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Outline

• Optical communications 101
• Controlling light on the micron scale
• Towards the photonic chip
• Photonic crystals (semiconductors for light)
• Slow light – The key to faster internet
The Semaphore:
An Example from History
Electromagnetic spectrum
 Approaches to Optical Communication

[Diagram showing various optical communication methods, including free-space transmission, lens guides, mirror guides, gas lasers, thin films, laser diodes, optical fibers, photomultipliers, photodiodes, and avalanche photodiodes.]
Light travels well through fibre

- High-refractive index core with low-index background
- Light stays in core by total internal reflection
Optical Fiber Attenuation and Fiber Amplifier Gain

![Graph showing optical fiber attenuation and amplifier gain over wavelength. Peaks at 3 THz and 25 THz with WDM channels indicated.](image-url)
Worldwide Fiber Deployment

Deploying Fiber at Mach 3

Optical Fiber

- Fiber is deployed at a rate of 2000 miles every hour

T. Li & A.R. Chraplyvy, 2001
All traffic carried on optical fibres worldwide ...
Example Metro network
• Light scatters when it travels through the atmosphere
• Range limited to a few kilometers

From: http://www.cablefree.co.uk/
Across a range of communications technologies, 10 Mb/s × km has been the cross-over point to optical technology.
Information capacity within computers

Optical interconnects

5-10 Years Chip-to-chip communications will enter the market.
Photonic chip – *Photonic integrated circuit*
Photonic crystals

1D Photonic Crystal
(Bragg grating and thin film stack)

2D Photonic Crystal
Planar Waveguids

2D Photonic Crystal
Microstructured Optical Fibre

3D Photonic Crystal

Natural
Introduction: Basic parameters

Bragg condition: \( \lambda_B = 2\bar{n}\Lambda \)

Bragg reflection occurs for range of wavelengths: \( \Delta\lambda / \lambda \approx \Delta n / n \)

At \( \lambda_B \) and close to it:
- Bragg reflection due to PBG
- Further from \( \lambda_B \): dispersion
Fiber Bragg gratings are key!

<table>
<thead>
<tr>
<th>FEATURE</th>
<th>TYPICAL</th>
<th>MAXIMUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>length</td>
<td>Few cm</td>
<td>&gt;1 meter</td>
</tr>
<tr>
<td>periods</td>
<td>10,000</td>
<td>&gt;1000,000</td>
</tr>
<tr>
<td>$\Delta n$</td>
<td>$10^{-4}$-$10^{-3}$</td>
<td>~0.05</td>
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</table>

UV Laser Source

Phase Mask (SiO$_2$)

Single mode fiber

Diffracted +1 order (~ 40%)

Diffracted +1 order (~ 40%)

Fringe Pattern from Mask

![Reflection vs Wavelength](image)
My product (patented, developed, published, deployed $$$$$$$$$$$$$$$$$$$$$$$$$$)

Thermally tunable dispersion compensator for 40Gb/s optical transmission systems

- Wide bandwidth and tuning range
- All-fiber device
- No moving parts
- Continuous tuning
- Compact size
- Low PMD
1. Breakthrough technology

Photonic Crystal: Ultra-compact & ultra-control

Ultra-tight confinement

Ultra-dispersion

Ultra-small

Δλ = 1%

~ 50°

10μm
2D slab SOI structure fabricated at IBM on a 8-inch CMOS line - "S. McNab and Y. Vlasov, IBM Watson".
Coupling light into PCWG and how to probe these structures?

Hard to couple light into a PCWG

- Mode shape/size mismatch
- $v_g / n_{eff}$ mismatch
Silica optical nanowires

• Spliced Optical fibre tapered using standard flame brushing method (Birks & Lee, Vol. 10 JLT 1992)
• Fibre dimensions reduced by up to 500 times
Optical fiber nanowires

- Photonics circuitry
- Photonic sensing
- Evanescent coupling
Evanescent coupling between tapered fiber and a PCWG or passive resonator.
Evanescent coupling to chalcogenide PC waveguides using silica nanowires
Silica nanowires

a) 300 μm

b) 110 μm

c) 90 μm
Underwater Optical Fibre
Merging traffic
What & Why?

• Slow light is …
  – pulse propagation at velocity \( \ll c \), or
  – optical delay comparable to pulse duration

• Fundamental interest
  – phase velocity \( (c/n) \): little control
  – group velocity \( (c/n_g) \): enormous control
  [e.g. L. V. Hau, *Nature* (1999): \( v_g = 17 \text{ m/s} \)]

• Device applications:
  – enhance nonlinear effects
  – optical delay lines / optical buffers
Atomic resonance

- “Cycling at the speed of light” in cold atoms
- 17 m/s (Hau et al., Nature 1999)
- Narrowband (<MHz)
Slow light in photonic resonance

- Photonic resonance
  - Bragg grating, photonic crystal
  - Broadband (>GHz)
  - Compatible with telecom!

Expect more delays
Joe T. Mok and Benjamin J. Eggleton

Slow light research has been a fast-moving topic in recent years, with potential applications from quantum computing to telecommunications. Techniques are now emerging that can slow down light in optical fibres.
Problem

- Problem:
  - dispersive broadening
  - length-limited $\Rightarrow$ delay-limited
    (fractional delay $\sim 0.1$ to $3$)

- Our solution:
  Balance dispersion with nonlinearity
  $\Rightarrow$ Soliton!
  - here a gap soliton [Winful, Chen and Mills (1980’s)]
  - eliminate dispersion to all orders
  $\Rightarrow$ no length/delay limitation
Fibre Bragg grating (FBG)

- Features of interest are:
  1. Transmission bandgap
     - Bragg wavelength \( \lambda_B = 2nd \)
  2. Group velocity
     - \( 0 < v_g < c / n \)
  3. Dispersion
     - Undesirable
Slow light in linear regime

Note: The *average* refractive index is the same for all *z*.
How to cancel broadening?

- Gap soliton
  - launched inside bandgap $\Rightarrow$ strong reflection
  - at high intensity $I$
- Kerr effect

\[ n = n_0 + n_2 I \]

- Near bandedge
  $\Rightarrow$ Low group velocity
- Dispersion + nonlinearity = soliton
  $\Rightarrow$ No broadening
Gap soliton (below threshold)

Note: The average refractive index is the same for all $z$. 
Gap soliton (above threshold)

Note: The *average* refractive index is the same for all *z*. 
Dispersionless slow light using gap solitons

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eHealth

eTeaching

Astrophotonics

VISIR under the Cassegrain Focus of the 8.2-m VLT Melipal Telescope

Defence applications

Australian Government
Department of Defence
What have we achieved?
World leading research!

NSW, February 2008

- Funding: 2003-2008, renewed 2008-2010
- 12 Chief Investigators, 50 researchers, 50 students, >20 international partners
- Fundamental science, Strong collaboration, Major international programs, Strong IP, End-user engagement and commercialization path, Outreach, E&T etc