Photonics in Ireland

Dr Andrew Ellis

June 2004

Grúpa Chóras na Fótóinice

Outline

- Photonics in Ireland
- Photonics in Cork
- Photonics Systems Group
- 40 Gbit/s transmission systems

Science Foundation Ireland

- Technology Foresight Ireland Reports, April 1999
  - » Biotechnology, ICT Central to Economic Growth
  - » Technology Foresight Fund, €646 million between 2000-2006
  - » SFI was created to administer this fund
- Introduction to SFI
  - » www.sfi.ie
  - » Helping Ireland Recruit and Retain Research Groups
    - Biotechnology
    - Information and communications technology
  - » Magnifying the Impact of Good Ideas
    - "potential of the research to shape other fields and, where possible, to generate technological advances"

Irish research institutions in Photonics

- 6/14 Institutes of Technology & 7/8 Universities
  - » TCD, DCU, UCD, Tallaght IT, Dublin IT, Maynooth
  - » UCC, NMRC, Cork IT
  - » NUIG, Carlow IT, Athlone IT, U Limerick, Waterford IT

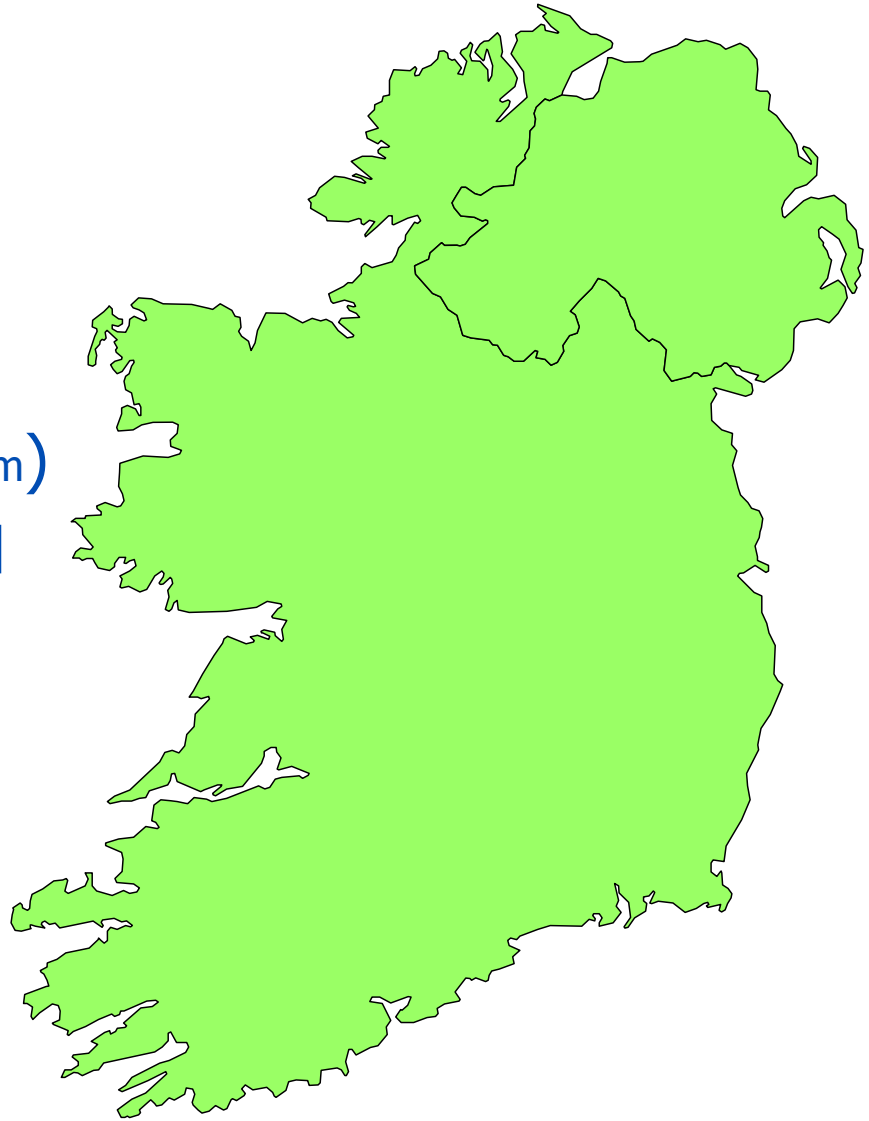
Photonics areas in Ireland

- Photonic products /devices
  - Sensors
  - LED's & Lasers
  - Detectors
- Photonics tools (to make or measure products)
  - Plasmas
  - Laser machining
- Photonics in medicine dentistry & healthcare
  - Retinal imaging
- Photonics for discovery
  - Spectroscopy,
  - Astronomy
  - Imaging
- Photonics Systems

Photonics Summary

- 7 PTRLI funded research centres (a capital investment program)
- 26 SFI funded research activities (a research excellence program)
- Over 21 companies interested in photonics in Ireland
- Many other activities

- Listed below



Existing Irish Optoelectronics Research - PTRLI funded Centres

- National Nanofabrication facility (UCC)
- Materials and Surface Science Institute (UL)
- Institute for Advanced Materials Science (TCD)
- FOCAS : Facility for spectroscopy (DIT)
- NCSR : Centre for Sensors (DCU)
- RINCE : Networks and Communications (DCU)
- Centre for Plasma Science & Technology (DCU)

Existing Irish Photonics Research I

- SFI funded projects (to March 2004)
- Reverse chornological order

- Centre for Research on Adaptive Nanostructures and Nano Devices (TCD).
- Photonics Research Facility (UCC).
- Applications of Carbon Nanotubes and Self-Assembling Molecular Nanowires in Electronic and Optoelectronic Devices (TCD).
- Nanoscale Biophotonics (NUIG)
- Photonic Systems Research (UCC)
- Investigation of active and passive spherical glass microresonators (CIT)
- Carrier scattering and localisation in semiconductor alloys (UCC)
- All-optical processing using semiconductor optical amplifiers in terabit/s photonic communication systems (UL)

Existing Irish Photonics Research II

- SFI funded projects (to March 2004)
- Reverse chornological order

- Advanced Techniques of Optical Imaging and their applications (NUIG)
- Machine vision, imaging & tomography (DCU)
- Computation of the mechanical and electrical properties of oxide/semiconductor structures (NMRC)
- Quantum dot microlasers with a spherical dielectric microcavity (TCD)
- Electro-optical and spectroscopic research on devices using chiral smectic liquid crystals for photonic applications (TCD)
- Nonlinear dynamics and quantum optics of semiconductor lasers for photonic applications (UCC)
- Photon Counting Universal Sensors for applications in ICT and biotechnology (UCC)
- Femtosecond laser induced fibre Bragg and long period gratings (UCC)

Existing Irish Photonics Research III

- SFI funded projects (to March 2004)
- Reverse chornological order, plus other support

- Silicon-Based photonic circuits containing 2 and 3 dimensional photonic crystal waveguides and light sources (NMRC)
- Novel routes to the production of nanoscale electronic and photonic materials (NMRC)
- Plasma production measurement and control (DCU)
- Signal processing perspective on multicarrier communication technology (DCU)
- Opening the extreme ultra-violet lithography source bottleneck (UCD)
- ZnO-based material system for ICT applications (DCU)
- Scanning near field optical microscopy (TCD)
- Pulsed laser deposition of thin films (TCD)
- The Physics of next generation ICT photonic devices (NMRC)
- Pulsed optical communication systems (DCU)

Existing Irish Photonics Research IV - other projects

- pulsed optical communication systems / semiconductor amplifiers (DCU)
- nanosecond laser flash photolysis (TCD)
- acoustic gratings in fiber as train sensors (TIT/UL)
- polymer films for biosensor development (TIT)
- Metrology and sensing (DIT)
- Calculations on semiconductor microstructures (DIT)
- Free space beams and optical modulators (DIT)
- Applied Optoelectronics centre (DIT)
- Far infrared space optics including theory (NIUM)
- Sub millimeter wave optics / astronomy / imaging (NIUM)
- Plasmas / laser atom interactions group (NIUM)
- Quantum information studies with polarization entangled photons (NUIM)
- Sensors / sol-gel/thin film (Carlow IT)
- Tunable semiconductor lasers (UCD)
- Dye sensitized nanocrystalline solar cells / metal-semiconductor self assembled nanocrystals (UCD)
- Environmental monitoring / spectroscopy (UCD)
- Nonlinear dynamics of high power lasers (UCC)
- Centre for surface and interface analysis (CIT)
- Laser machining / fused tapered fiber couple production using laser (NUIG)
- Imaging / astronomy / LIDAR (NUIG)
- Image processing (NUIG)

A Selection of Irish photonics companies

Source: OFC attendance & Photonics Ireland link

- Avena Communications – Connectors and accessories for harsh environment applications
- Cel Automotive Electronics - Technologically advanced products for automotive manufacturers
- Eblana Photonics - Outsourced etched semiconductor lasers
- Firecomms - Optical data transmission light sources and sensors including visible vertical cavity lasers
- Intune Technologies -Control and characterization of wavelength tunable / switchable semiconductor lasers
- Optical Metrology Inovations Ltd (OMI) - Metrology / wafer deflection-stress measurement
- Molex Incorporated - Fiber optic interconnection products and systems
- Methode Electronics - Products employ optoelectronic technologies NanoComms
- Plasma Ireland – Plasma for textile processing
- Pxit - PXI test equipment for lightwave devices
- Fibre Pulse Ltd - Fiber connectors etc
- FONS Corporation - Passive optical components and fiber optic cable packaging
- Xsil - Laser Machining / materials processing
- StockerYale - Custom-Engineered LED Modules
- Agilent Technologies
- Volex Europe Ltd – Fibre cable assemblies
- Analog Devices – High peformance signal processing solutions
- Stratus Technologies - Servers

Photonics in Cork

Cork 2005
European Capital of Culture

- Photonics in academia
- Vibrant photonics start up culture

Irish Photonics Research In Cork

- UCC Department of Physics

- Optoelectronics and Nonlinear Optics
  - » Semiconductor laser physics and quantum optics. High power semiconductors lasers, Vertical cavity surface emitting lasers, Quantum dot semiconductor lasers, broad area semiconductor lasers, nonlinear dynamics of external cavity semiconductor lasers.
- Astrophysics Infrared, optical and X-ray observations
- Photonic Systems
  - » Nonlinear optics for optical signal processing; optical and optoelectronic device physics and their systems applications; optical and quantum communications.
- Electronic Structure Theory
  - » Condensed matter theory, computational physics, atomic and electronic structure of materials. Carrier transport in semiconductor alloys. Coherent phonon and carrier dynamics in photo-excited materials. Quantum Monte Carlo methods. Randomly driven non-linear dynamical systems.
- Femtosecond Group
  - » Femtosecond laser spectroscopy and photochemistry. Fused silica photosensitivity and poling induced by high-intensity UV light. Inscription of fibre Bragg and long-period gratings.
- Laser Spectroscopy Group
  - » Spectroscopy and dynamics of molecular systems in the gas and liquid phase: Ultra sensitive laser- and lamp-based cavity enhanced absorption and cavity ring-down spectroscopy. Atmospheric trace gas detection and gas dynamics. Electronic structure and dynamics of jet-cooled large organic molecules. High resolution luminescence and excitation spectroscopy, Raman spectroscopy of bio-molecules. Nonlinear processes and multi-photon absorption of porphyrins. Laser ablation and synthesis of metal nanoparticles.

Irish Photonics Research In Cork

- UCC Department of Electrical and Electronic Engineering

- Quantum Electronics & Optoelectronics
  - » Photon counting universal sensors for applications in ICT and BioTechnology, 2002 - 2006
  - » Optical receivers for plastic optical fibre communications
  - » Advanced instrumentation for single-molecule DNA sequencing
  - » Optoelectronic Device Physics
  - » Electronic trransport in low dimensional structures
  - » CMOS Monolithically Integrated Photoreceiver Incorporating an Avalanche Photodiodes
  - » Electron transport across bulk and multiquantum barriers
  - » Geiger-Mode Avalanche Photodiodes
- Lasers
  - » Development of laser systems operating in the submillimetre or far-infrared (FIR) region of the electromagnetic spectrum.

Irish Photonics Research In Cork - NMRC

NMRC
Ireland's ICT Research Institute

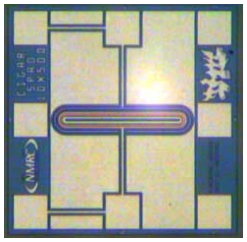
Shaping the Future

NDP
NATIONAL DEVELOPMENT PLAN

sfi
science foundation ireland

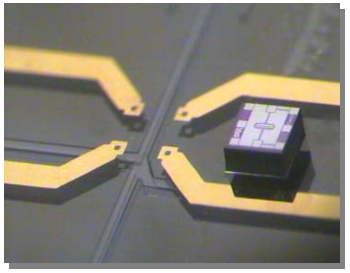
Photonic Fabrication Facilities Brendan O' Neill

Nanosystems/Compound Semiconductors

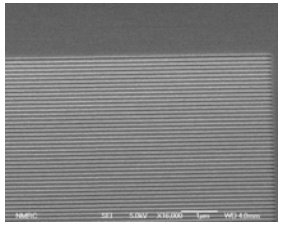


Silicon

Microsystems



Diffraction grating with 50nm features using the JBX

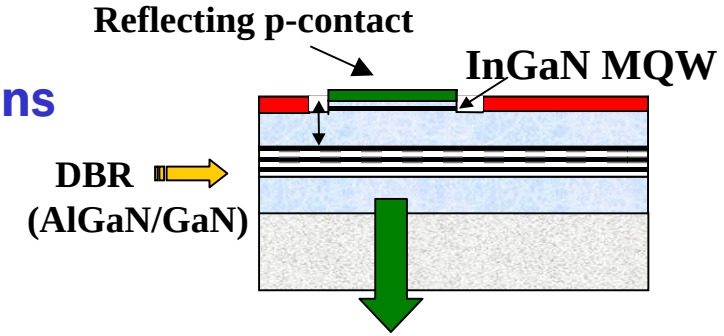


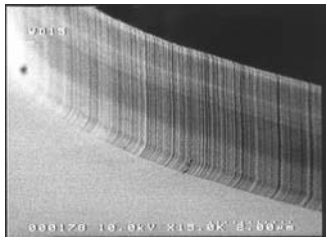
E-beam/FIB

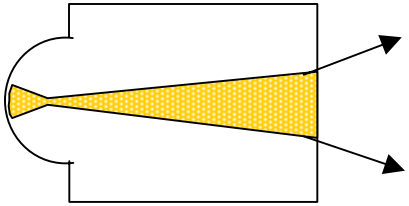
E-beam lithography, resolution down to 20nm.
FIB nanofabrication, with etch and deposition capability

Active and Passive Components Brian Corbett, Gabriel Crean

Visible LEDs and VCSELs for POF Applications



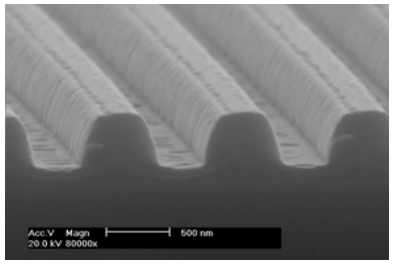


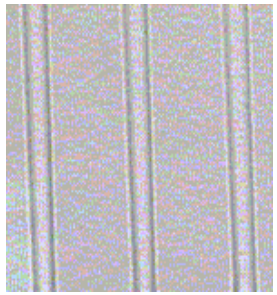


High Brightness Lasers

Planar Lightwave Circuits (PLC)

- Novel sol-gel approach to waveguide
- Microimprinted all-polymer waveguide



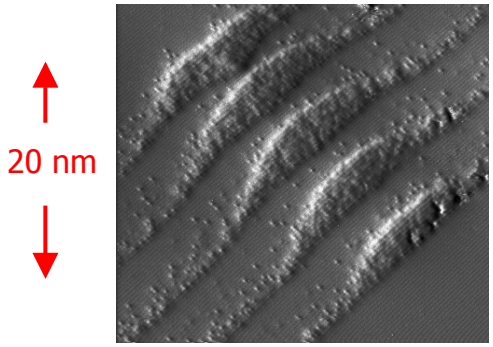


Photonics Theory

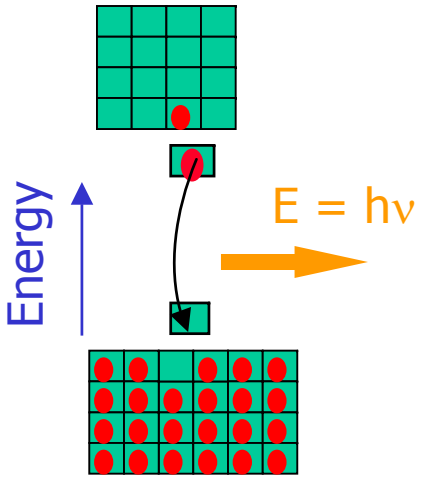
Eoin O'Reilly, Sasha Uskov

Band structure and photonic engineering of new materials

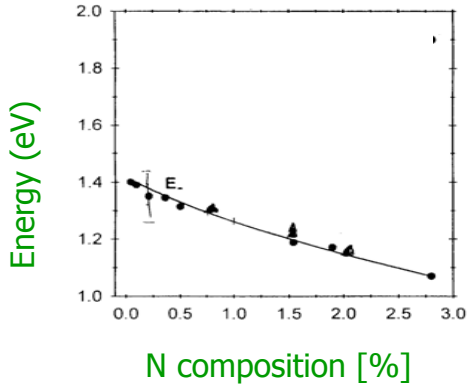
Quantum Dots



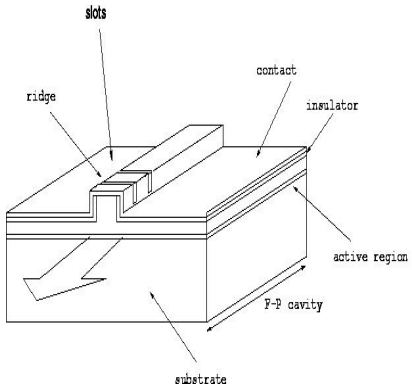
- Atom-like energy levels
- Surrounded by semiconductor energy bands

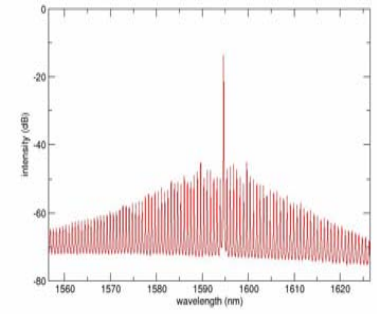


Ga(In)NAs: extreme alloys



Optical Cavity Engineering

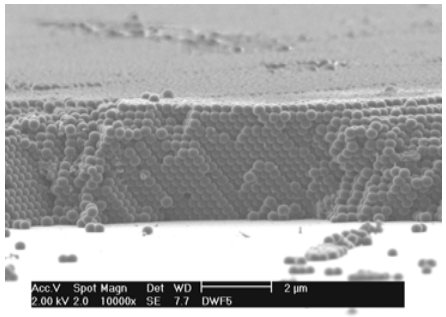




Nanophotonics and Emerging Photonic Materials

Martyn Pemble, Clivia Sotomayor Torres

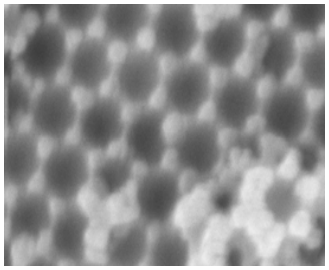
Bulk Opal Synthesis



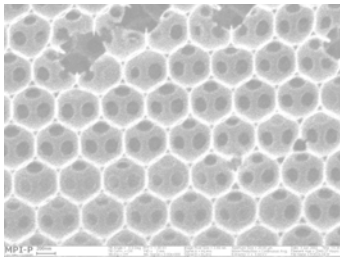
Rapid on-wafer growth

Inverted Structures

Using Templates and MOCVD Growth



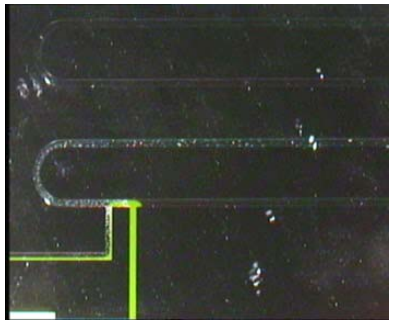
GaP



InP

Opal^{-1}

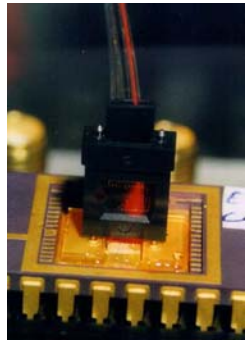
Photonic Applications

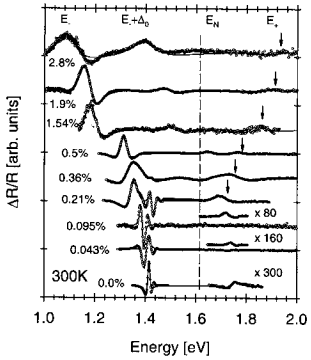


Biophotonics

Visble sources

Firecomms
Photonic Communications Technology





Characterisation

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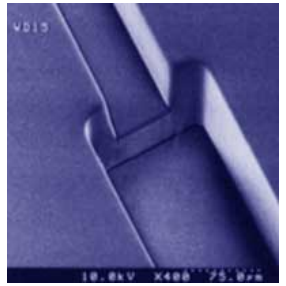
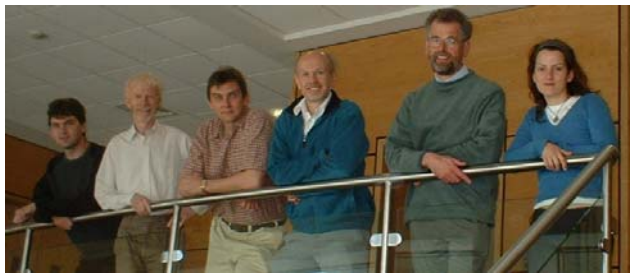
optical metrology innovations limited

Processing and Fabrication

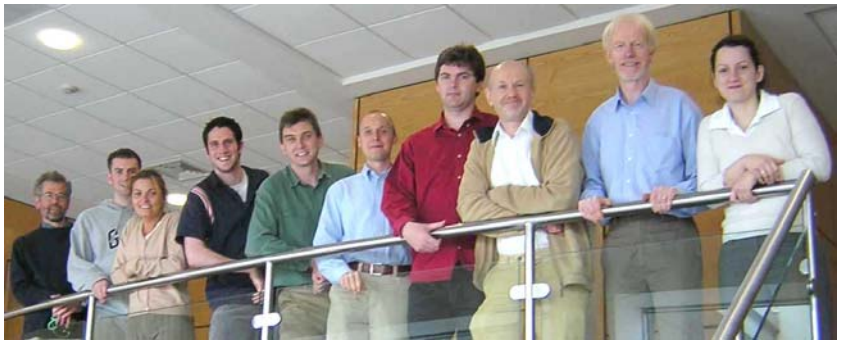
NanoComms



Irish Photonics Research in Cork - Photonics System Group



September 2003



March 2004

embarkinitiative
Investing in People and Ideas

September 2004

NDP
NATIONAL DEVELOPMENT PLAN

sfi
science foundation ireland

SFI proposal overview

- Mainly focused on communications applications
  - » Including: optical signal generation, transmission, restoration, processing, switching and quantum encryption
  - » Largely experimental
- No materials or device fabrication
  - » Essential to collaborate with other groups in Cork, elsewhere in Ireland and abroad

Current laboratory plans

- Testbeds
  - » 40 Gbit/s system testbed
  - » Access system testbed up to 10 Gbit/s
  - » Picosecond time-resolved IR spectroscopy and interferometry
  - » Radio-over-fibre testbed
  - » Quantum cryptography testbed
  - » Wavelength-division multiplexing testbed
  - » Optical regenerator testbed
- Shared facilities, overlapping activities

Space

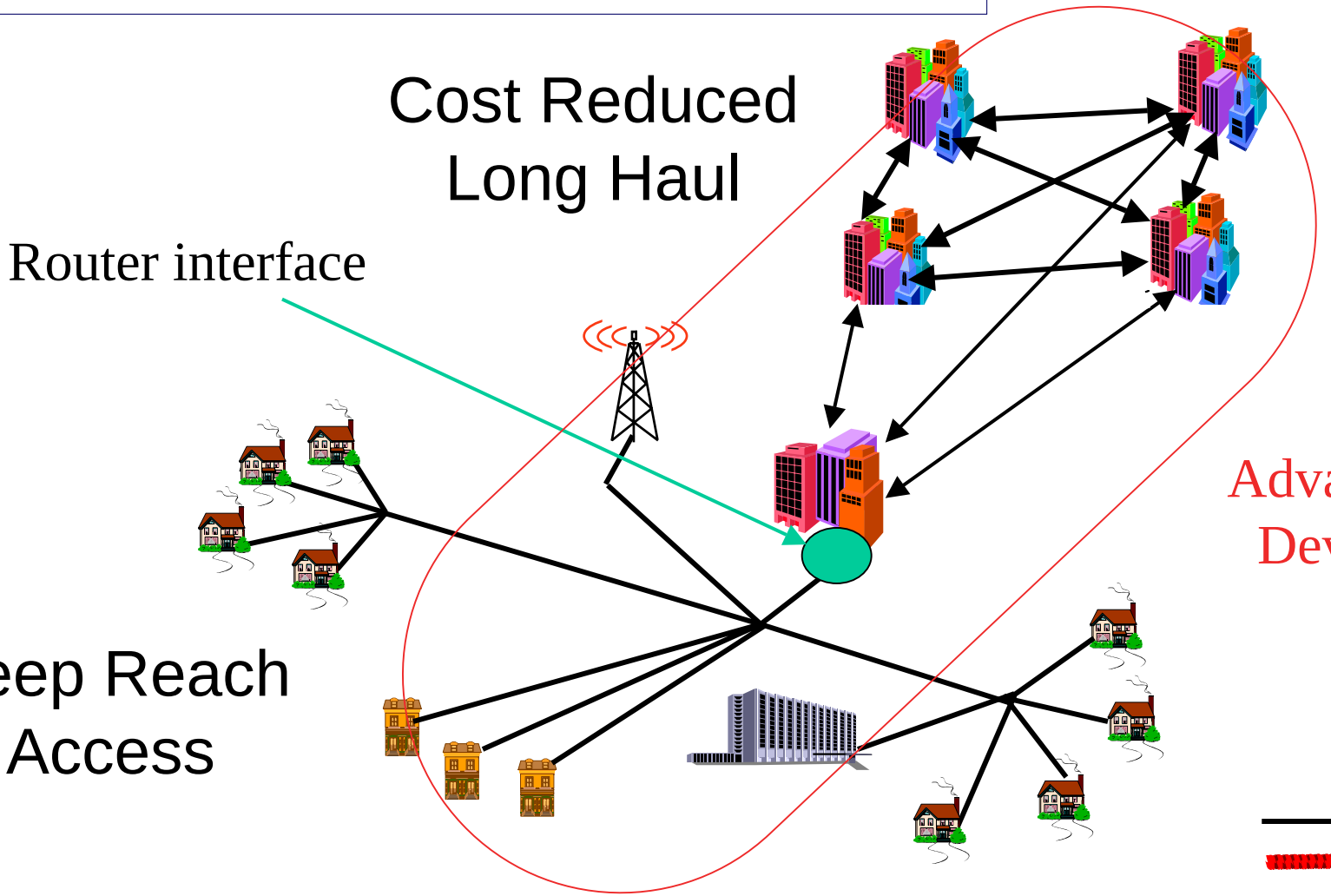
- Located temporarily at Cork Airport Business Park
  - » Building 2200, 1st floor

- Planning to move to UCC Lee Maltings Complex in Cork City, autumn 2004
  - -New SFI photonics building
  - -Close to NMRC and UCC main campus
  - -Will house several photonics groups

Optical Communication

- Boom and bust
  - » Forecast and investment
  - » Capacity play out
  - » Capital investment starting to return
- Return to "normality"
  - » In terms of customer demand
  - » Manufacturing base profoundly altered
  - » When !!
- Many people offering a post mortem / predictions

A Future Network



Future Network Needs

- Immediate Needs
  - » Drive out cost from network
    - Cost reduced technology in Core
    - Intelligent use of technology in Access
    - Not necessarily cost reduced
  - » Requires new technology
    - New architectures & Fewer "Layers"
- Fundamental customer demand
  - » Still growing
  - » New applications grow
  - » Old applications saturate
- Will be driven by access growth
  - » But *eventually* limited by
    - Routing
    - Long Haul Capacity

Technical topic areas
- Different time horizons

- Wavelength-division multiplexing
  - » High spectral efficiency
  - » Multi-wavelength all-optical signal regeneration
- Photonic access and local area networks
  - » FTTX
  - » Radio over fibre
- Metro area network and point-to-point transmission
- Non-linear optical devices for signal processing
  - » Physics and applications of semiconductor optical amplifiers
  - » Nonlinear optical physics of electro-absorption devices
- Quantum communications
- Fast optical switching for supercomputer interconnect

Components for 40 Gbit/s Systems

This work carried out at

Corning Research Centre, Suffolk, UK.

Now

Centre for Integrated Photonics

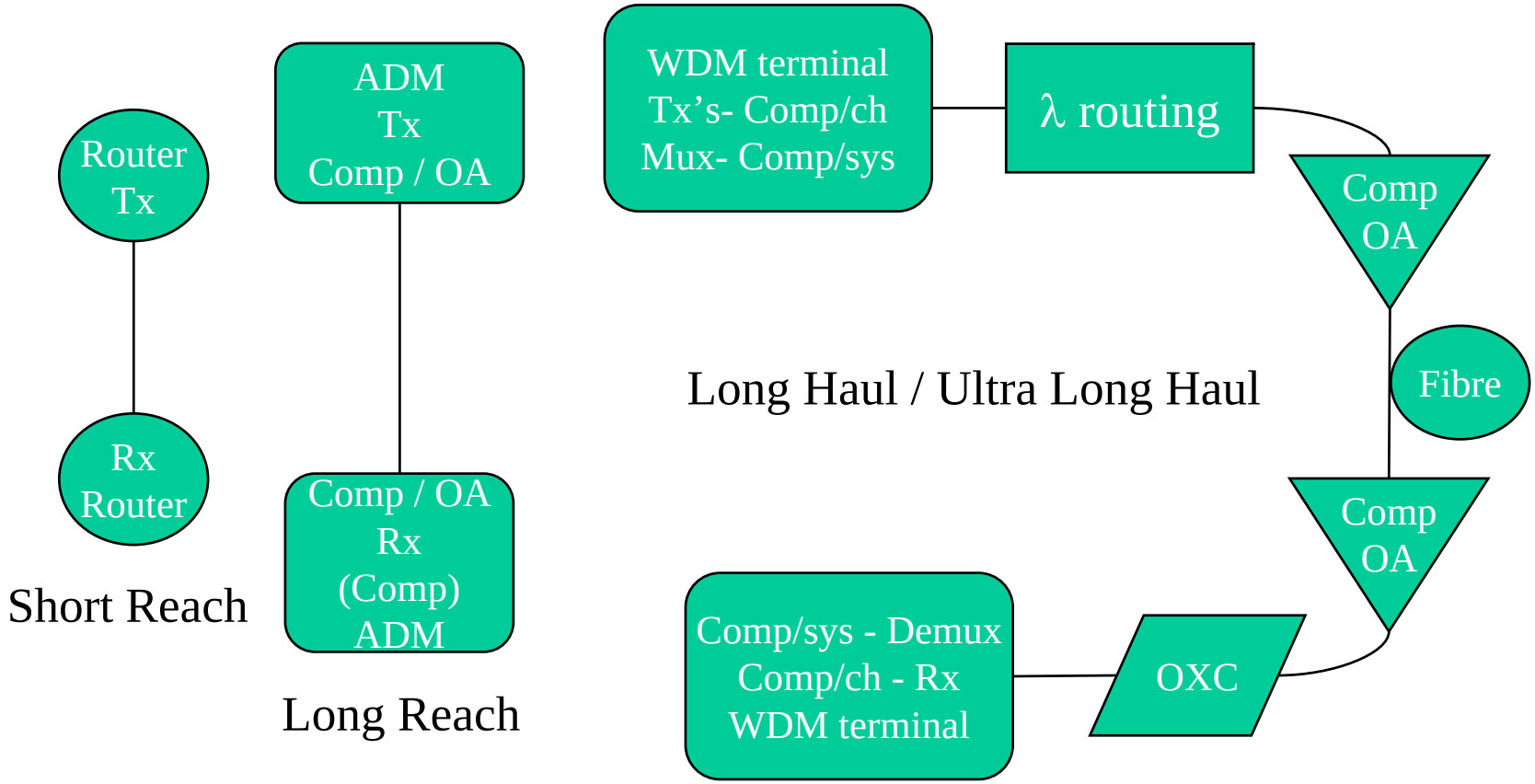
People now at

UCC, CIP, Durham, Cambridge …..

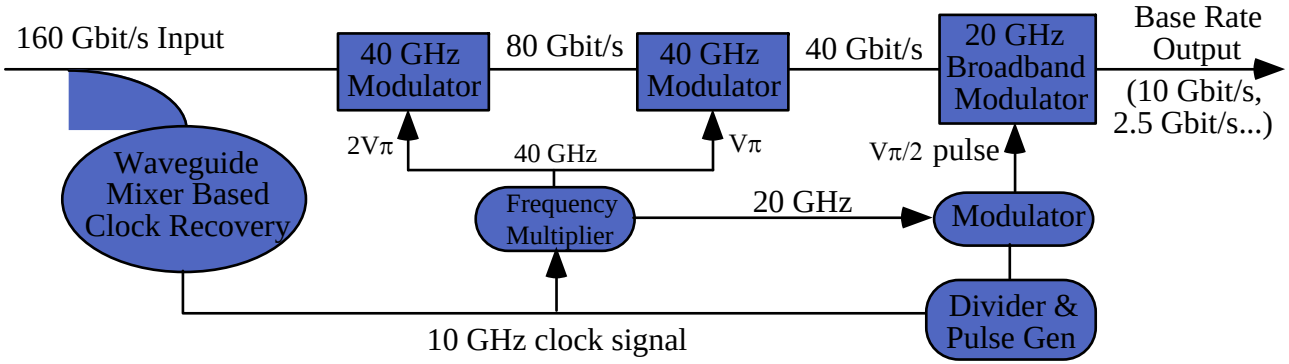
Outline

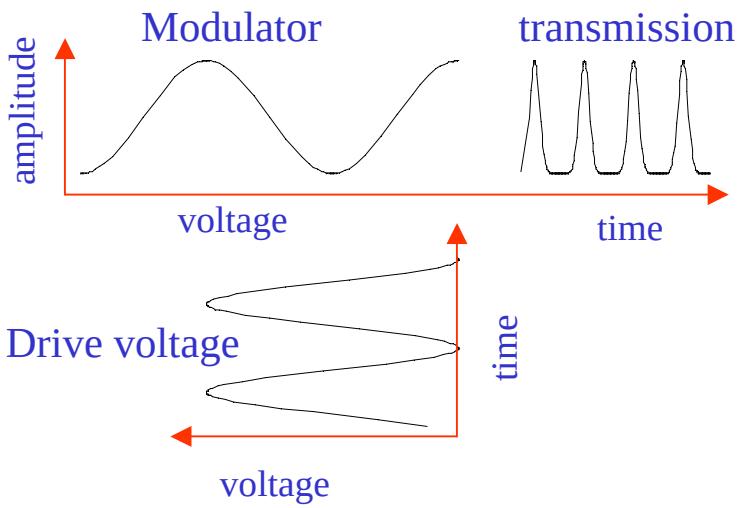
- 40 Gbit/s systems
- 40 Gbit/s measurements – theory
- 40 Gbit/s measurements – experimental approach
- 40 Gbit/s electroabsorption modulators
  - » Short reach systems
  - » Intermediate reach systems
- Challenges for long haul

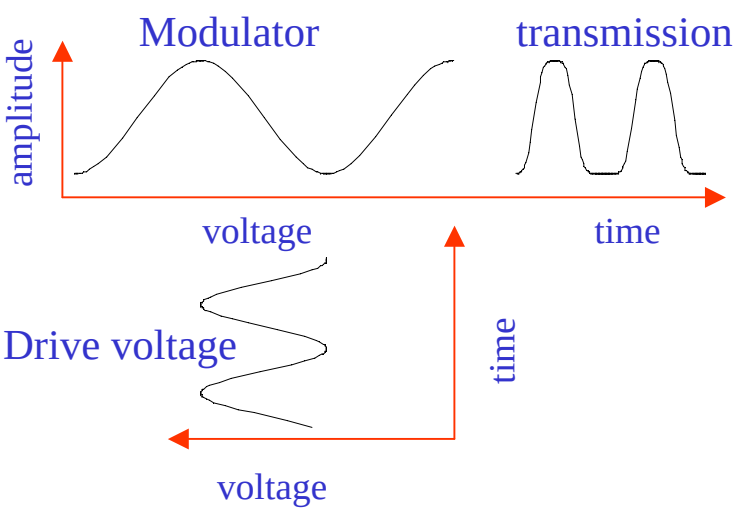
Typical 40 Gbit/s Networks



Demultiplexing of OTDM Signals

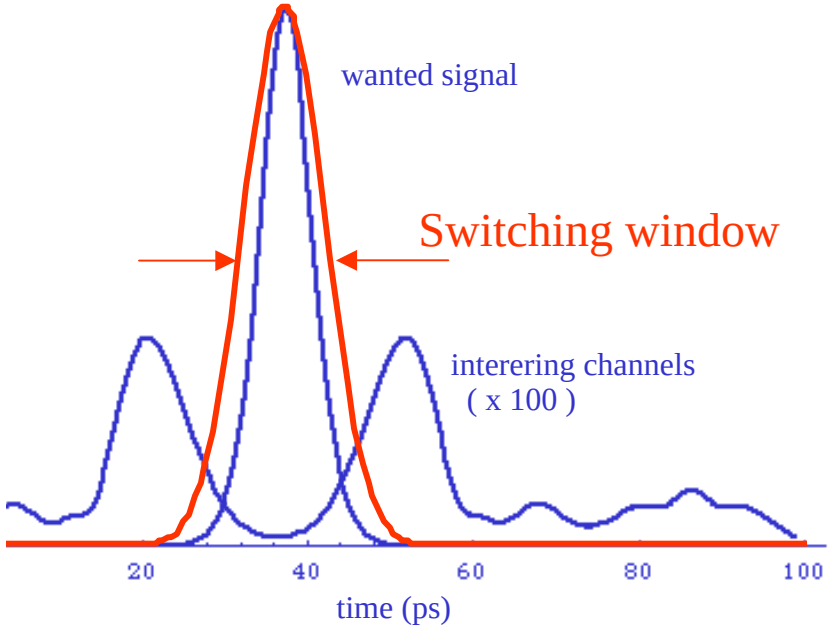






OTDM Demultiplexing

- Switching window
- Cross talk
- Jitter tolerance
- SNR variation (sp-sp)



OTDM Demultiplexing Cross Talk

Assuming pulse width less than switching window.
Un-switched channels reduce effective extinction ratio (eye closure penalty, power wastage).

$$\Delta P_{(dB)} = 10Log_{10}\left(\frac{P_i + \sum_{k\neq i} P_k}{P_i - \sum_{k\neq i} P_k}\right)$$

$$\Delta P_{(dB)} = 10Log_{10}\left(\frac{SXR+1}{SXR-1}\right), SXR = \frac{P_i}{\sum_{k\neq i} P_k}$$

Optically amplified systems suffer SNR degradation due to un-switched channels.

$$SNR_{elect} = \frac{P_{sig}}{2h\nu\Delta f_{electt} + 4P_{spon}\frac{\Delta f_{electt}}{\Delta f_{opt}}} \cdot \frac{SXR-1}{SXR+1}$$

Noise Sampling

- Demultiplexer shapes signal – power loss
- Demultiplexer shapes ASE noise
  - » Reduces total ASE power
  - » Samples finite population of ASE photons within one bit period
    - Sample variance greater than population variance
  - » Essential to account for receiver impulse response

$$S(t) = \int_{-\infty}^{\infty} m(\tau)s(\tau)h(t-\tau)d\tau$$

$$N_{sig-spon}(t) = \int 2\left\langle n_t{}^2 \right\rangle m(\tau)^2 s(\tau)h(t-\tau)^2 d\tau$$

$$\sigma_0^2 = \sigma_{th}^2 + 2B\left[ef_{111}P_0 + ef_{011}P_{spon} + f_{112}\frac{P_0 P_{spon}}{\Delta\nu} + f_{022}\frac{P_{spon}^2}{2\Delta\upsilon}\right]$$

$$\sigma_1^2 = \sigma_{th}^2 + 2B\left[ef_{111}P_1 + ef_{011}P_{spon} + f_{112}\frac{P_1 P_{spon}}{\Delta\nu} + f_{022}\frac{P_{spon}^2}{2\Delta\upsilon}\right]$$

$$f_{s,d,r}(t) = \frac{1}{T}\int_{-\frac{T}{2}}^{\frac{T}{2}} s(\tau)^s m(\tau)^d h(t-\tau)^r d\tau$$

Full Cross Talk Calculation

Accounting for cross talk in signal to noise ratio calculation

$$S(t) = \int_{-\infty}^{\infty} m(\tau)s(\tau)h(t-\tau)d\tau$$

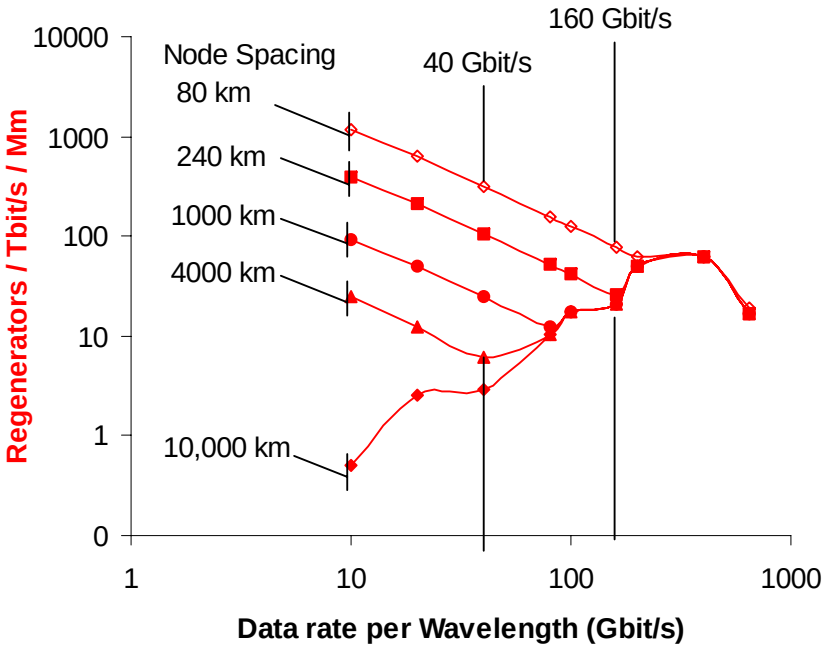
$$N_{sig-spon}(t) = \int_{-\infty}^{\infty} 2\left\langle n_t^{\,2} \right\rangle m(\tau)^2 h(t-\tau)^2 \sum_{k\neq i} s(\tau) + s(\tau - kT)d\tau$$

Challenges for 40 Gbit/s long haul

- Progress of 10 Gbit/s systems
  - » FEC
  - » High speed DSP
  - » DCF free design
  - » High spectral efficiency
- 40 Gbit/s cost structure
  - » Electronic mux/demux & drivers
  - » Compensation techniques
  - » Component tollerance
    - Dispersion, PMD, PDL
  - » Implementation of high spectral efficiencies
- Should 40 Gbit/s wait for DSP to catch up?
- Does Optical Regeneration play a role?

Optical regeneration

- Global Networks
  - » Dominated by transmission
    - 10 Gbit/s per wavelength
- Local networks
  - » Dominated by switching
    - 160 Gbit/s + per wavelength
- Continental scale networks
  - » Engineering compromise required
    - 40 Gbit/s per wavelength
    - Alternative solutions to optical regeneration



Thank you

Go raibh maith agat…