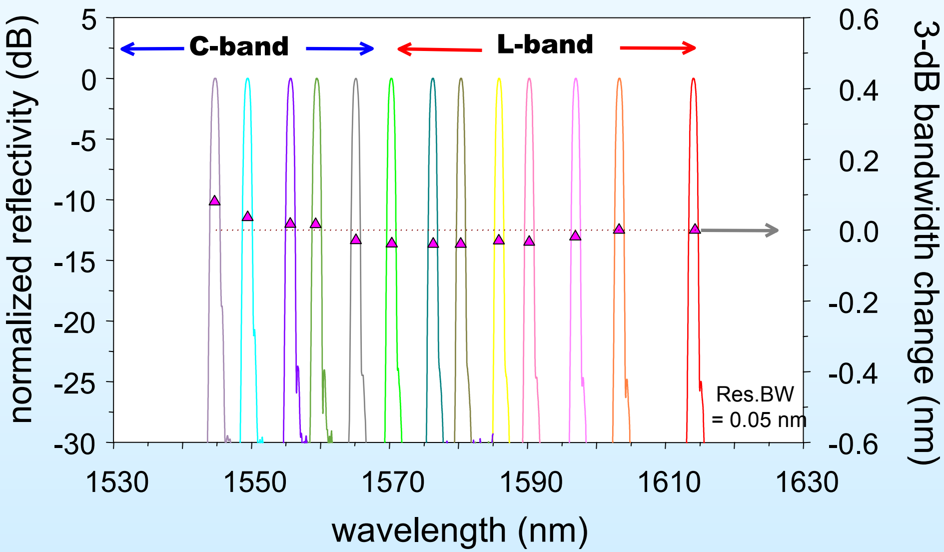
THIS COULD BE YOUR FINEST HOUR.



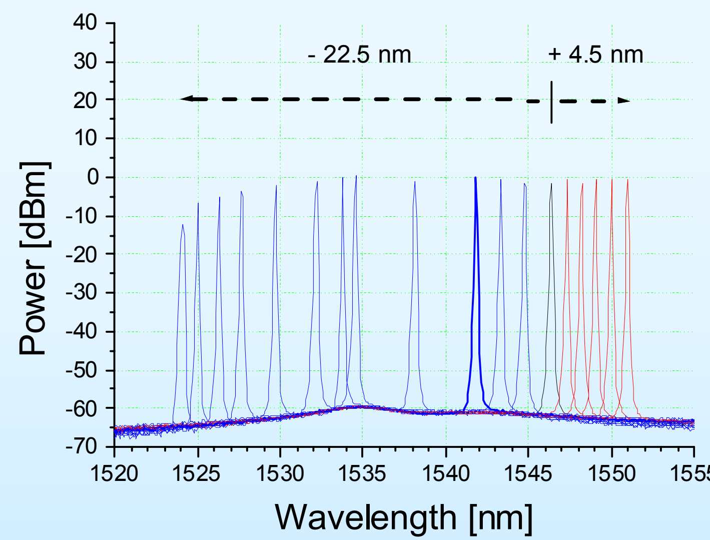


Tunable grating filters and DFB lasers

- *Compression*-tunable Bragg grating filter
  Record 70nm continuous tuning-range
  (1544nm – 1614nm)



- *Compression*-tunable fibre DFB-laser
- Continuous hop-free tuning



M. Ibsen *et al.*, *ORC* , 2002.

M. Ibsen et al., "Advanced fibre Bragg grating devices", *AIP-ACOFT'02.*

Optical Switching

- Large NxN switch matrix required (128x128) for networks
  - speed 1ms
- Fast (ps), sensitive switches required for processing
  - reshaping, switching

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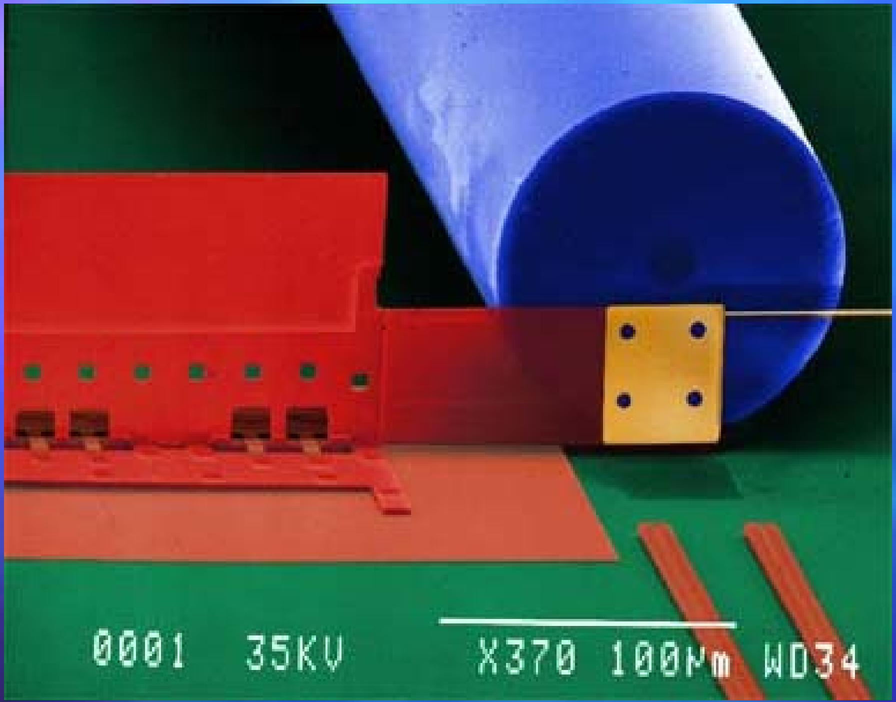
Slow optical switching



- The most effective optical switch is mechanical!
- The smaller the mass the faster the switch
- Speed in ms range at present
- VOA and NxN switches commercial

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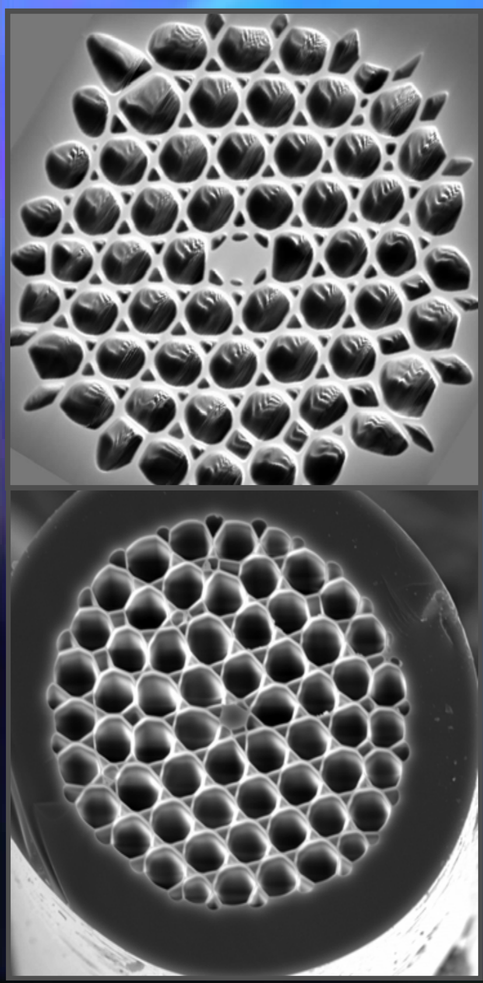
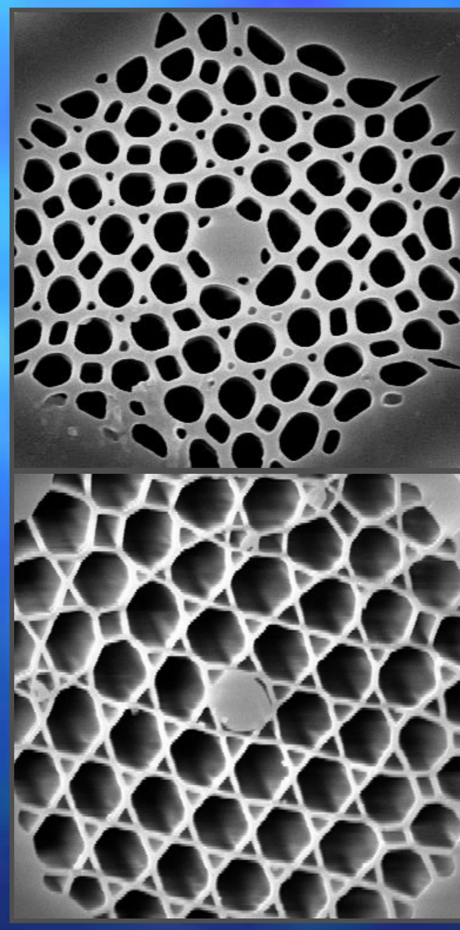
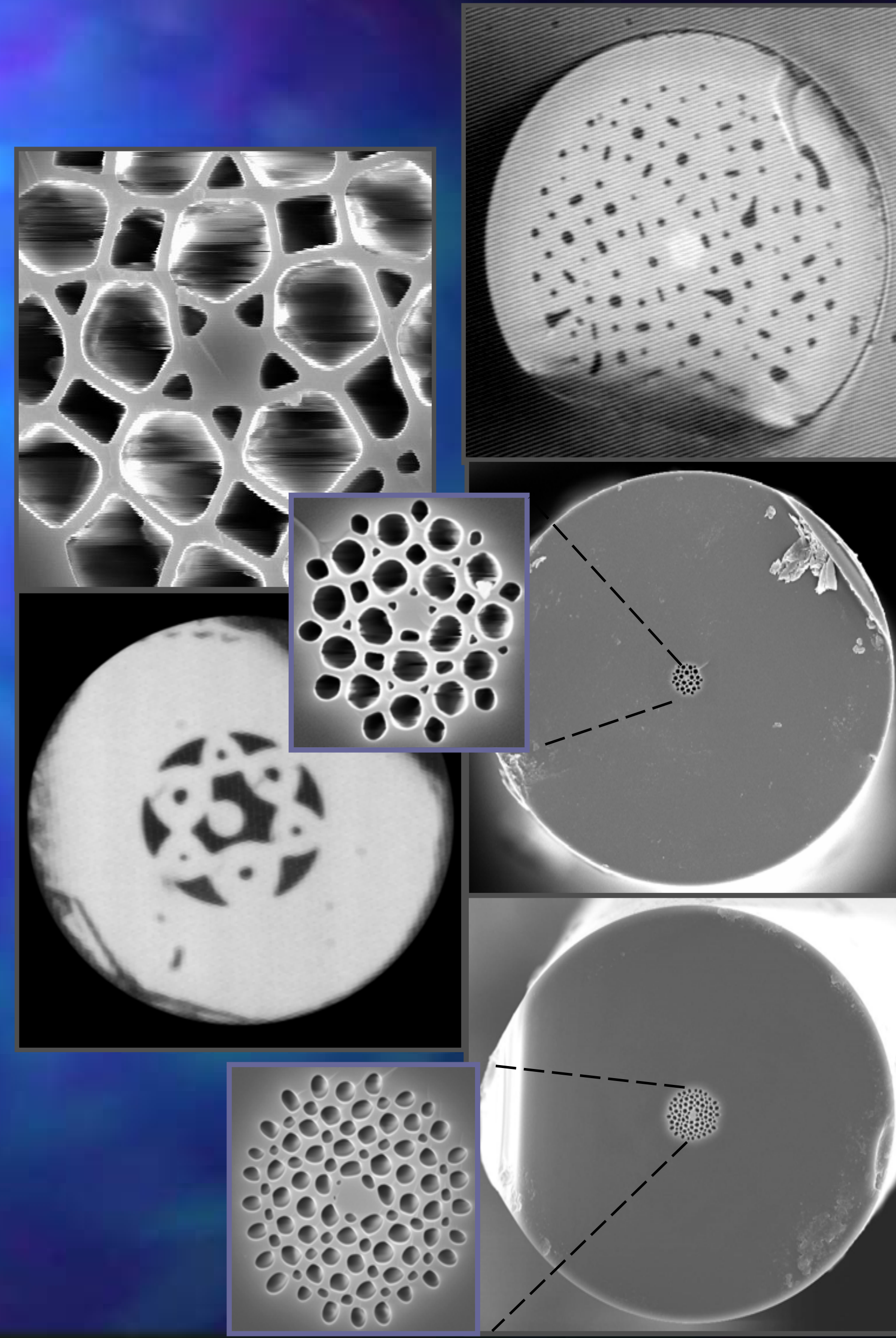
Ultra-fast switching:
Holey Fibres at the ORC…



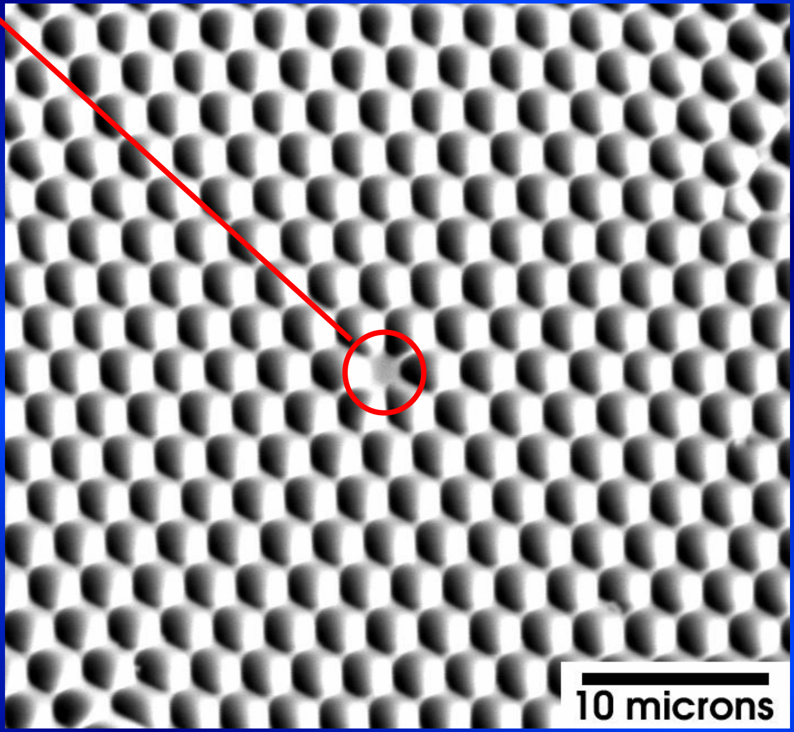




Background

Fibre core

Silica holey fibre



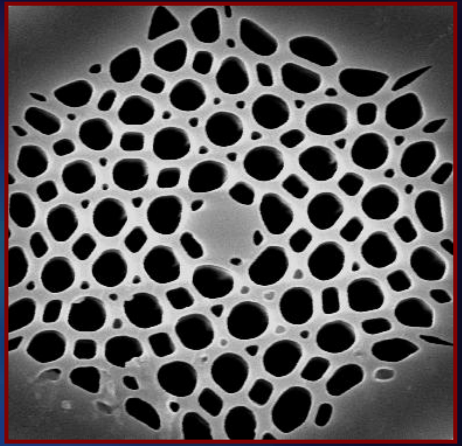
- Core formed by solid region
- Air holes act as fibre cladding
- Wavelength-scale features lead to novel optical properties
- Made by stacking capillaries

Small core ($3 um^2$)
+
large air-fraction cladding

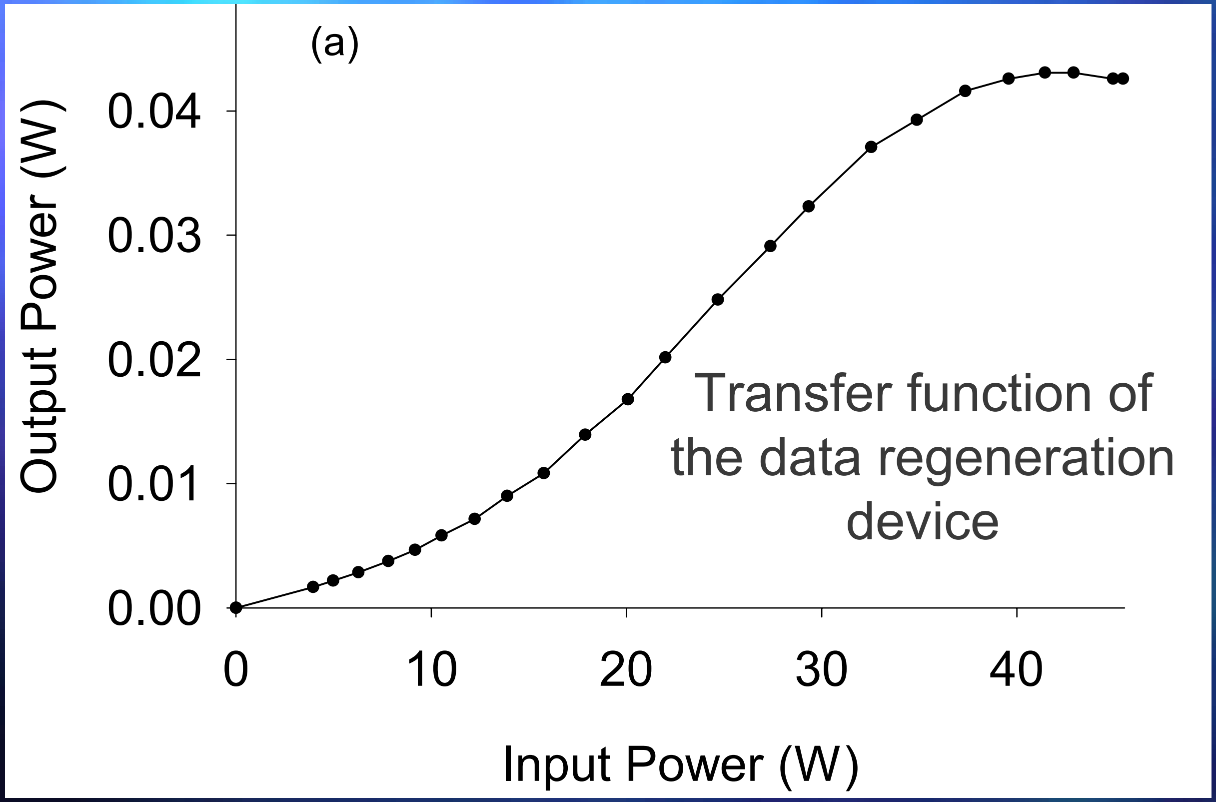
→ **Tight mode confinement**

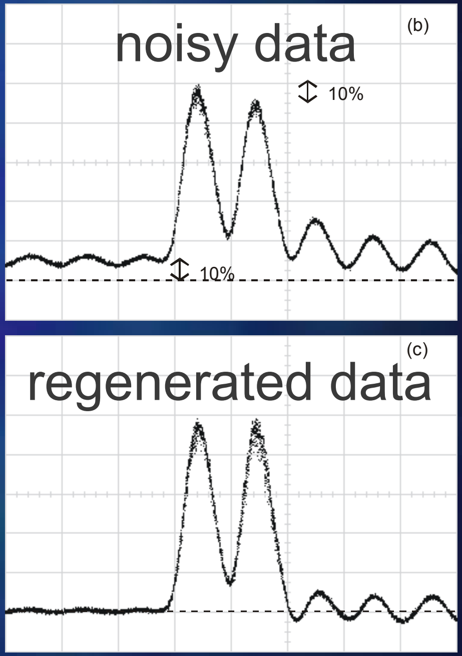
→ **Low switching threshold**

Switching/regeneration Results



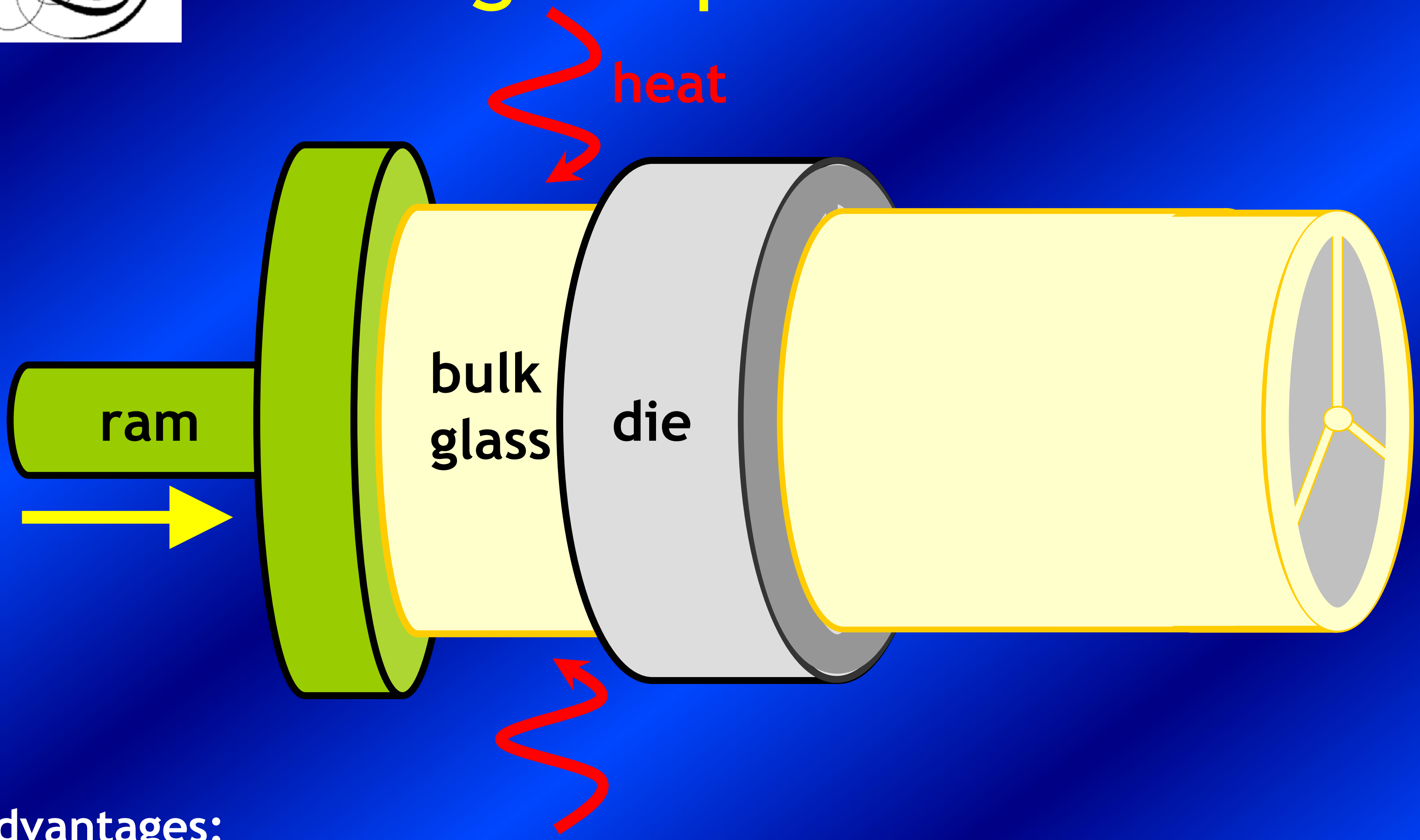
All optical switch using 3m HF, 16W switching power





- **Further large reductions in switching power by using soft glass**

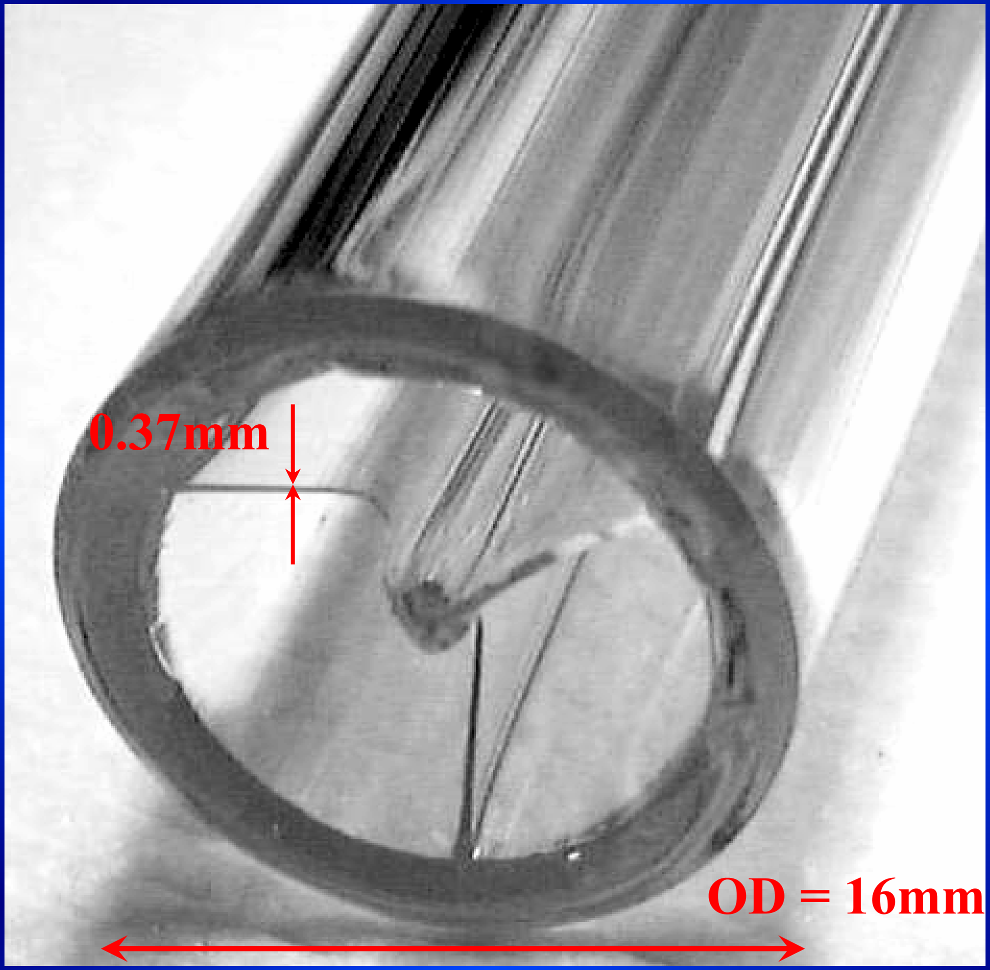
Soft-glass preform extrusion

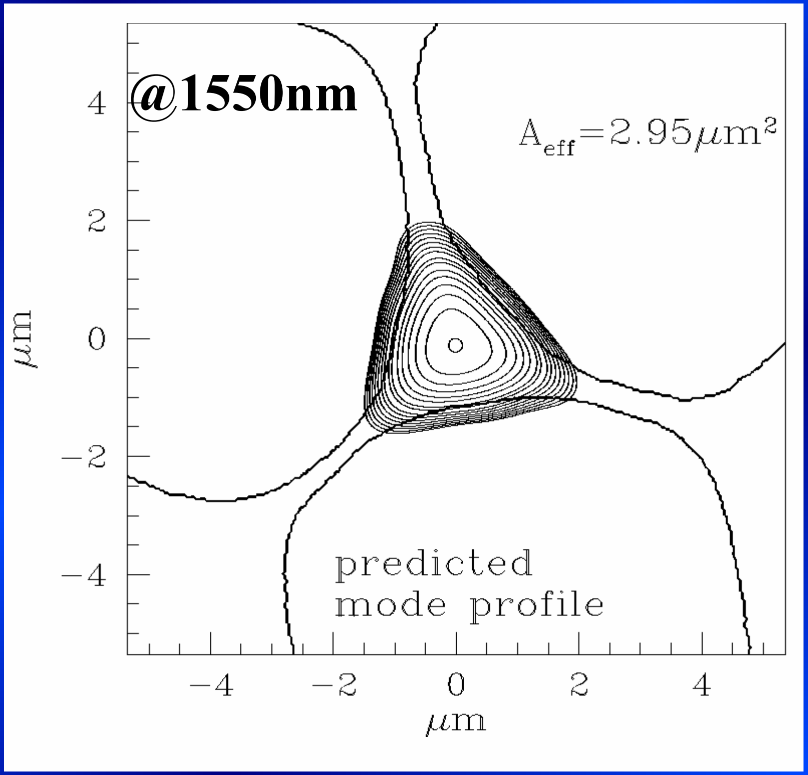


Advantages:

- Controllable/Reproducible
- Good surface quality
- Efficient use of glass
- Fewer interfaces c.f. stacking
- Wider range of profiles possible
- Suitable for many materials

SF57 Extruded preform

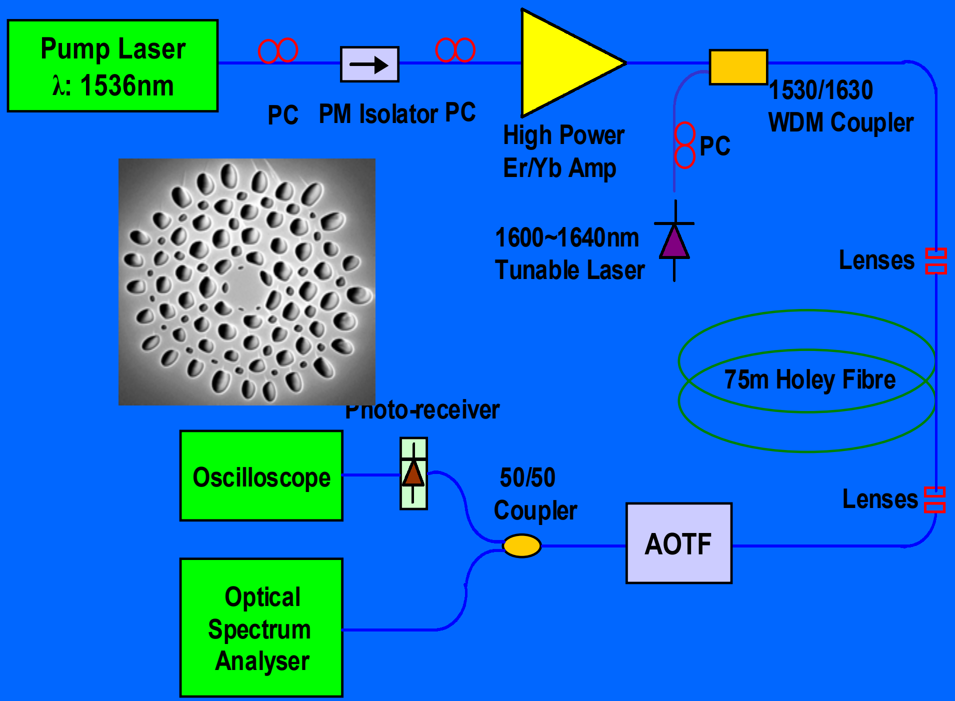


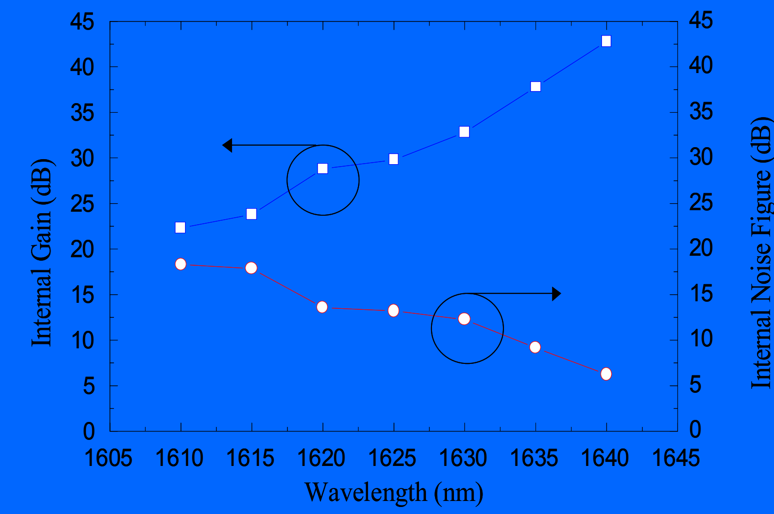


Can be polarization preserving
Dispersion ≈100ps/nm/km (anomalous)

SF57 glass has nonlinearity 20x silica

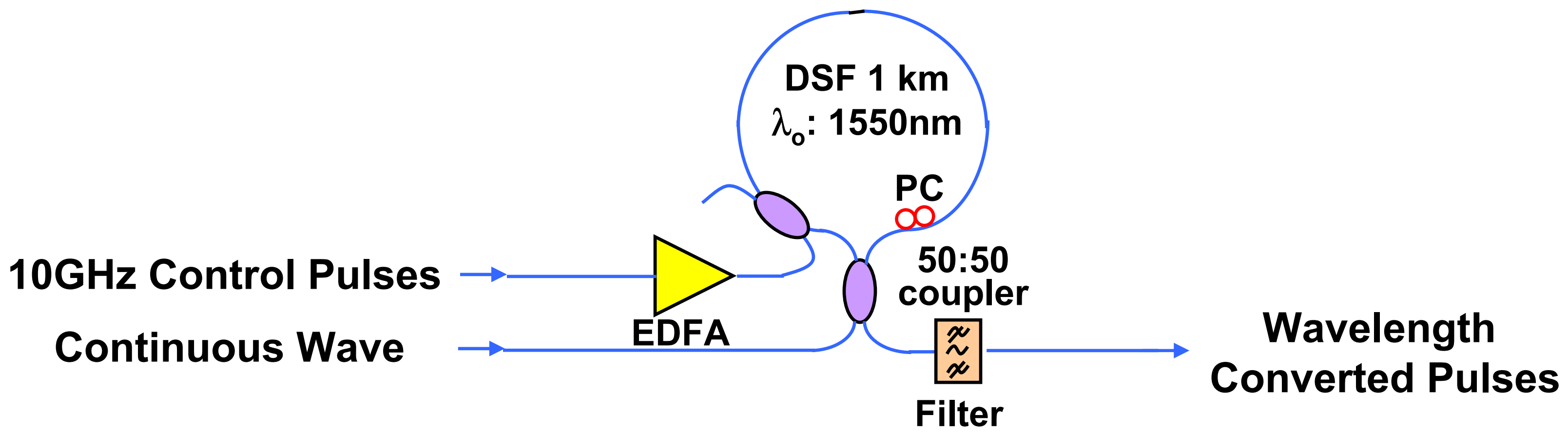
Holey Fibre Raman Amplifier

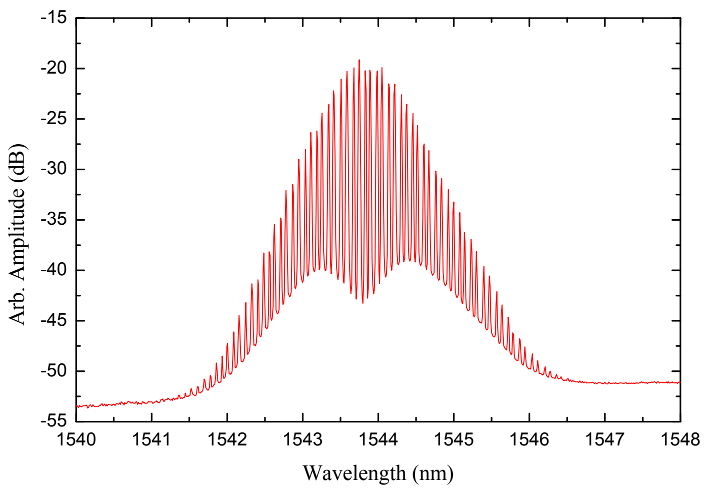


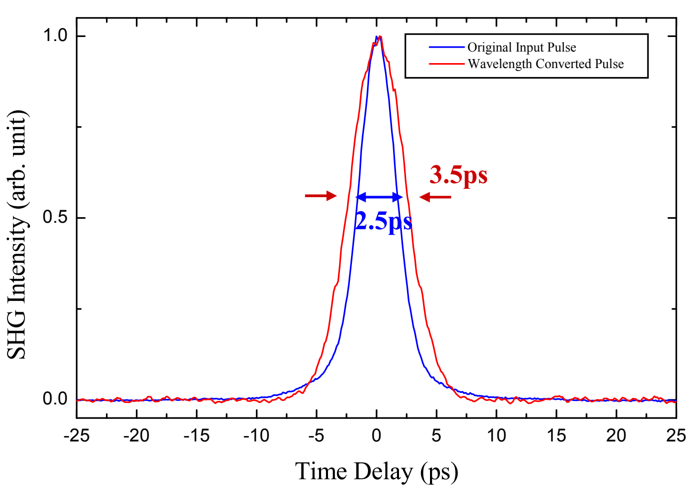


- High nonlinearity fiber gives reduced device length/pump power
- Pumped using high power amplifier
- Gains up to 42dB, noise figure 6dB demonstrated

Wavelength Conversion through a Nonlinear Optical Loop Mirror







Pervasive power

- The cost of pump diodes is dropping rapidly
- Costs drop per Watt for large-area high-power devices
- Costs will be driven by the emerging industrial solid-state laser market (cutting, welding, defense)

Opportunities for: parallel-pumping of telecom devices
short-pulse instrumentation
X-ray generation

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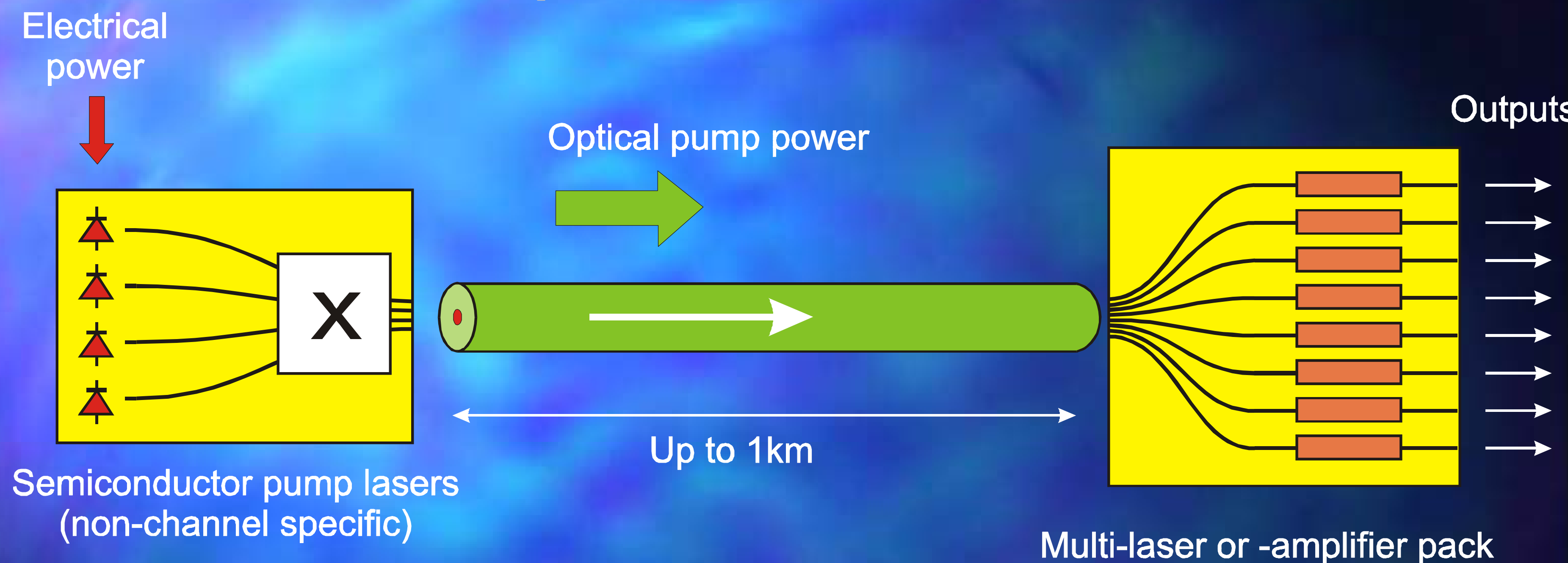
The Optical Power Rail



Advantages

- Power management at convenient locations
- Cost savings by sharing reduced no. of SDLs
- Built-in SDL pump redundancy
- Inventory problem solved by non-channel-specific SDLs

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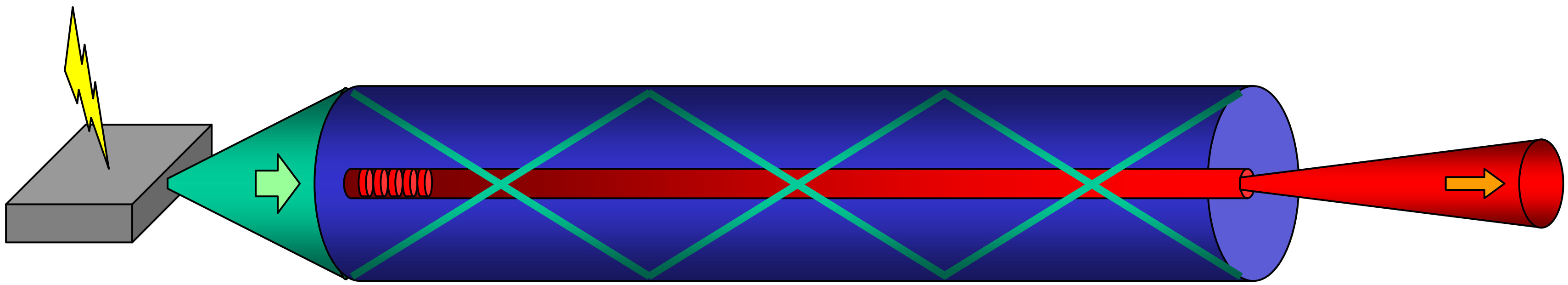
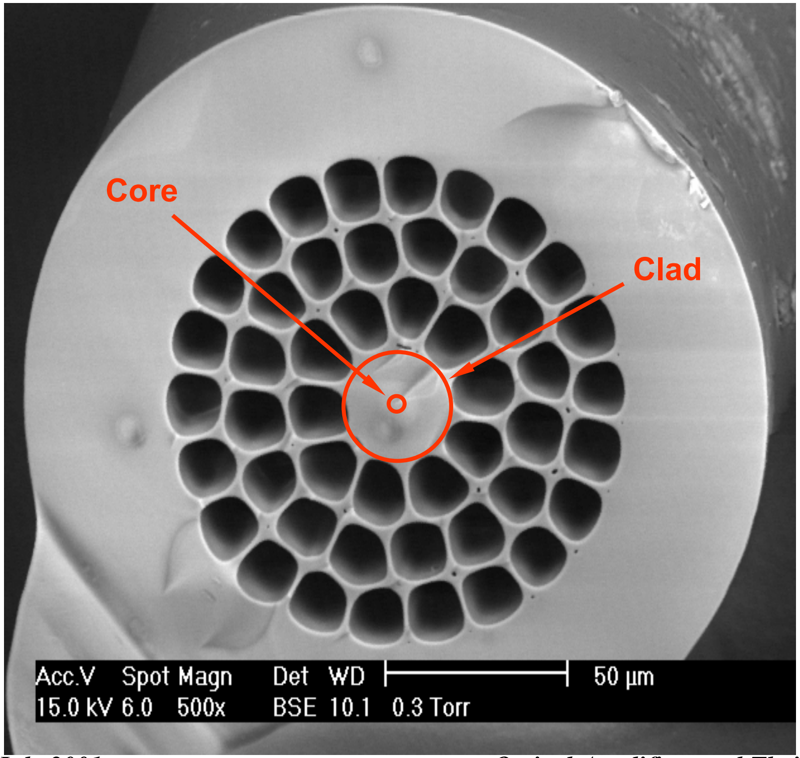
Cladding Pumped Fibre Device



- Large inner cladding guides MM pump beam
- RE-doped core converts pump to high brightness signal
- Core diameter – 5- 50 mm
- Pump cladding diameter 50 – 500 mm
- Device length 1 – 100 m (depends on core/cladding ratio)

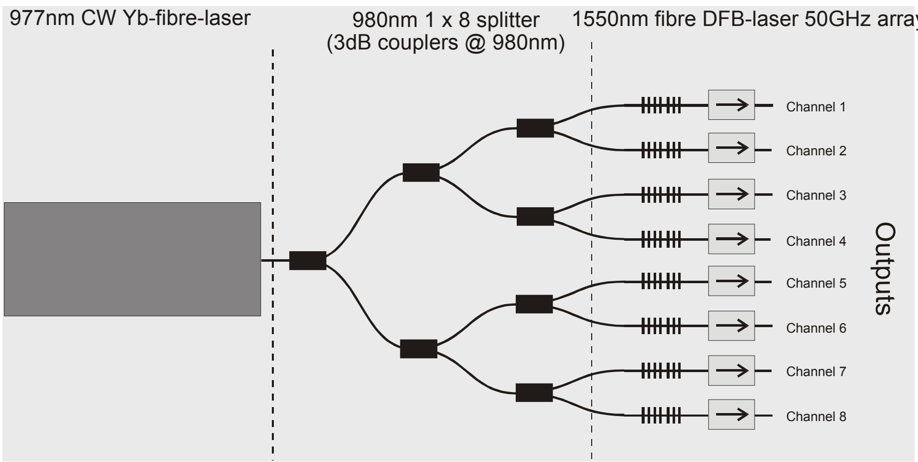
976 nm Fibre Laser: Yb-Doped Fibre



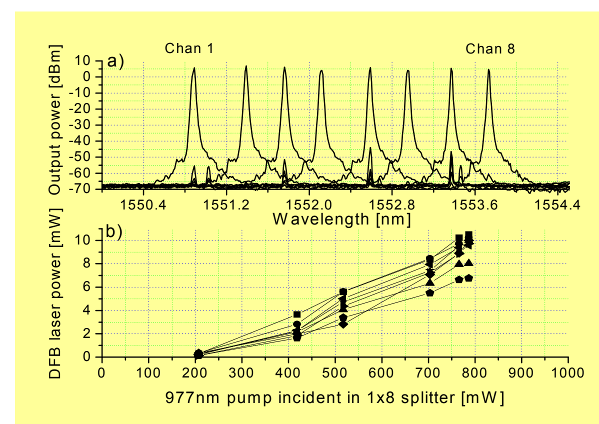
- Pump cladding – 35 µm
- Pump NA= 0.4 nm
- Fibre efficiency > 70%
- Device length – < 40 cm
- 2W output at 976nm

8-channel DFB Array

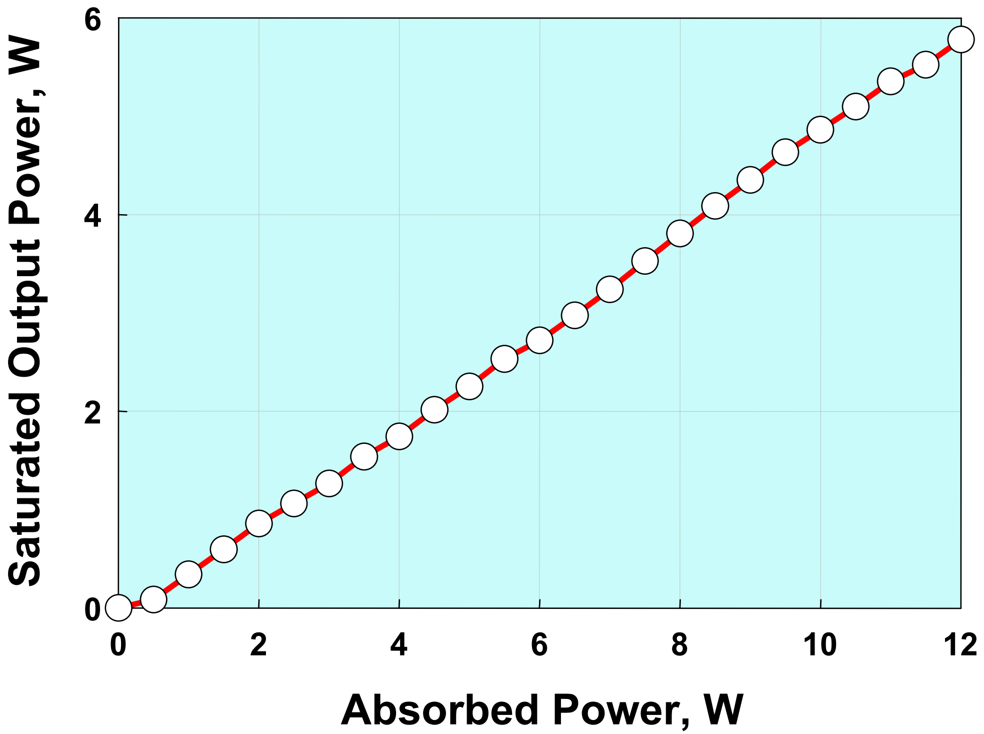
Module Layout



- Single fiber pump source
- 10 – 16 dBm channel output
- Shared pump prevents channel failure



High Power Er/Yb Fibre Amplifier



- 5.5 W output power at 1550nm
- Efficiency close to theoretical limit
- Small signal gain >50dB
- Noise < 5dB 1533 -1560nm

Scalable to 1kW and above?

Optical Component Cost Is the Problem

- Long-Haul is relatively insensitive to cost
- Metro and FTTH are very cost sensitive
- Optical components and subsystems assembly is still done manually!
- New low-cost manufacturing techniques - replication, stamping, polymers
- Automated process machinery becoming available

There is no optical equivalent of silicon!

How far have we got with partial integration?

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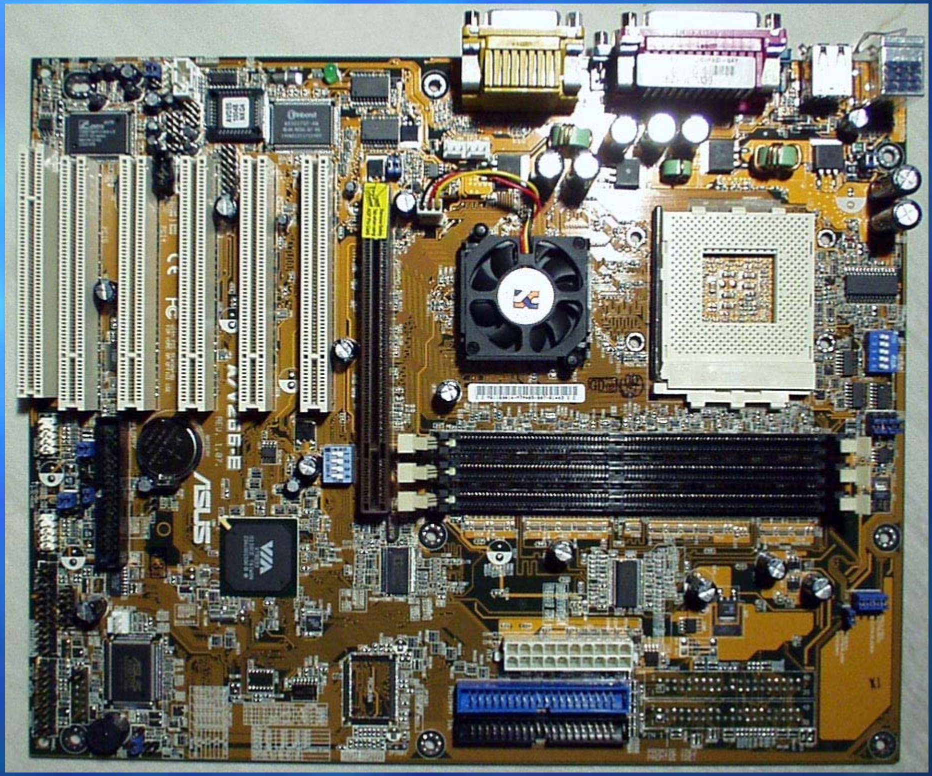
Just how integrated is electronics?



PC motherboard

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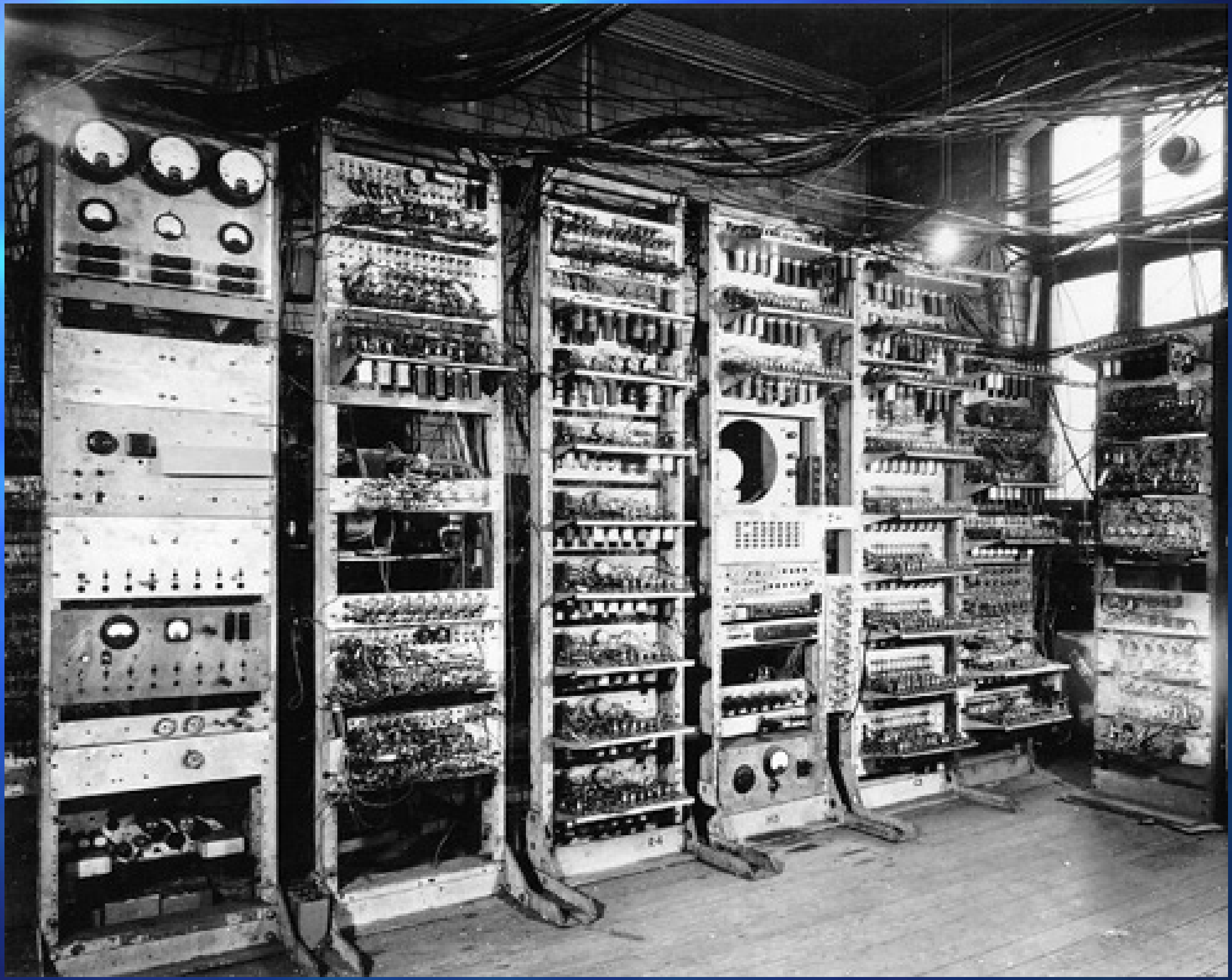
Photonics in its infancy



1948 Manchester Mk1 valve computer

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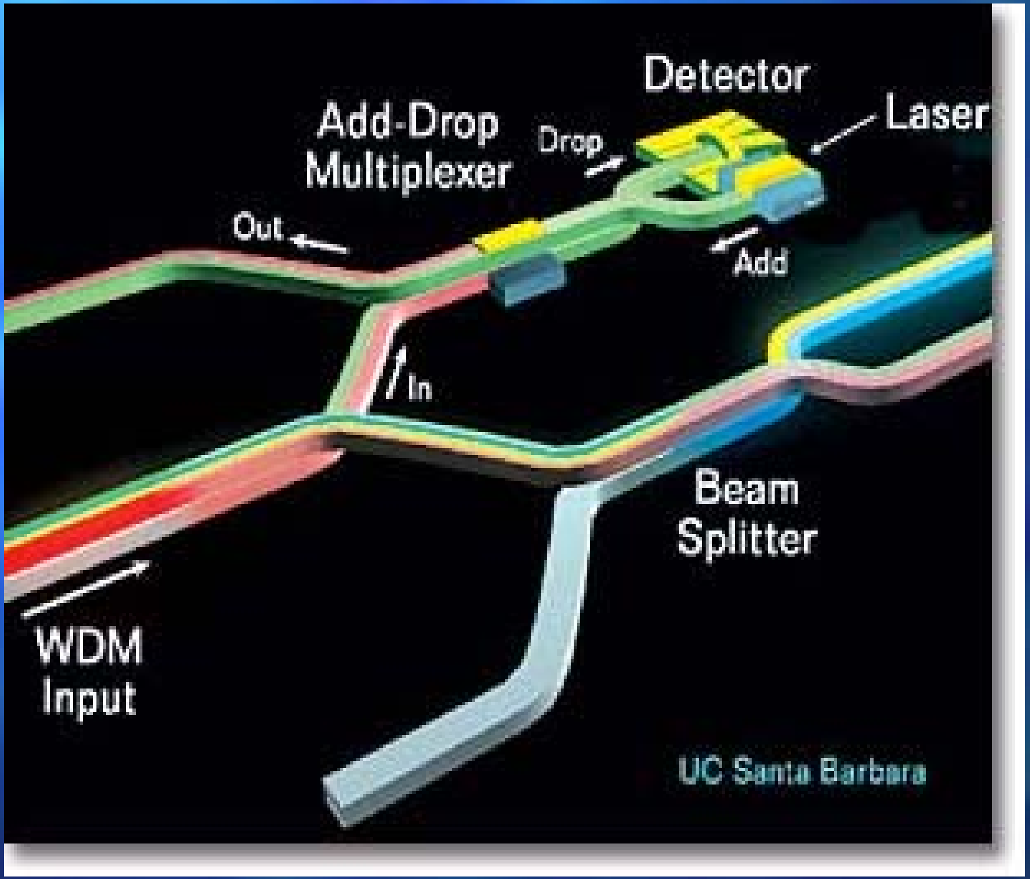
Photonic integration



- **3-dimensional optical circuits give increased freedom**

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New planar waveguide technologies

- Parallelism of WDM has driven planar optical circuits
- New low-cost technologies needed (polymers, replication etc)
- Thermal stability a major issue
- 3-dimensional waveguides?
- Why not compound glass?
- Will we sacrifice performance for cost?

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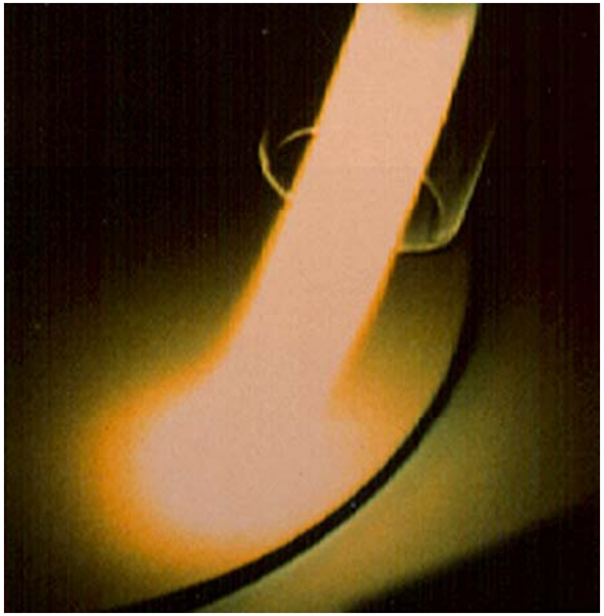
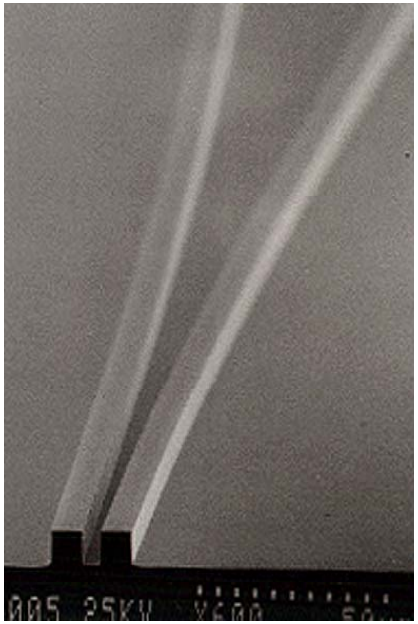
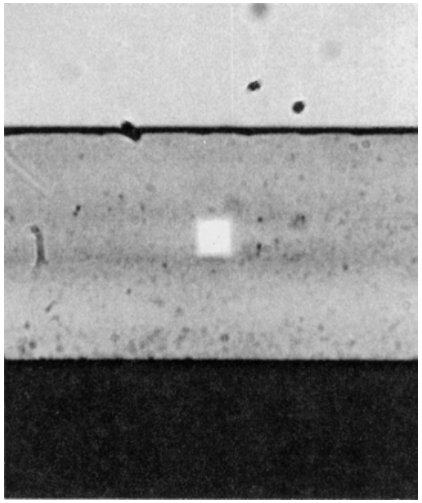
Silica-on-silicon glass Deposition and Core Structures



Glass deposition in FHD

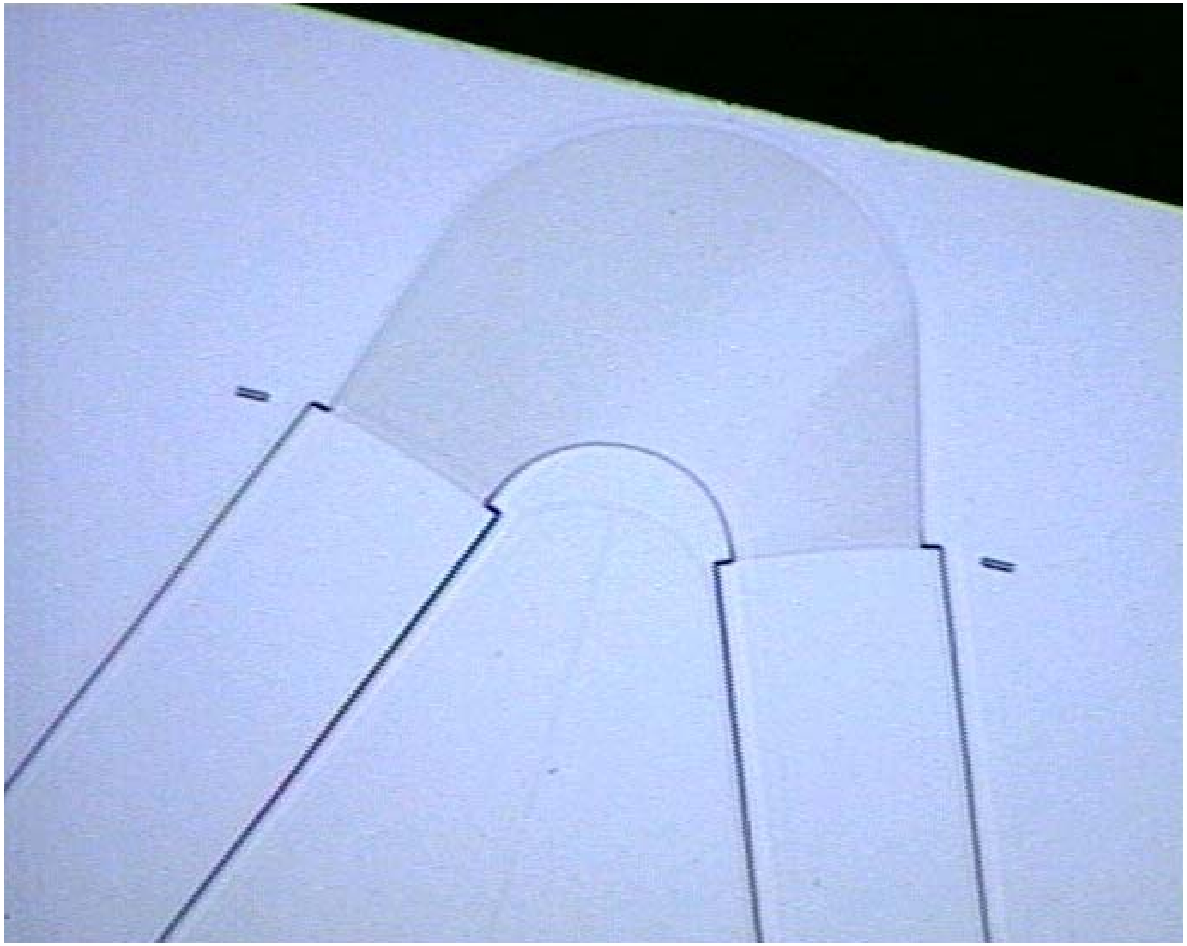


Core ridge structures in directional coupler after RIE



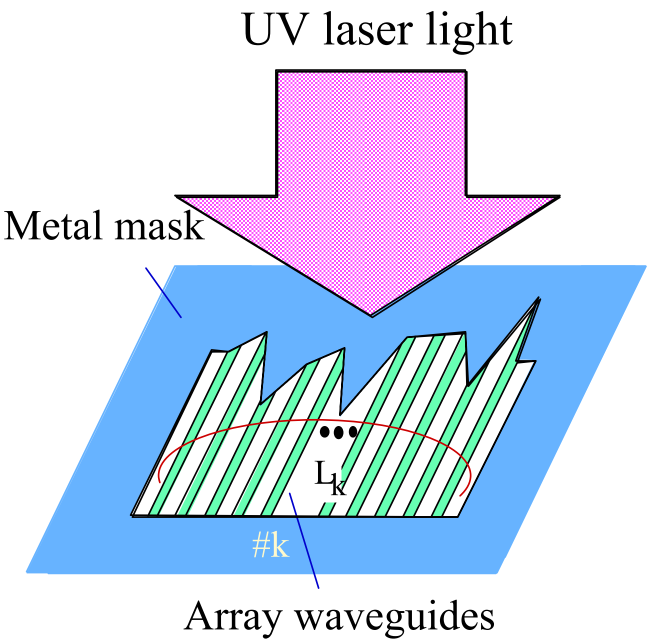
Embedded core

Close-up View of AWG

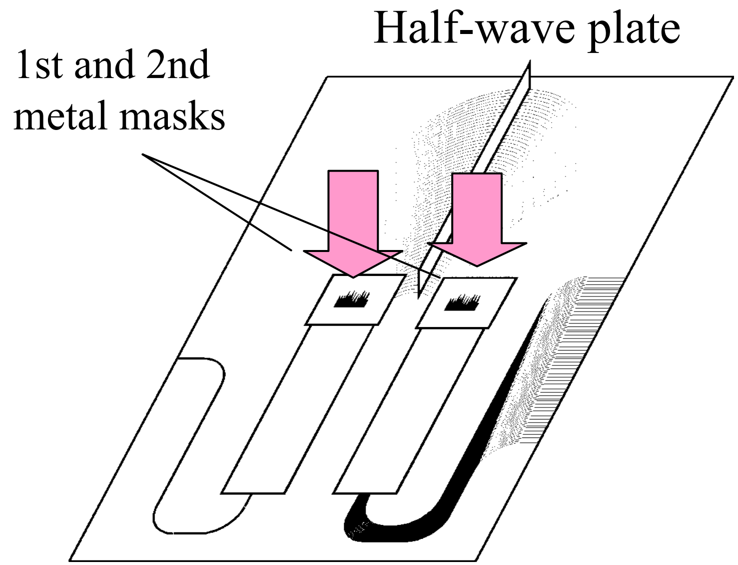


Phase-Error Compensation using UV Irradiation

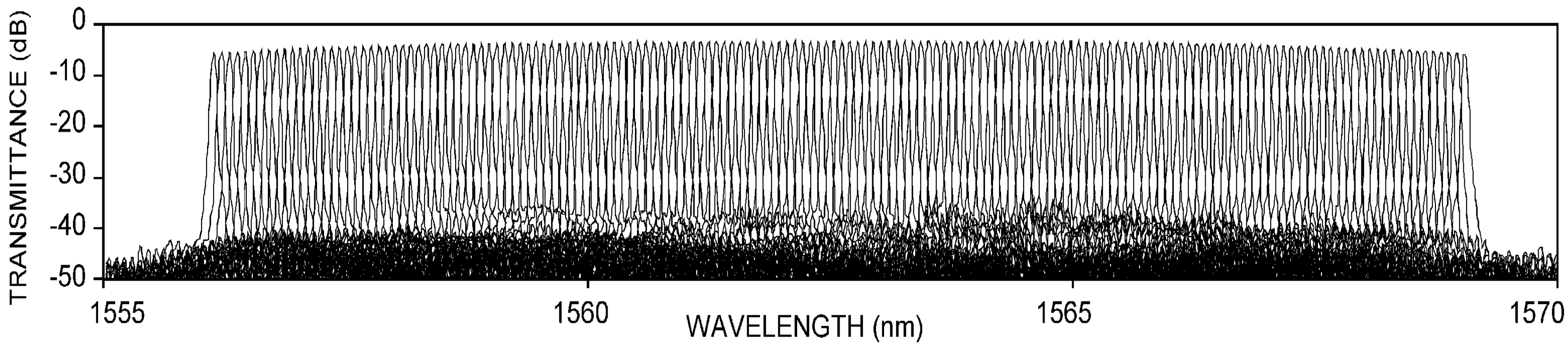
NTT
Photonics Labs.



(a) Collective phase trimming

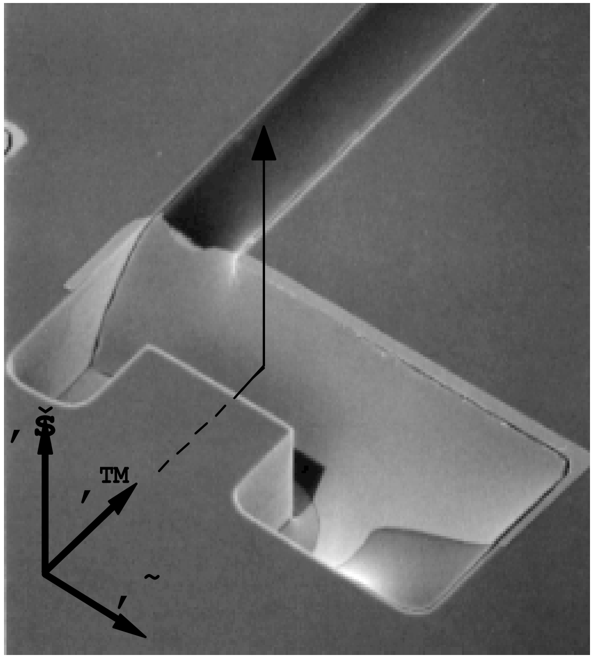


(b) UV irradiation through metal masks

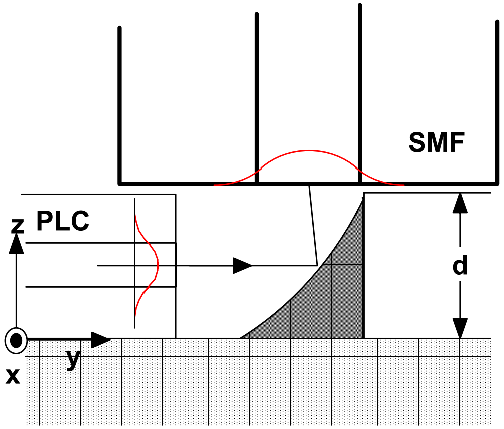


(c) Transmission characteristics of 160ch-10GHz AWG

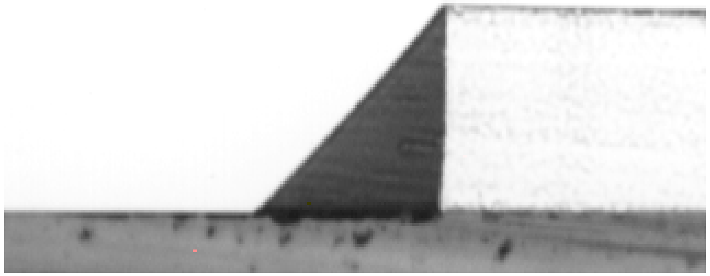
PLC Micro-mirror for Surface Coupling



Bird'-eye view



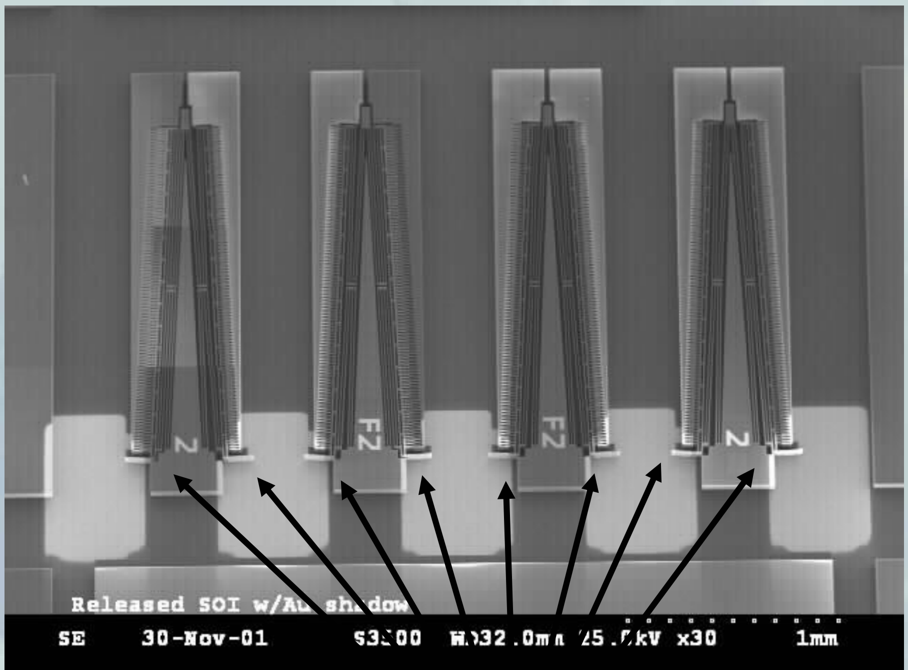
Cross-sectional configuration



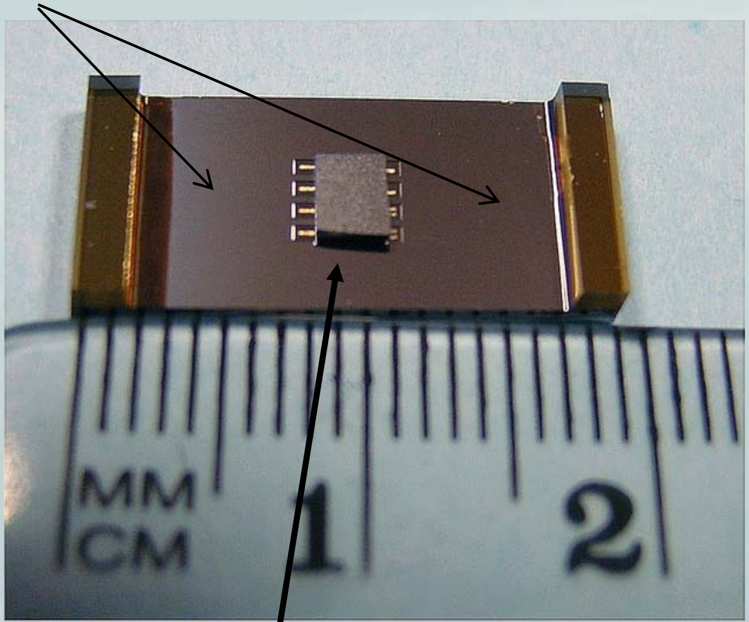
Cross-sectional photograph

Silica Platform + Flip-chip MOEMS

Silica waveguides



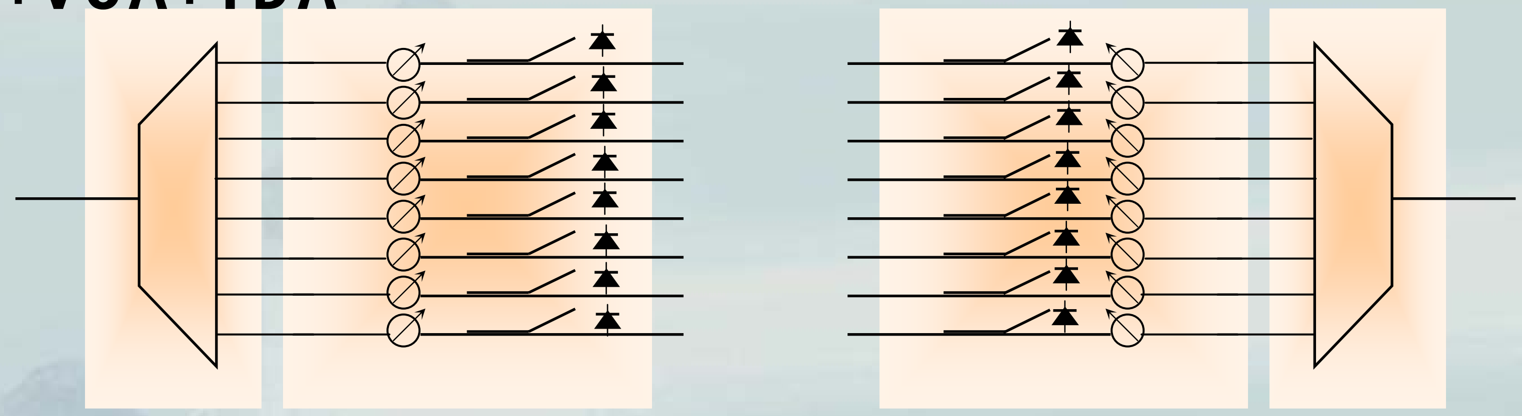
8 array MEMS chip

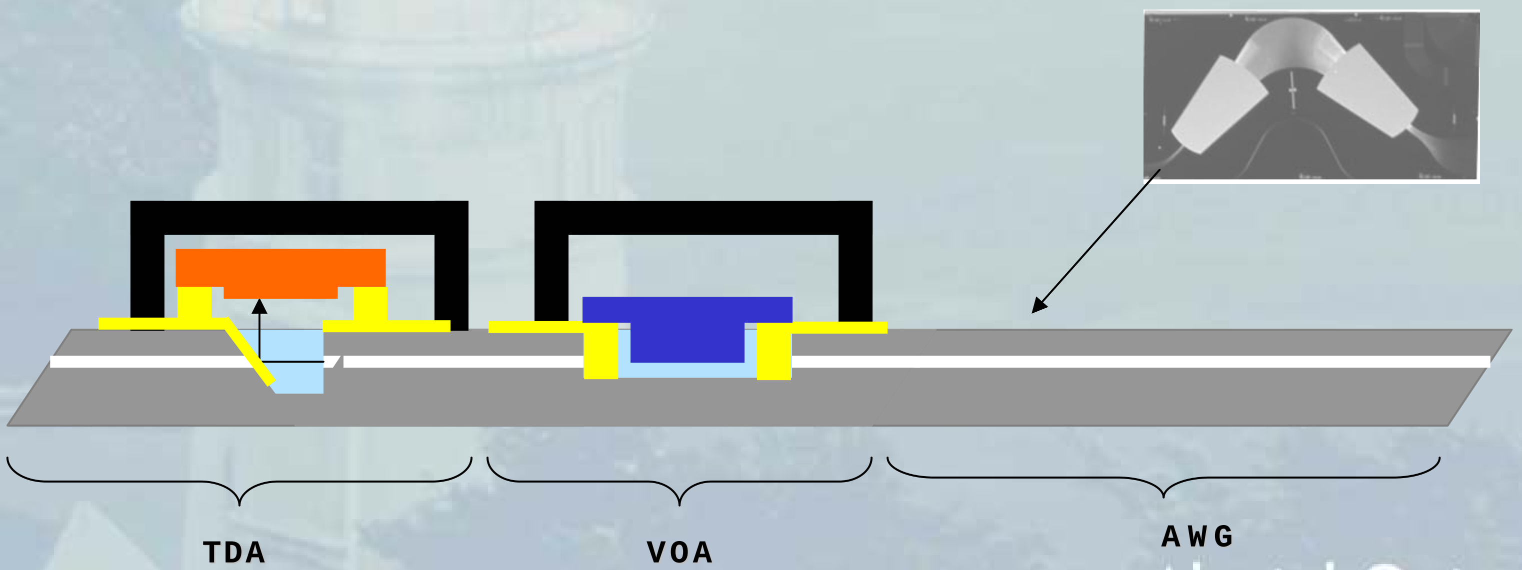


8 array MEMS chip flip-chip mounted on SiO2/Si hybridisation platform for 8 channel VOA

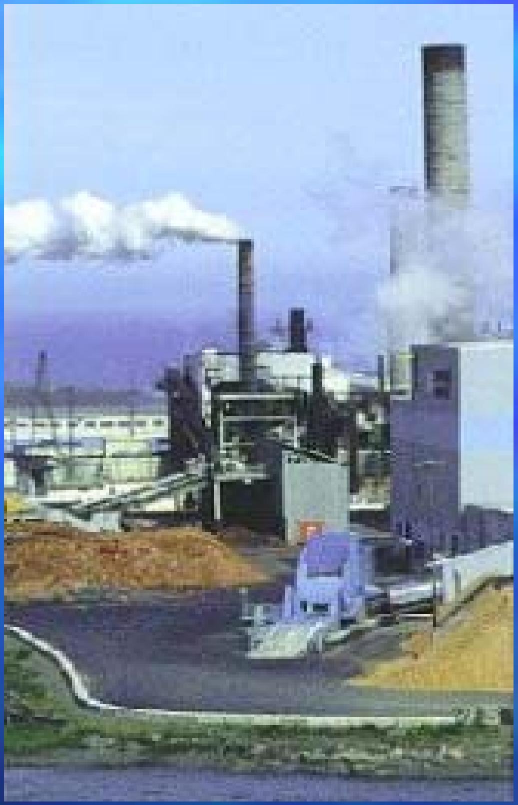
Passive/MOEMS Hybrid Integration

AWG+VOA+TDA





Glass or semiconductor technology?



Cheap optical fibres

Expensive components

- **Can we bridge the gap?**

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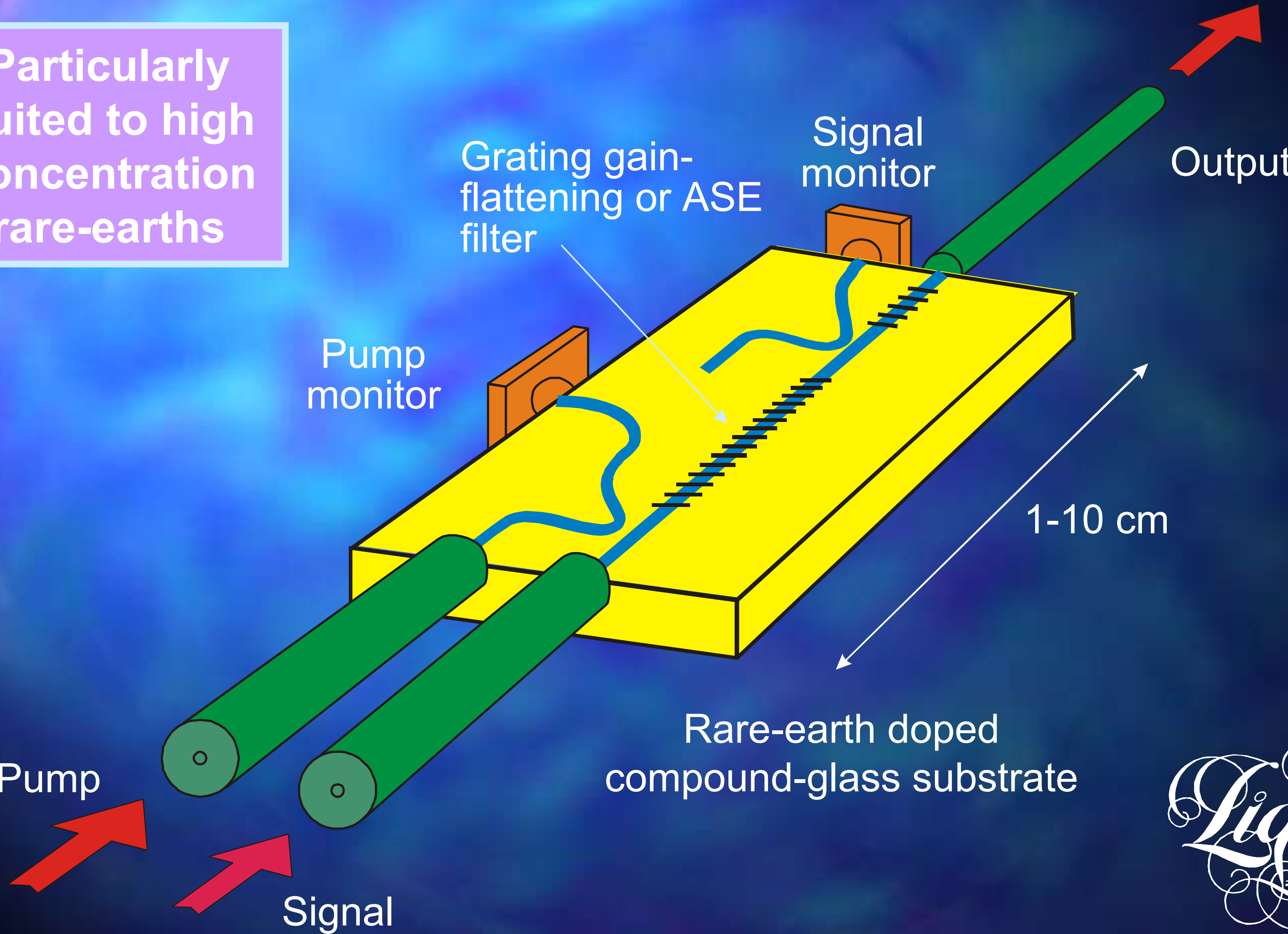
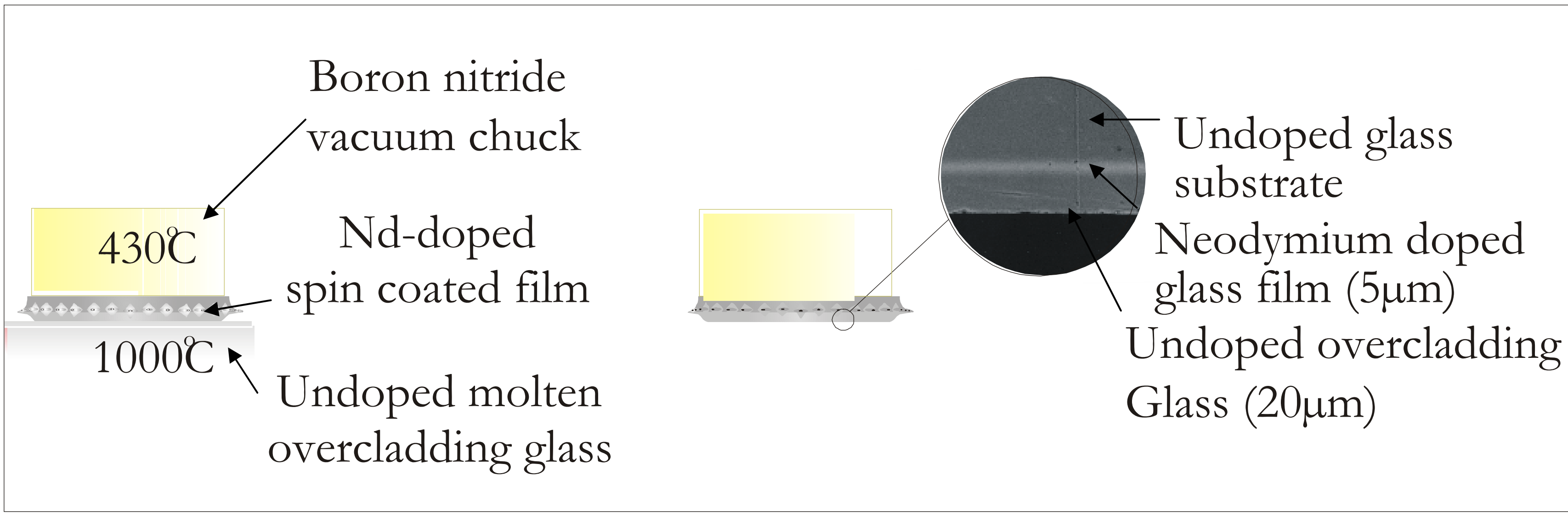
Planar Amplifiers

Particularly suited to high concentration rare-earths



University of Southampton

Hot Dip Spin Coating of Planar Glass Waveguides



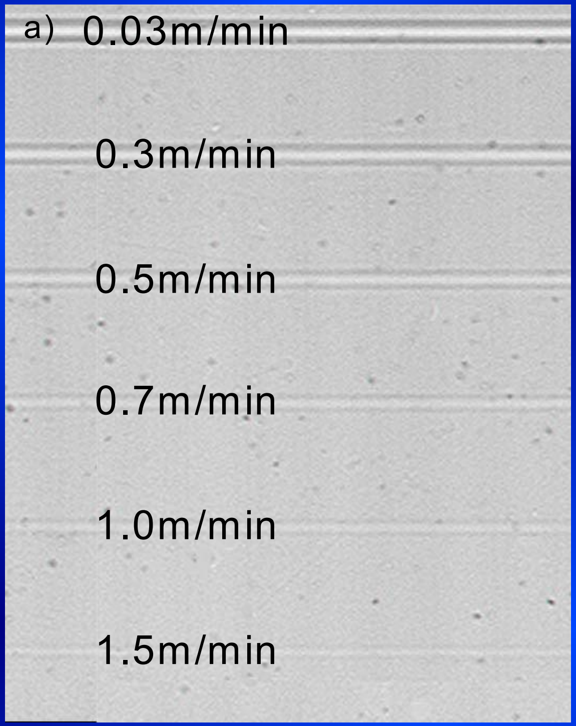
- UV writing lowers refractive index of channel.
- Use 2-Step process to produce 5µm thick planar waveguide.
- Guide between channels pumped at 800nm (100mW).
- Lasing at 1317nm observed.

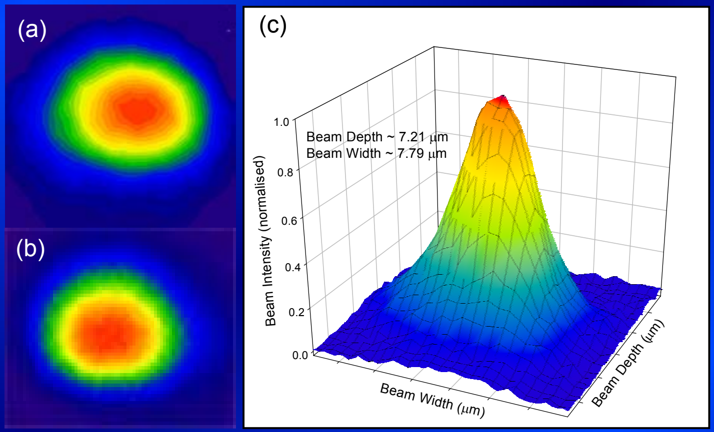
or photorefractivity

- Cerium doping leads to strong UV absorption
- CW exposure with frequency doubled argon ion laser and 6u spot
- Writing speed 1.2-630mm/min
- Laser power 0.5W

CD and DVD rewritable technology is thermal!

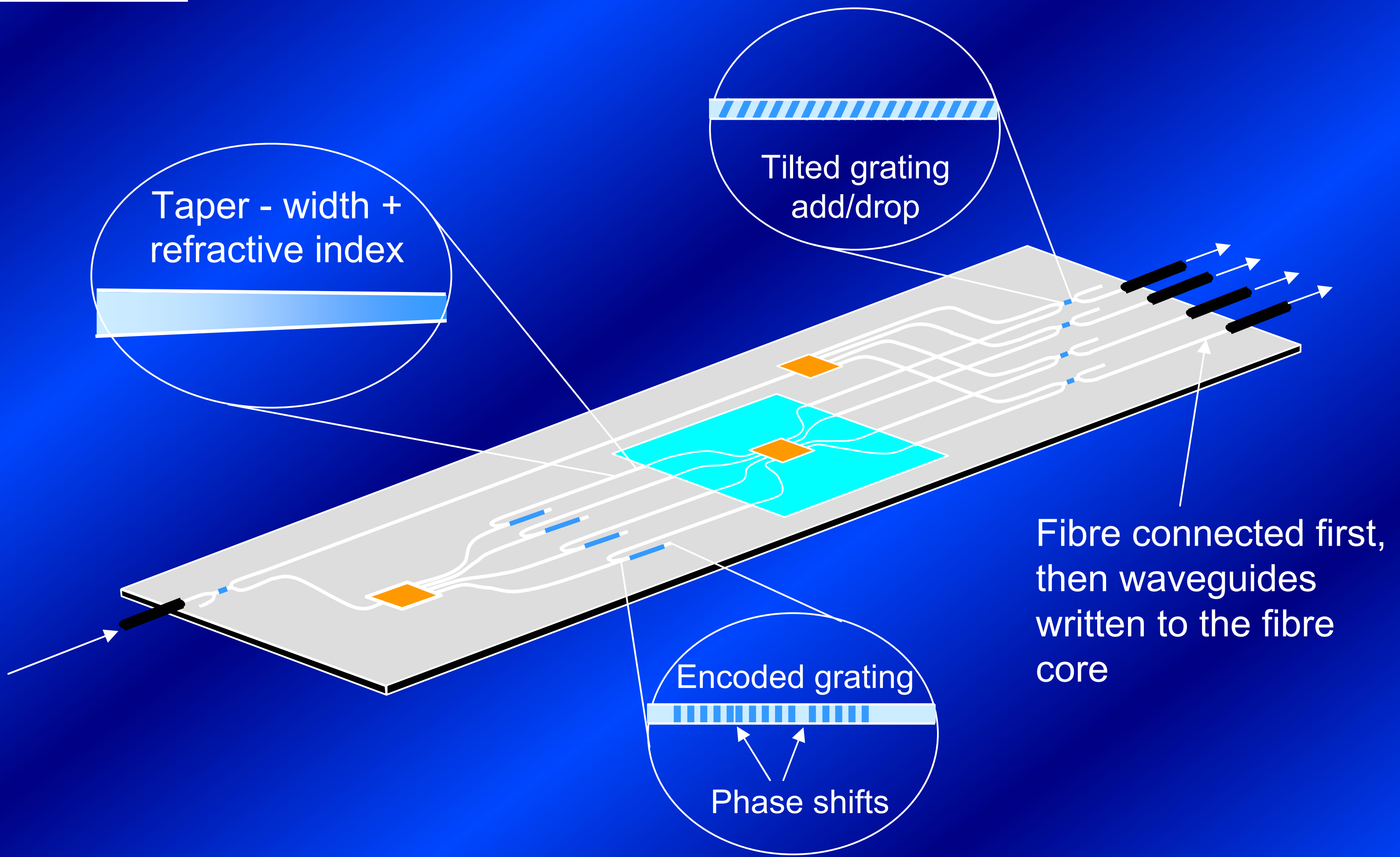
Channel Waveguides in GLS glass





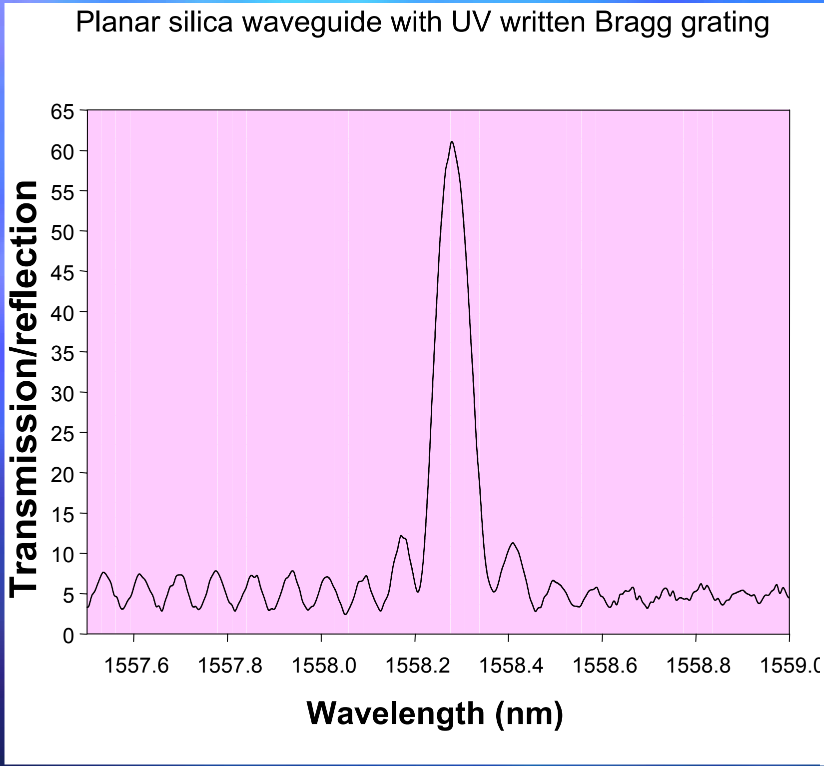
Losses 0.38 ± 0.05 dB/cm

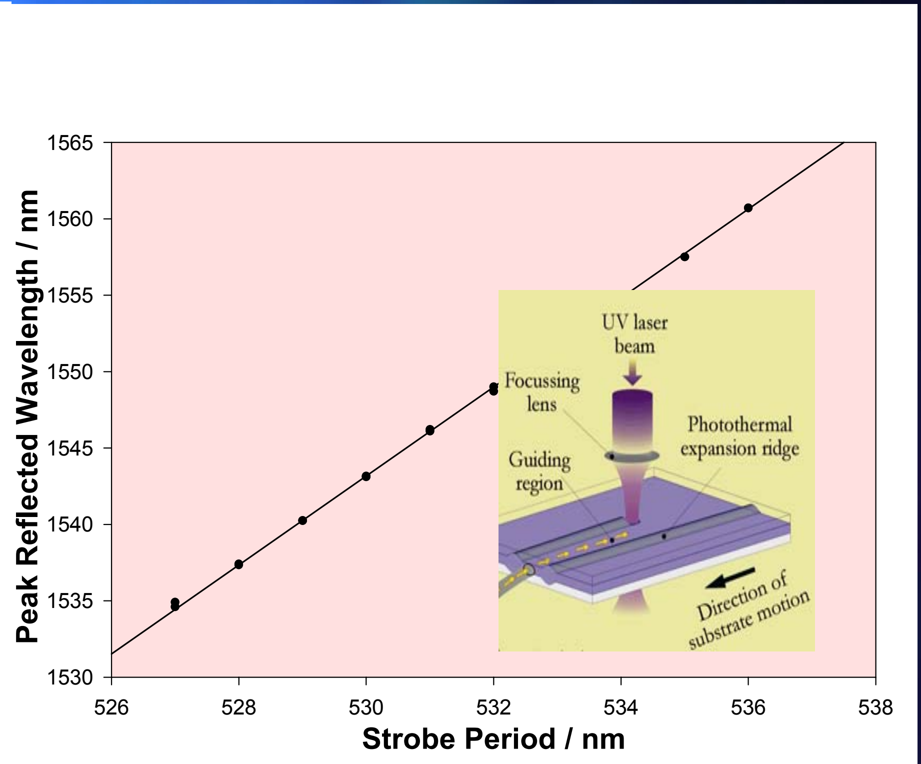
Simultaneously UV-Written Planar Waveguides and Bragg Gratings



- Gratings can be chirped, appodised and contain phase shifts
- Waveguides can be aligned to the fibre rather than the fibre to the waveguide
- Mode converting tapers

UV-written waveguides with Bragg gratings

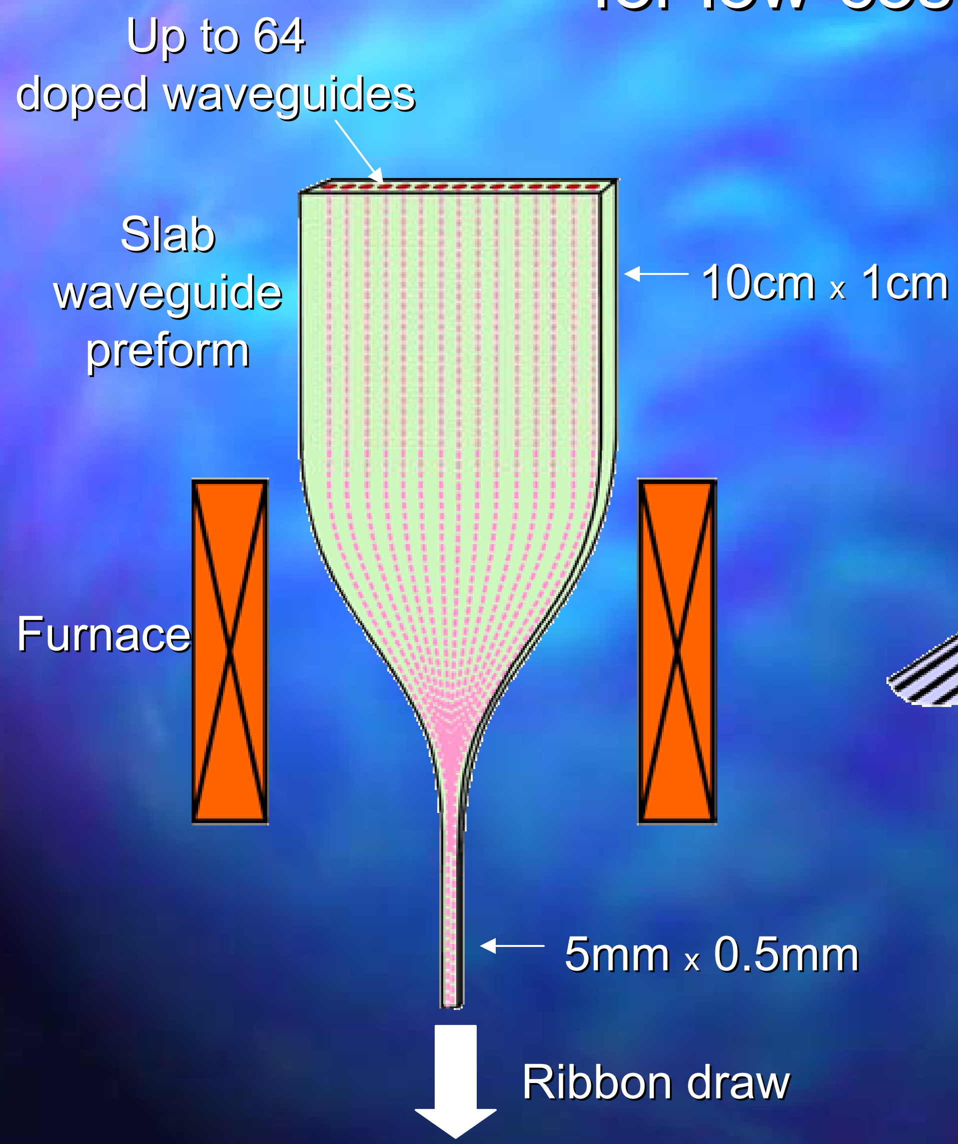


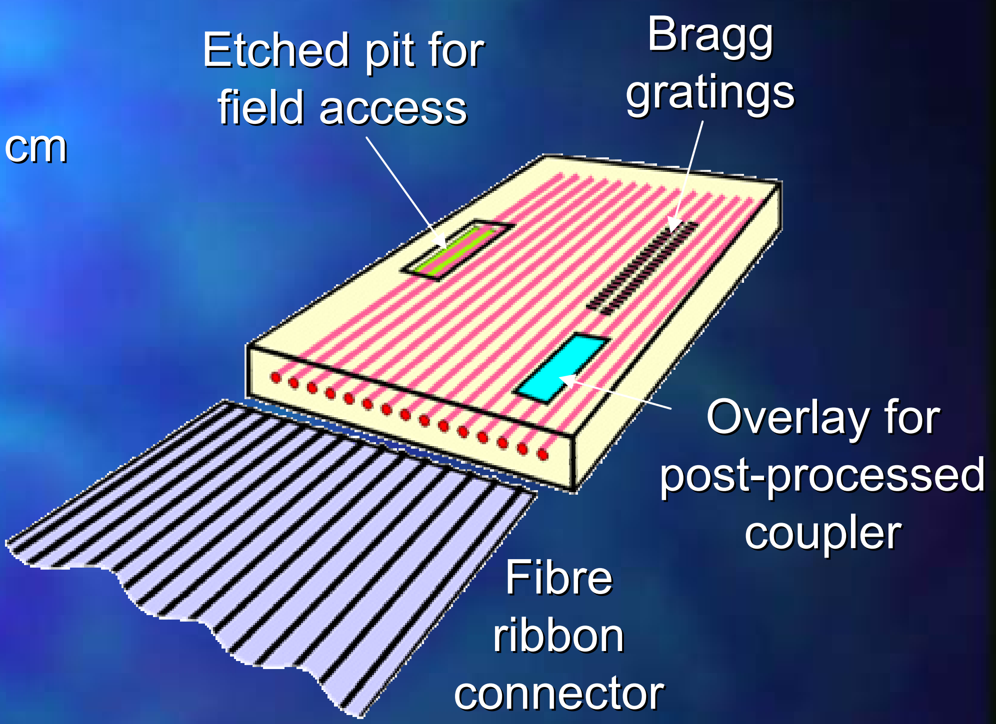


- Silica-on-silicon waveguides

Wavelength shift by write-strobing as phase mask moves

Combining fibre and planar technology for low-cost production

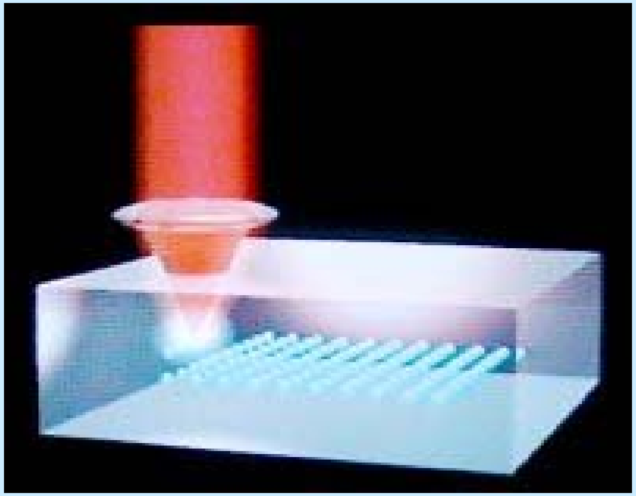


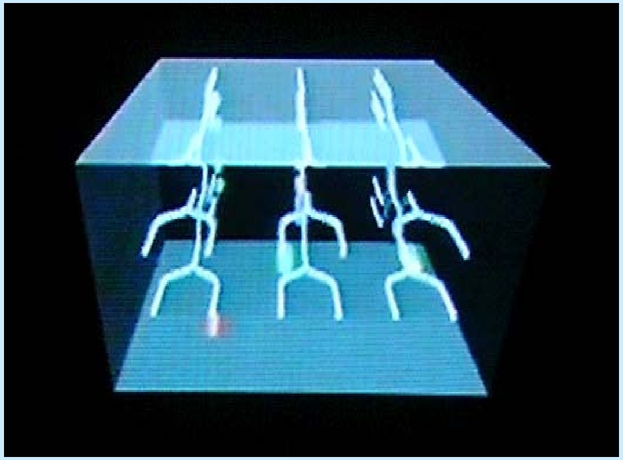


SOUTHAMPTON

Femtosecond Direct-writing: *The Principle*

- Tight focusing of laser into glass
- High intensity leading to multi-photon absorption
- Structural changes in matter confined to focal volume due to short pulse duration – 3-D
- Photosensitivity not required
- -ve or +ve index changes





Intensity ~ 10^{14} W/cm^2
Temperature ~ 10^6 K
Pressure ~ 10^6 bar

Light

Hirao Active Glass Project

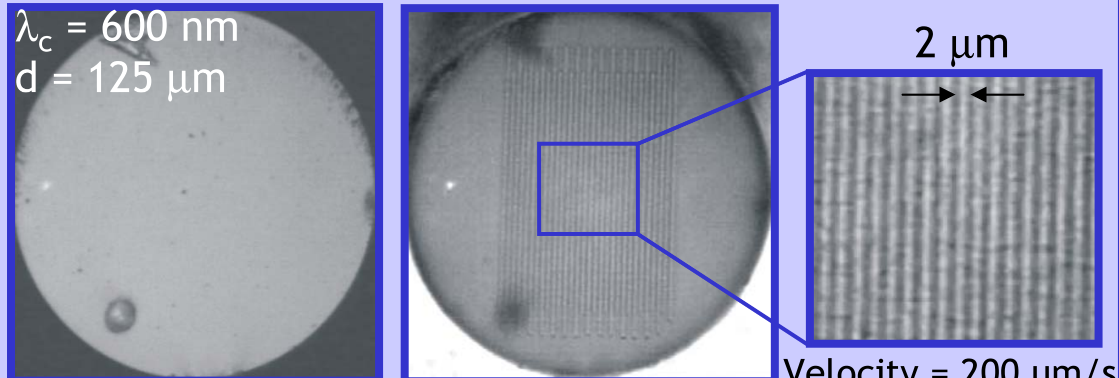
Microscope Images of 'Fiber Gratings'

Gratings :
Period = 2 μm
Depth = 5 μm
Form:
- 1-d
- 2-d
- Hexagonal

Viewing microscope focused:

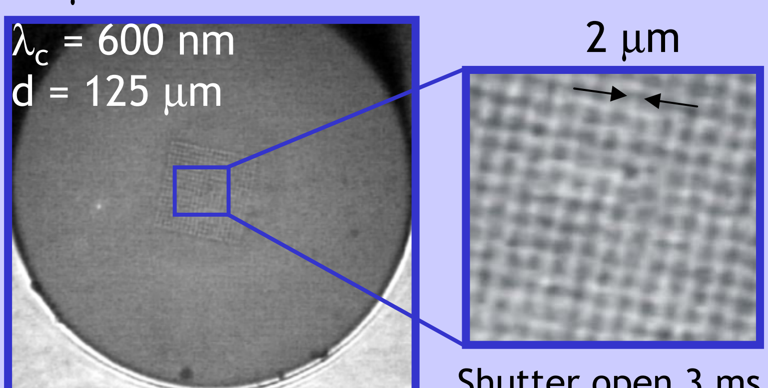
on surface

5 μm below surface



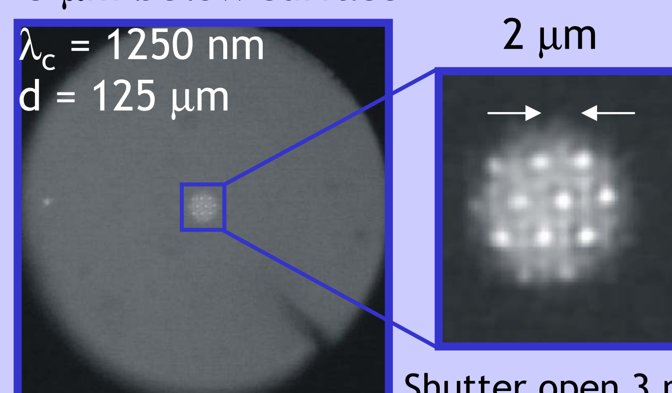
Velocity = 200 μm/s

5 μm below surface



Shutter open 3 ms

5 μm below surface



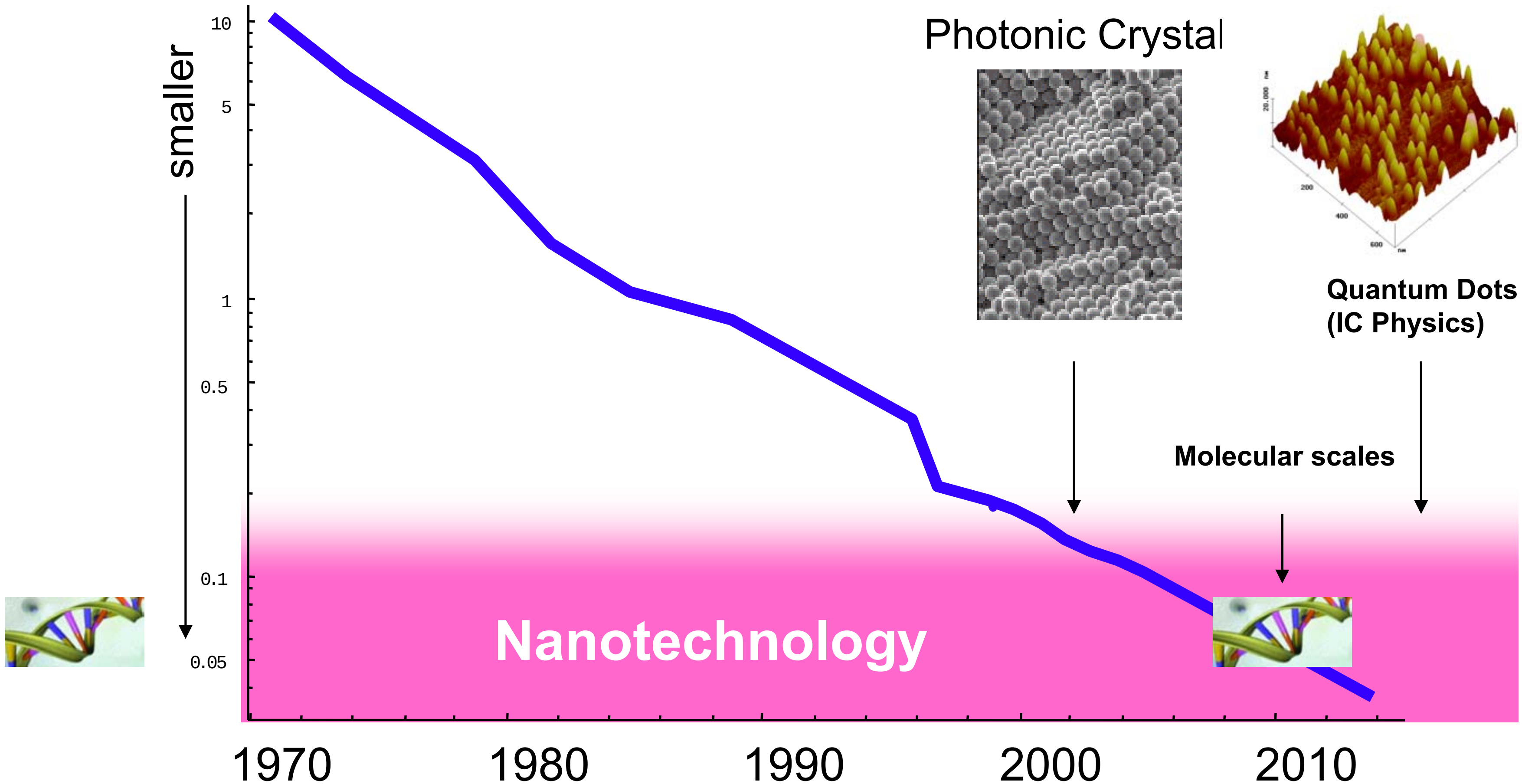
Shutter open 3 ms

Prospects for full integration

- Full integration requires light generation, modulation, switching, routing, filtering and detection
- An isolator is really difficult
- No current photonics platform satisfies these requirements
- What are the possibilities?

Optical fibre/
Human hair

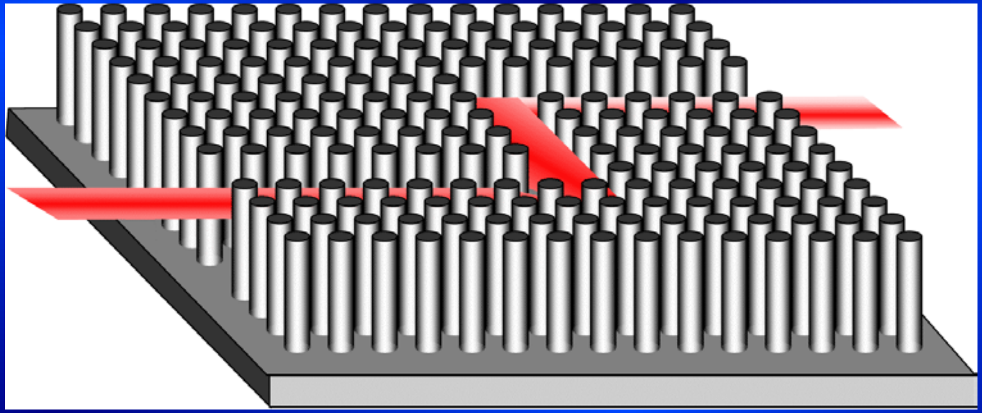
(Silicon) Industry Roadmap v time

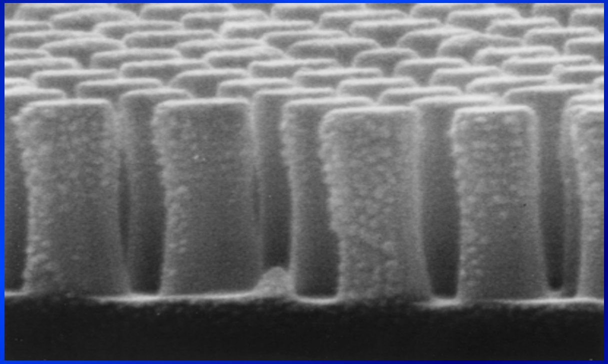


Acknowledgements: W J Stewart

Photonic band gap integration technology

- **High confinement implies dense circuits**
- **Could match electronic densities**



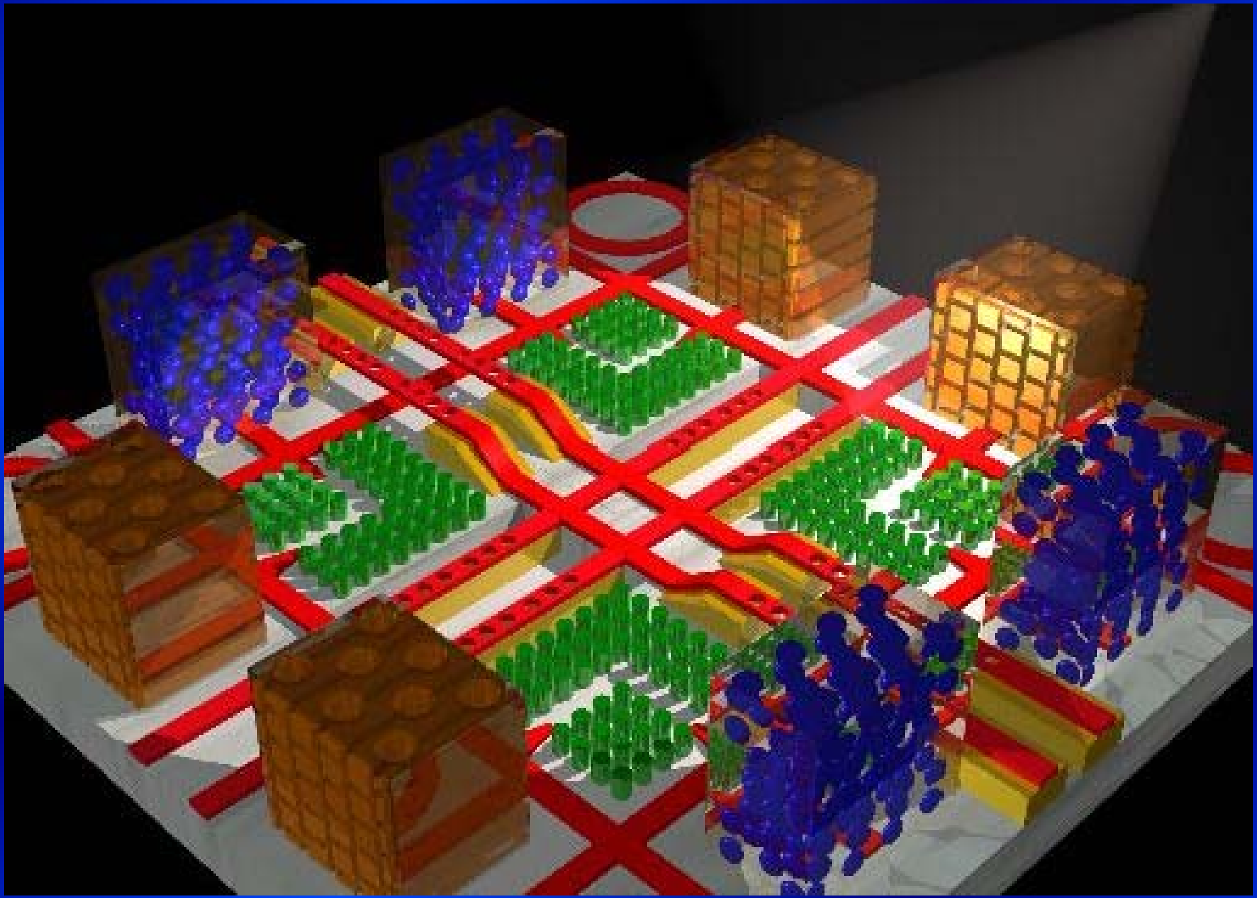


Problems:

- **Very high precision required to avoid spurious resonances**
- **High levels of backscatter make amplifiers/lasers difficult**

Acknowledgement: W J Stewart

Photonic Integrated Circuits



Joannopoulos, MIT

Conclusions

- Despite progress large-scale component integration remains a dream
- There is no winning platform technology for integration
- Glass and III/IV semiconductors are the current leaders
- Thermal stabilization remains a problem
- Hybrid technologies offer better performance and higher power
- Cost is still an issue and can be reduced by by new approaches