Photonics Research in Ireland: from Materials to Systems

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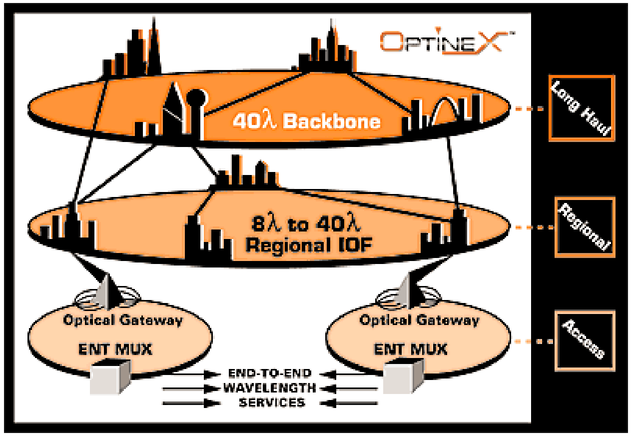
Acknowledgements

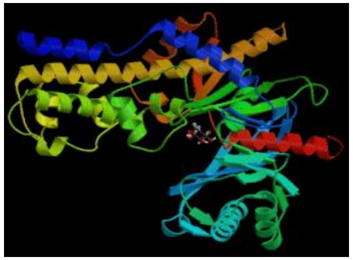
- Colleagues at Tyndall, UCC, CIT, DCU, TCD
- D. Cotter, A. Ellis, G. Huyet, S. O'Brien, E. Pelucchi (Tyndall)
- J. O' Gorman (Eblana Photonics)
- S. O'Brien, S. Osborne, A.V. Uskov, D. Williams, M. Crowley, S.B. Healy
- Science Foundation Ireland
- EU FP6 Funding

Photonics: Driver for technological innovation



Lighting & Displays

Information & Communication



Life Sciences & Health

Automotive & Industry

Emerging applications…

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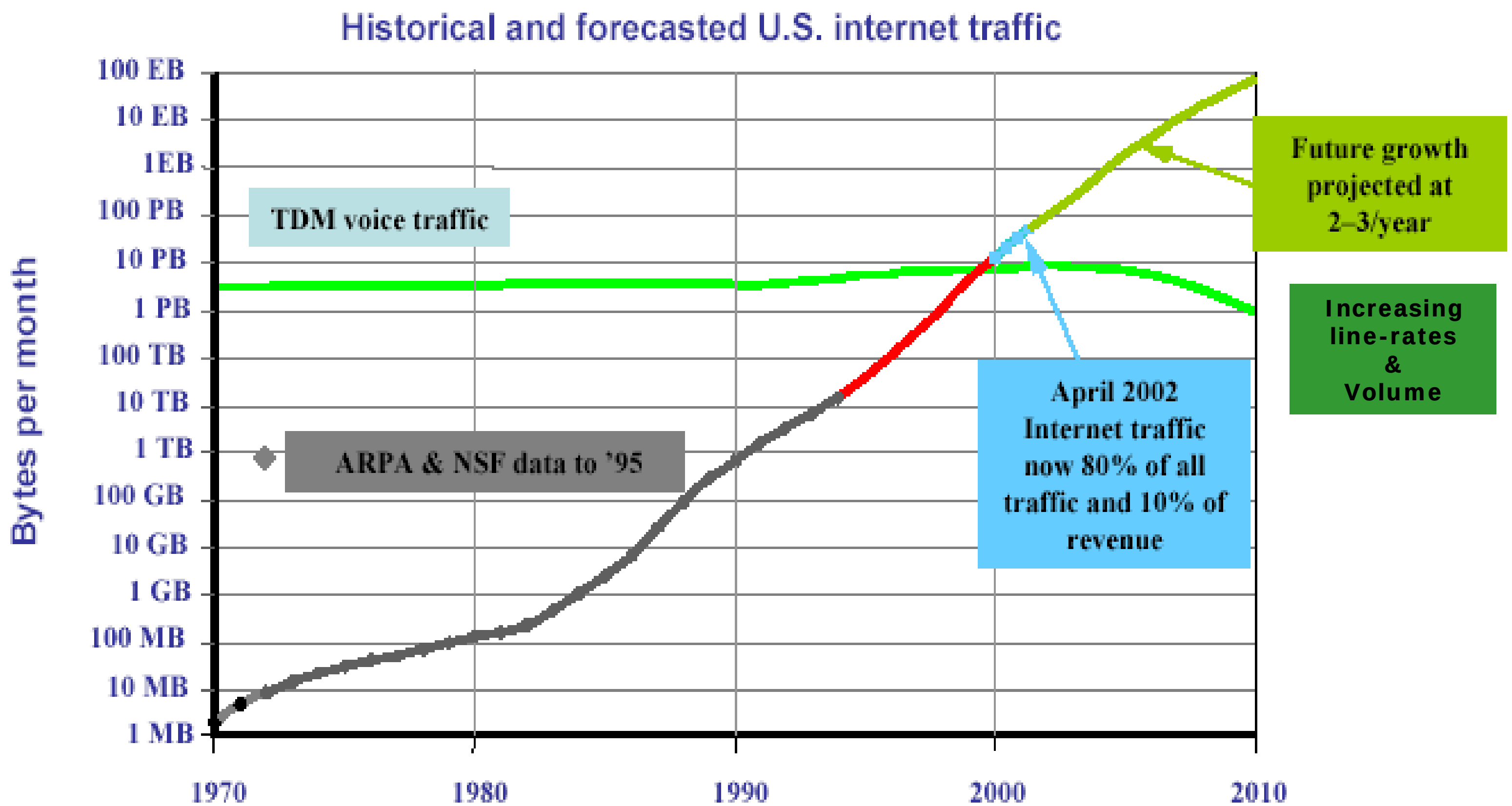
Moore's Law is the communications driver



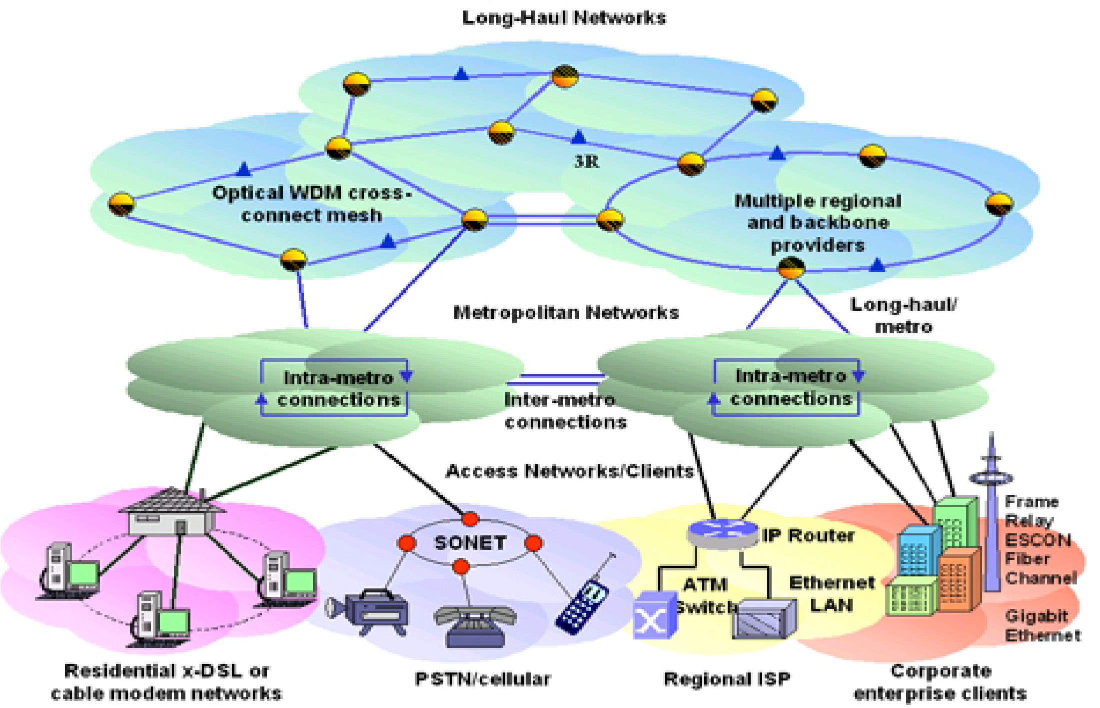
Source: http://www.caspiannetworks.com/library/presentations/traffic/GEthernet.ppt

Photonics world market in 2005 > €150 billion

Expected to triple within 10 years

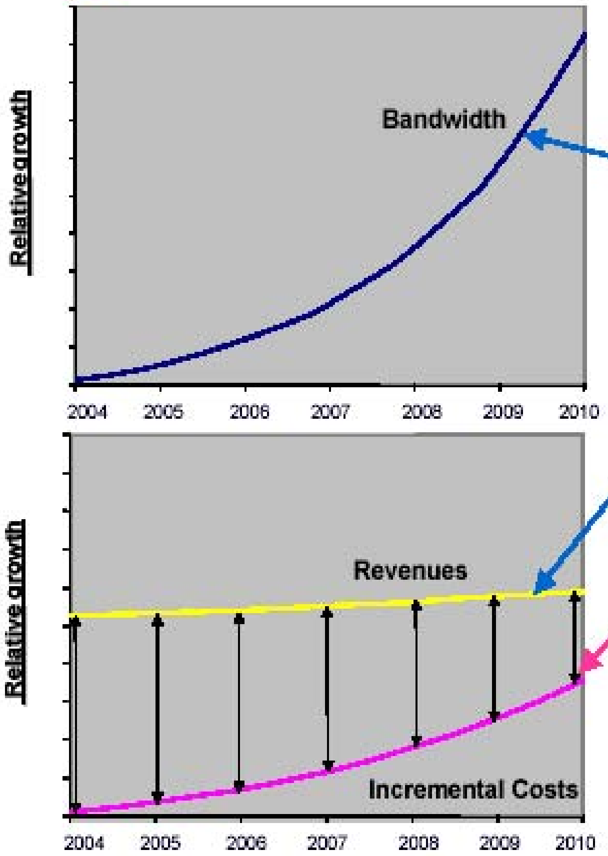
Communications sector exhibiting strong recovery and growth

- Increasing Customer Bandwidth Demands
- Slower Revenue Growth
- Current Network….



- **Low-cost sources (lasers, amplifiers)**
- **with high-speed operation**
- **and multi-wavelength control and selectivity**

Bandwidth Growth – The Margin Challenge



Greater bandwidths
- New services
- Maintain/grow revenues

But costs rise faster

… Margins are eroded

BT

Russell Davey, BT ECOC 05

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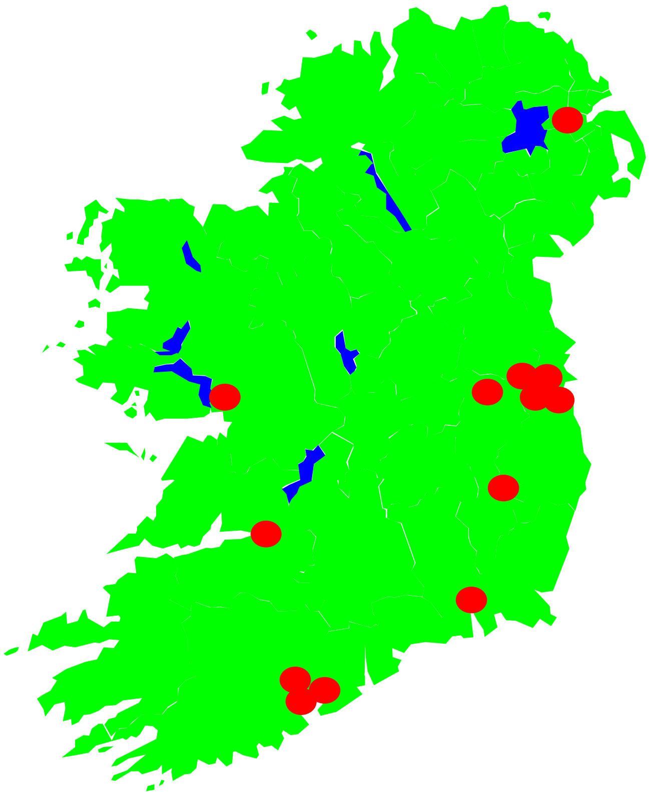
Photonics Research in Europe

- Opportunity recognised in Europe
  - Strategic Research Agenda in Photonics: PHOTONICS^{21} European Technology Platform
  - Recent opening of EU office devoted to photonics
  - 50% budget increase in FP7
- Opportunity recognised in Ireland
  - Substantial research activity funded by SFI, PRTLI and EI
  - Spawned and supported a number of HPSUs (including Eblana Photonics, Intune Networks, Firecomms, and SensL)
  - Factor in attracting Lucent to create Bell Labs Ireland
- Research critical mass:
  - Photonics Ireland 2007 (Galway, Sept 24 – 26 2007)

Photonics Ireland 2007



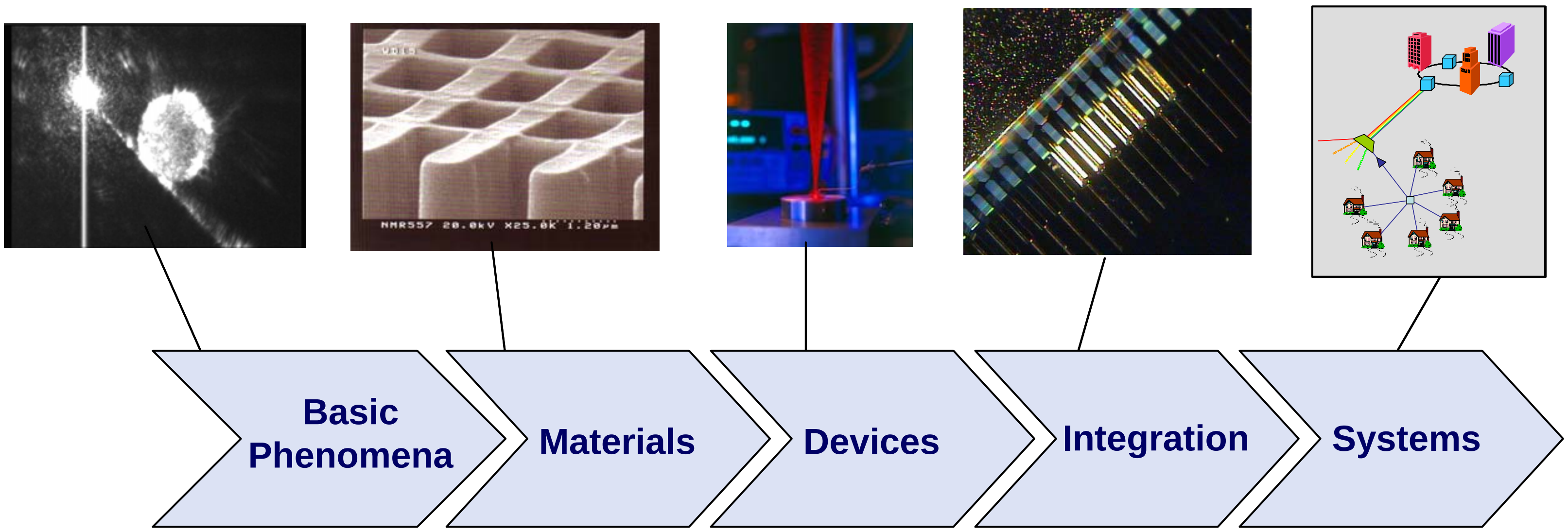
Symposia:

- Photonic Materials
- Photonic Devicves
- Quantum Optics
- Nanophotonics & Plasmonics

170 presentations from
13 institutions

Photonics@Tyndall – A multi-disciplinary activity

Combination of skills in physics, chemistry, materials science, engineering



"from atoms to systems"

Nic Choramaic | Pemble | Sotomayor - Torres | O'Reilly | Corbett | Huyet | McInerney | Peters | Cotter | Townsend | Manning | Ellis

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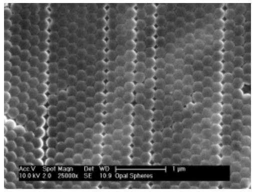
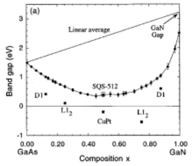
Photonics at Tyndall

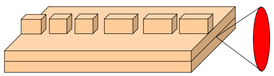
- Low-cost technologies



Opal thin films

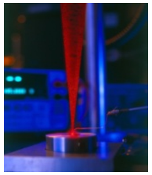


Dilute nitride alloys

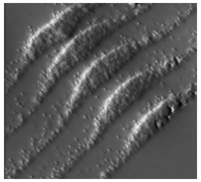


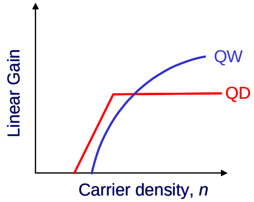
Single-mode
Fabry-Perot laser

- Materials & devices



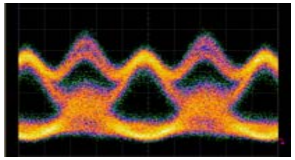
Red VCSL



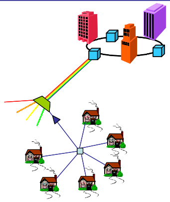


Quantum dot materials & devices

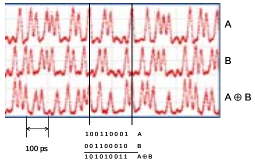
- Systems



Coherent WDM



Optical access



Ultrafast logic

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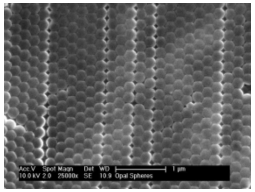
Photonics at Tyndall

- Low-cost technologies



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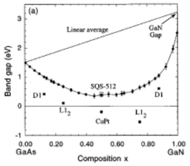

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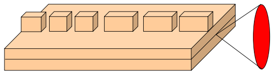
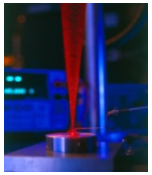


Single-mode Fabry-Perot laser

- Materials & devices



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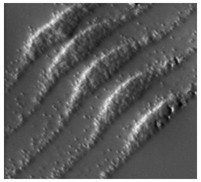
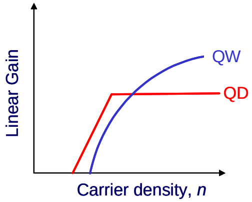
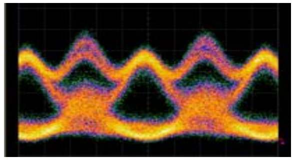




Quantum dot materials & devices

- Systems



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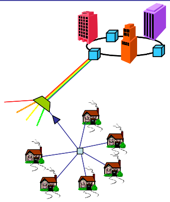

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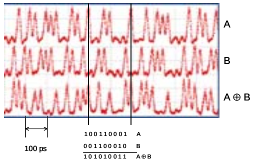

Ultrafast logic

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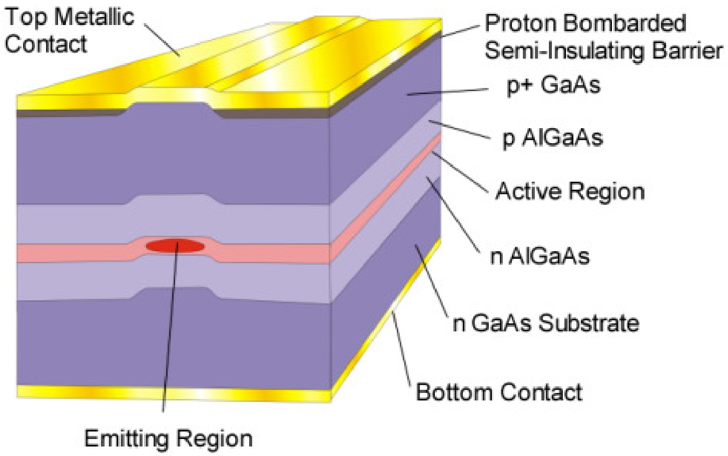
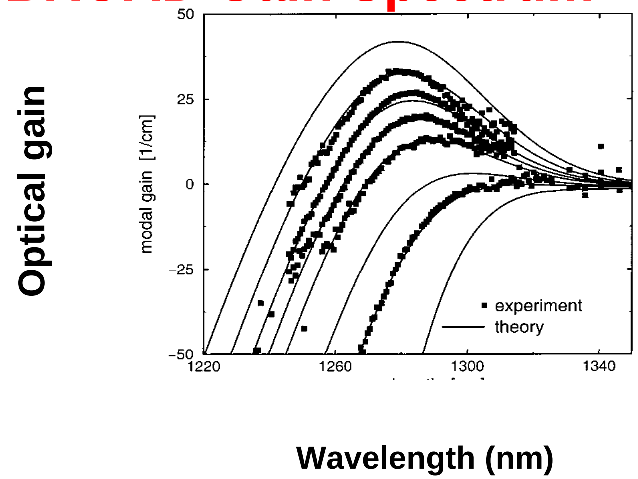
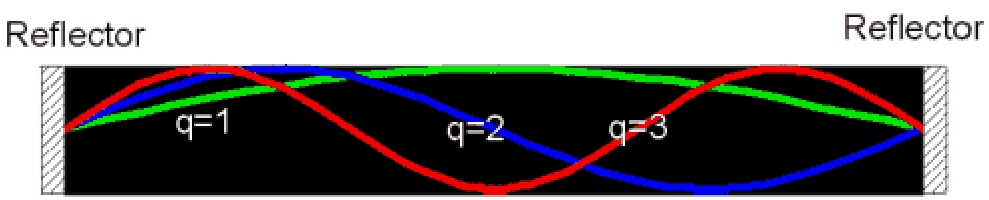
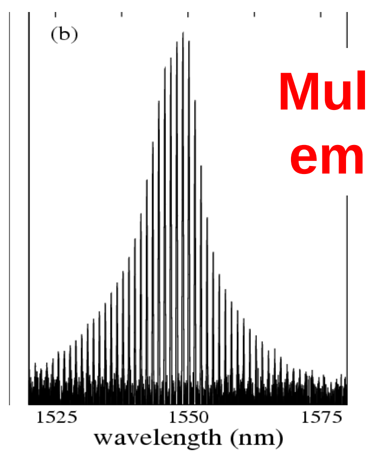
Semiconductor laser: wavelength selection?



BROAD Gain Spectrum



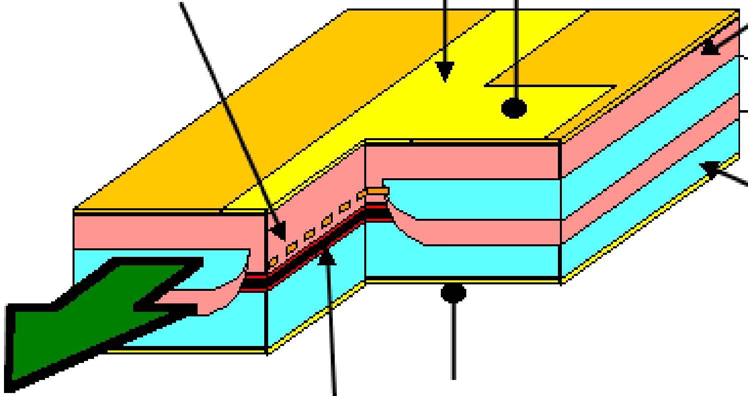




Multi-mode emisssion

+ MULTIPLE Fabry-Pérot modes

Conventional optical components: DFBs are complicated

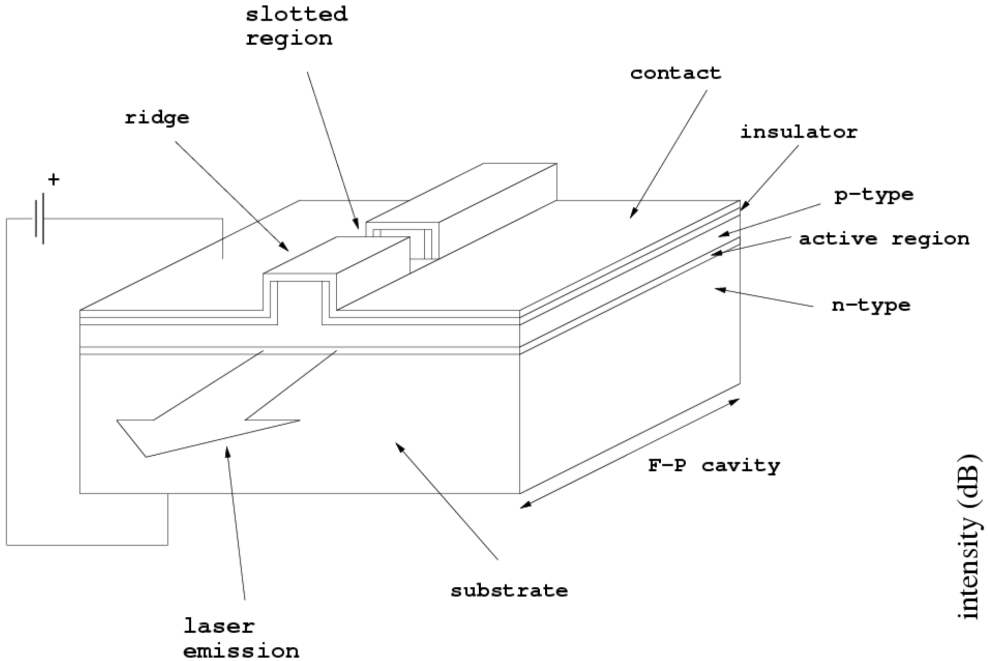


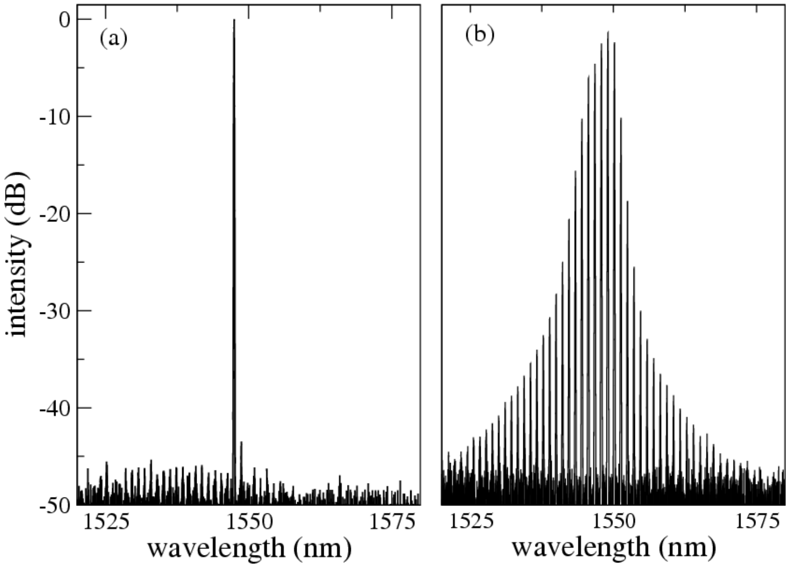
Evolutionary dead end !

- Multiple regrowth steps
- Performance is ultra-sensitive to both cavity cleave length and emitted power
- Complex grating structure must be defined to <10 nm accuracy across entire laser and wafer
- Low yield
- Unstable to optical feedback and needs external isolation
- Difficult and expensive to optimise for high temperature operation
- Difficult to use in a PLC due to sensitivity to feedback of reflected light making it difficult to capitalise on PLC features that enable low cost packaging
- Impractical to integrate with electronics

Index-patterned Fabry-Pérot Cavity

Introduce a low density of effective index perturbations along the length of a FP laser in order to create a single mode cavity





B. Corbett and D. McDonald, "Single longitudinal mode ridge waveguide 1.3 µm Fabry-Pérot laser by modal perturbation", Electron. Letts. 31, 25, pp2181-2182, 1995.

www.eblanaphotonics.com

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precision light for advanced communications

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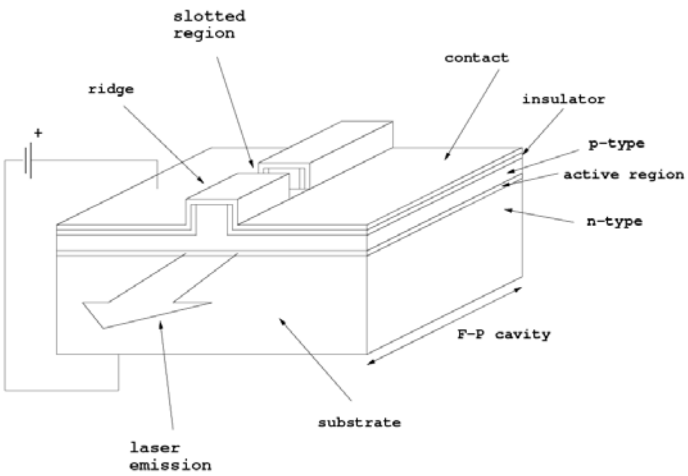
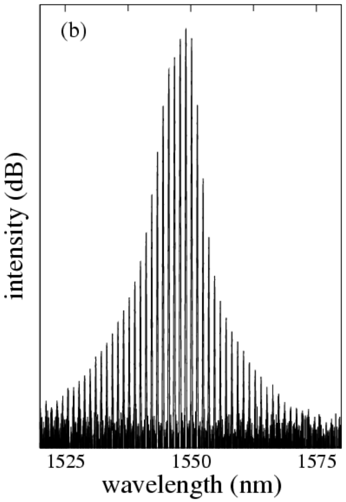
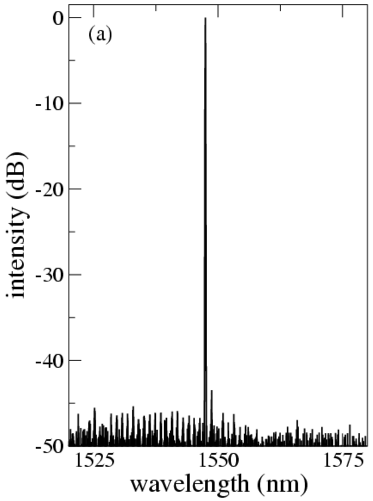
Optical Cavity Engineering in Fabry-Pérot lasers

A low density of index perturbations introduced along the laser ridge transforms the multimode spectrum into a single mode emission with high spectral purity





plain FP device



discrete mode device

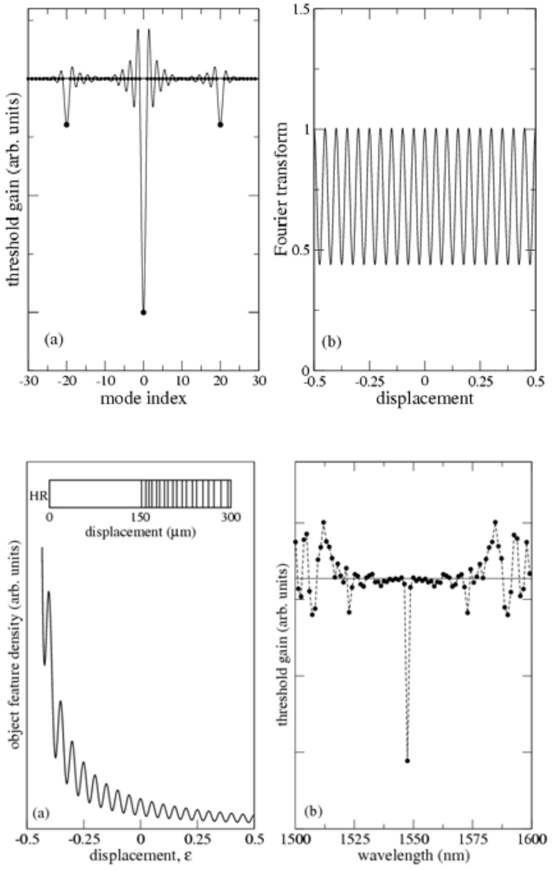
Unique approach that retains mirrors and perturbs Fabry-Pérot modes. Insight through our first solution of inverse problem opens many future developments and applications.

[S. O'Brien and E.P. O'Reilly, APL **86**, 201101 (2005)]

[S. O'Brien and E.P. O'Reilly, Irish patent; PCT patent pending]

Design of single-mode laser

- Excellent wavelength stability is achievable with few additional features



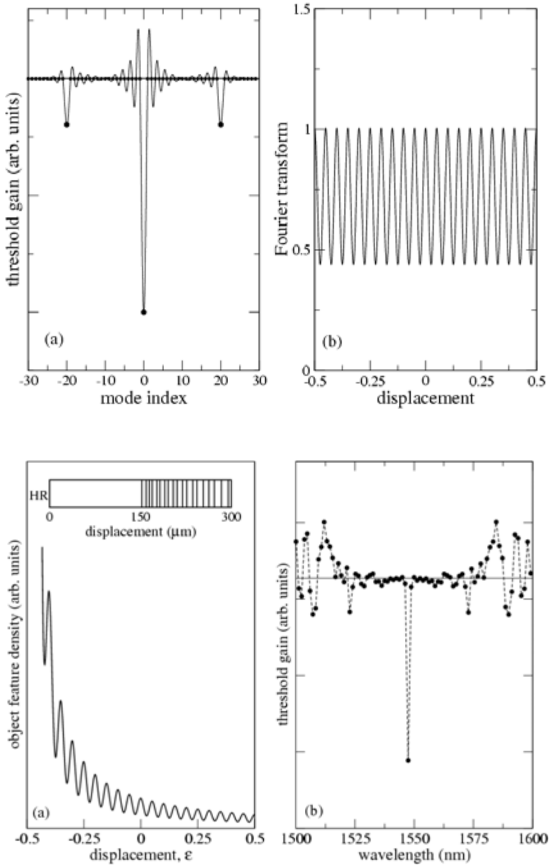
Ideal threshold gain function and corresponding FT

Inverse problem solution

Weighted FT and calculated threshold gain spectrum

Design of single-mode laser

- Excellent wavelength stability is achievable with few additional features



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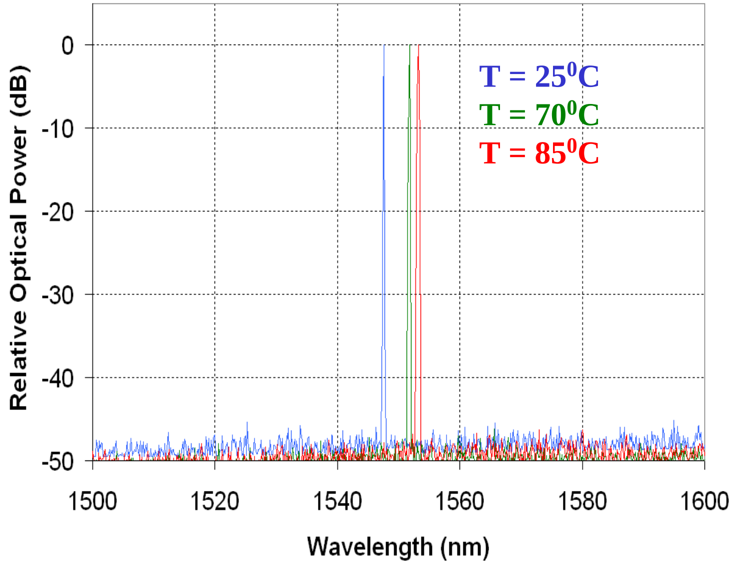
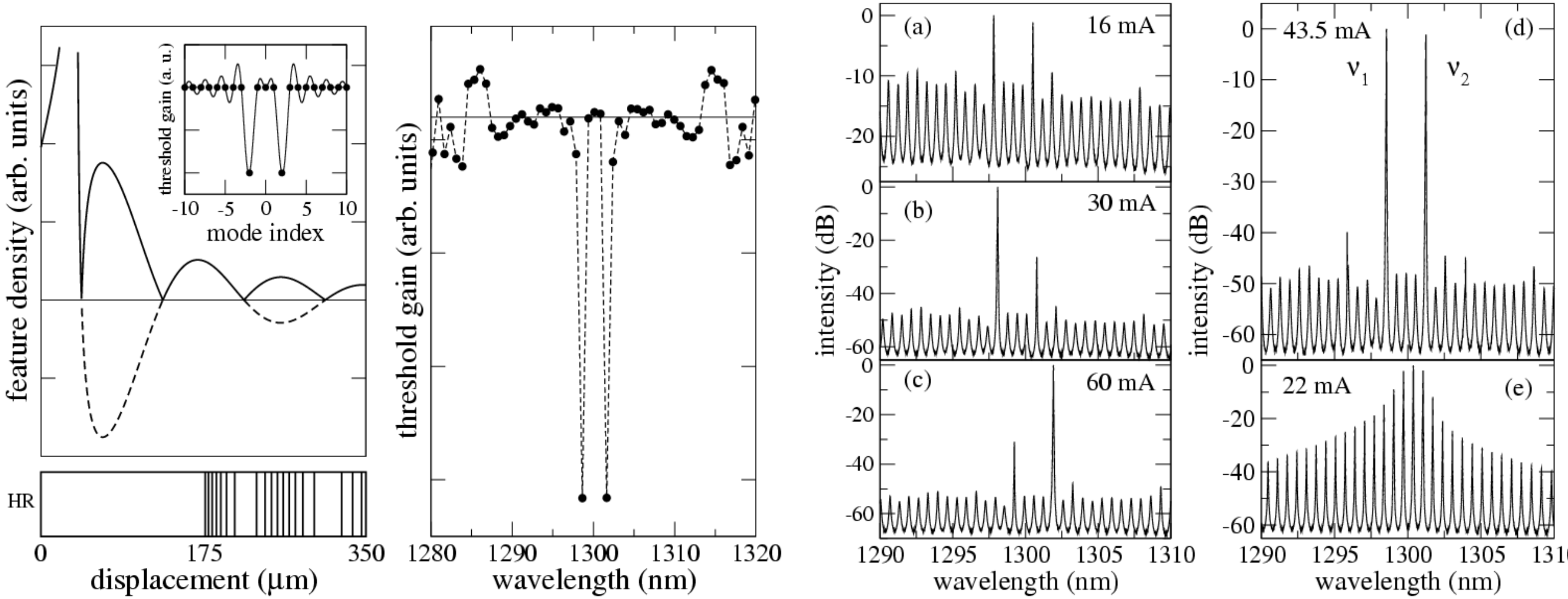


Temperature stable to 85 ^{0}C

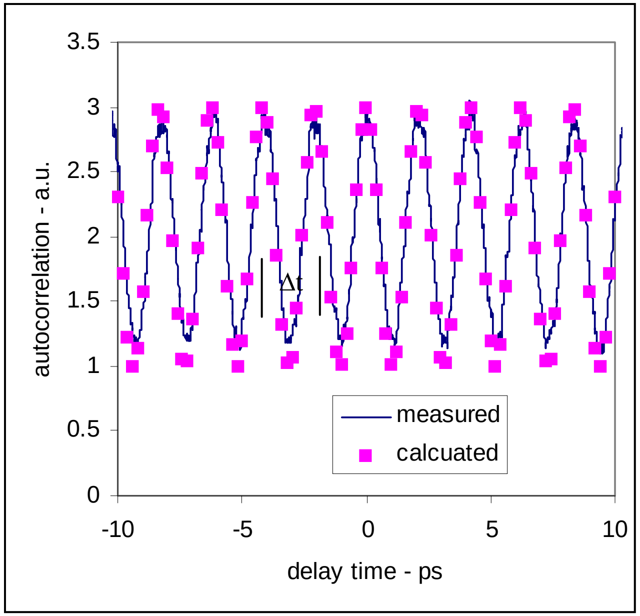
Multi-wavelength Fabry-Pérot laser design

- Demonstration of simultaneous two-colour lasing



S. O'Brien *et al.*, Phys. Rev. A **74**, 063814 (2006)

480 GHz modelocked signal



$\Delta t = 2.08ps \rightarrow 480GHz$

Contrast ratio ~ 3:1

I=46 mA, T=25 ^{o}C

For a given T only I need to be adjusted to get modelocking

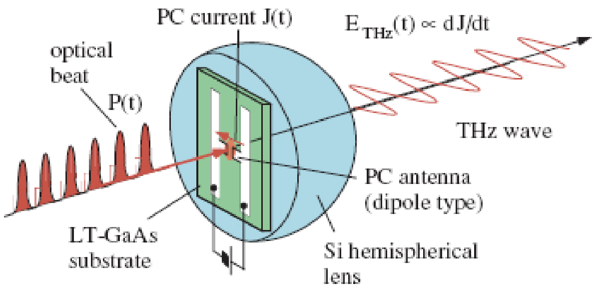
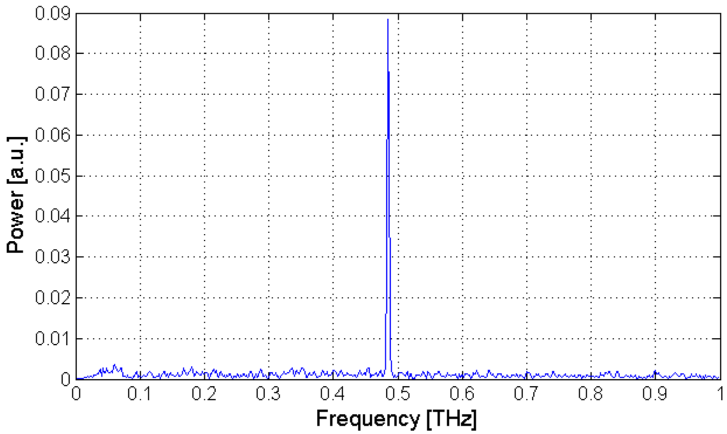
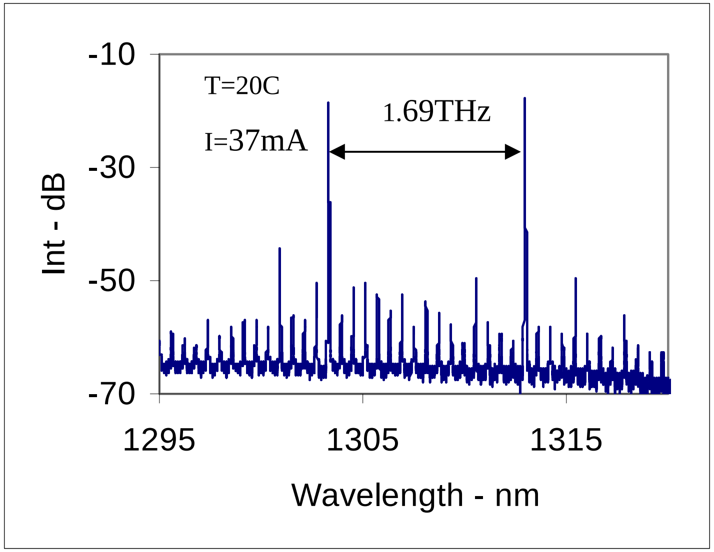


Figure 2. Schematic illustration of operation of photomixer photoconductive antenna for cw THz wave generation.



Tani et al., Semiconductor Sci. Tech. **20**, 151 (2005)

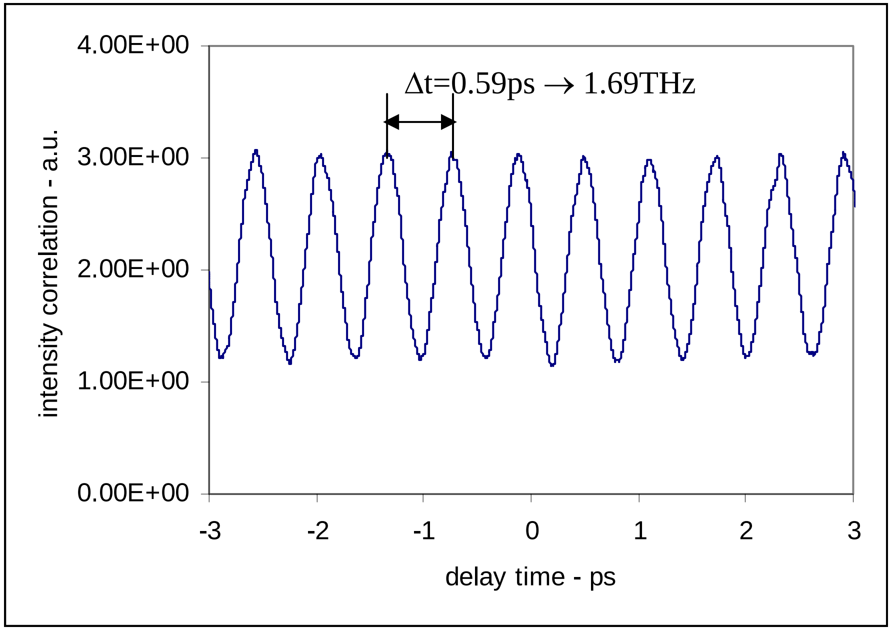
Terahertz modelocked signal: 0.5 to 1.7 THz



Modes separated by 16 longitudinal modes.

$\Delta\lambda$=9.64 nm $\rightarrow$ ν_b=1.69THz

Contrast ratio ~ 3:1



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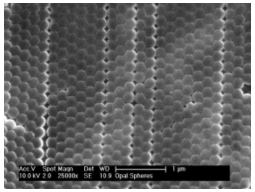
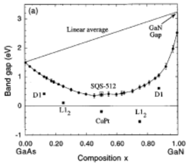
Photonics at Tyndall

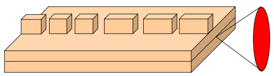
- Low-cost technologies



Opal thin films

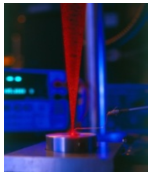


Dilute nitride alloys



Single-mode
Fabry-Perot laser

- **Materials & devices**



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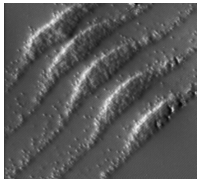
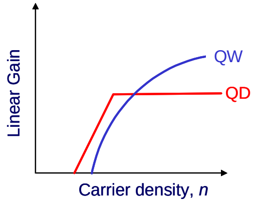
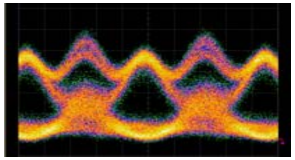




Quantum dot materials & devices

- Systems



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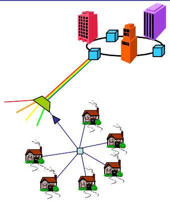
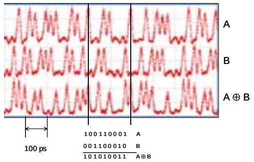


Optical access



Ultrafast logic

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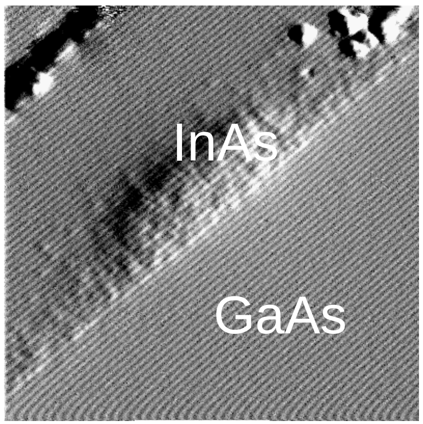
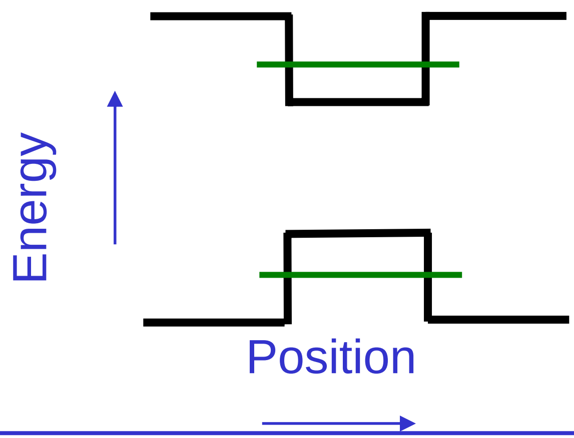
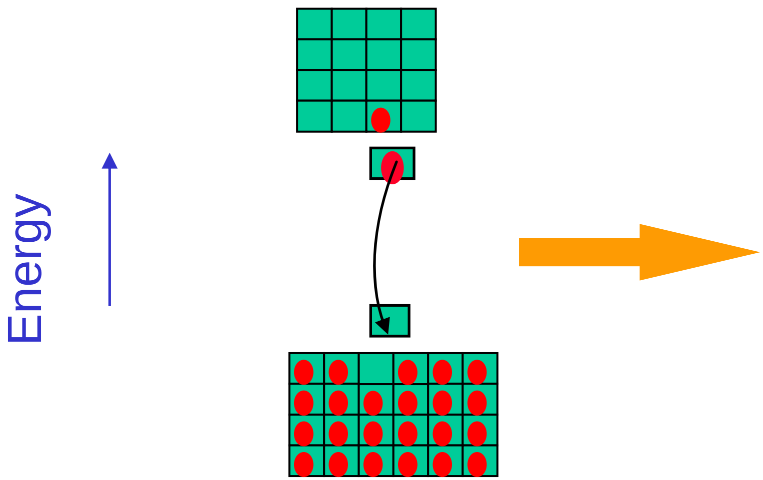
Quantum Dots – “Artificial Atoms”



10 nm

Potential confines carriers in all 3 dimensions

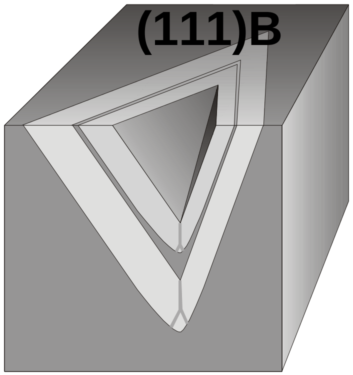


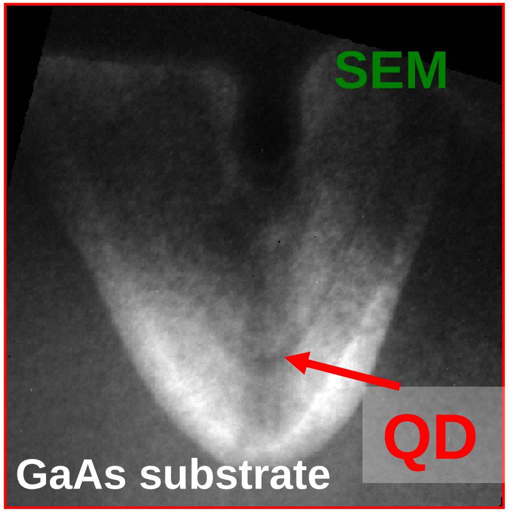


- Atom-like energy levels
- surrounded by semiconductor energy bands

Pelucchi: QD fabrication

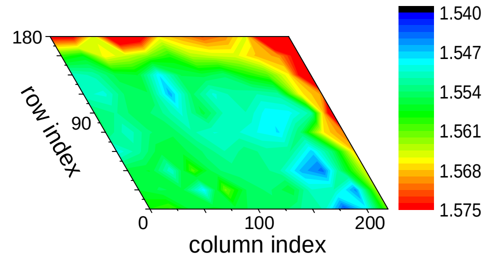
- Wet chemical etching using photo and electron-lithographical methods
- MOVPE deposition of GaAs/AlGaAs or InGaAs/GaAs
- QWR (100) or QD (111)B
- Diffusion-limited growth for reproducible QD emission with low inhomogeneous broadening
- Pelucchi moved as SFI-funded PI from EPFL to Tyndall in 1/07 to new MOVPE growth facility





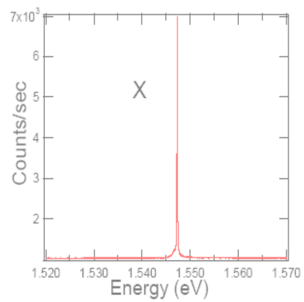
Pyramidal quantum dot achievements

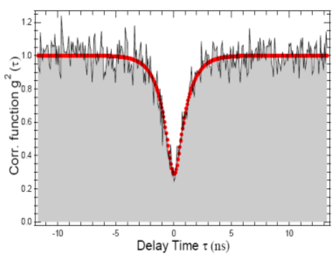
M. Baier, E. Pelucchi, S. Watanabe, and E. Kapon, “**High-uniformity** of site-controlled pyramidal quantum dots grown on pre-patterned substrates”, Appl. Phys. Lett. **84**, 1943 (2004).



Also in dense arrays…….~1x10⁹/cm²
4-8meV peak distribution

M. Baier,et al...” **Single photon emission** from site-controlled pyramidal quantum dots”, Appl. Phys. Lett. **84**, 648 (2004).

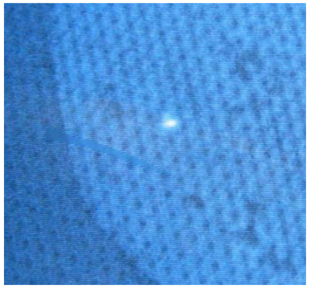


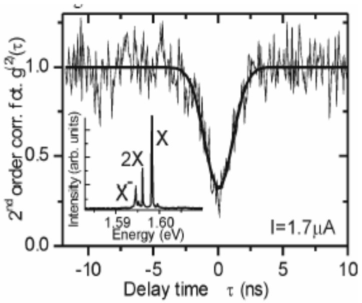


resolution limited FWHM…

M. Baier, C. Constantin, E. Pelucchi, and E. Kapon, **Electroluminescence** from a single pyramidal quantum dot in a light-emitting diode”, Appl. Phys. Lett. **84**, 1967 (2004).

single photon electrically pumped…M.H..Baier et al unpublished



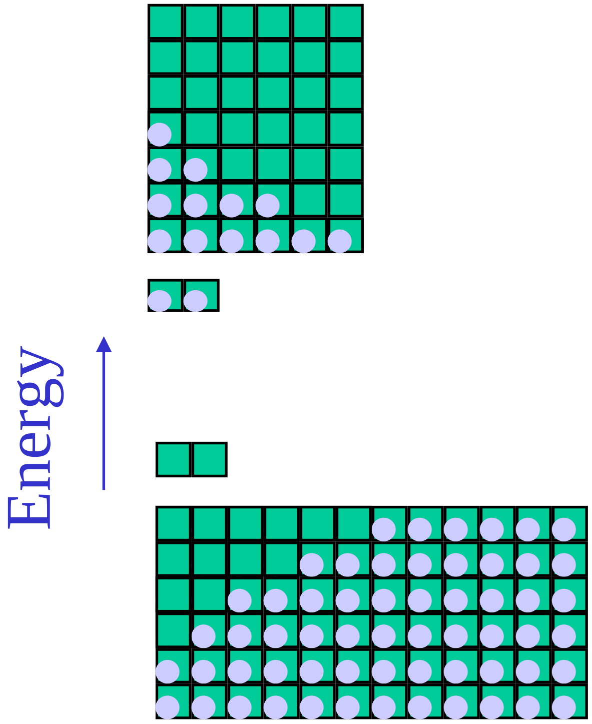


Electrically pumped

Quantum Dot Lasers and Amplifiers

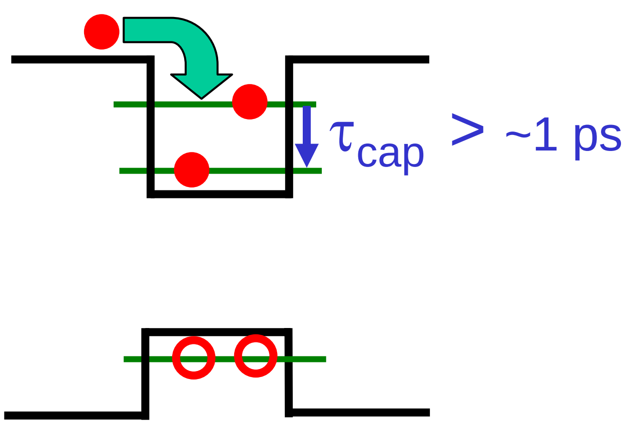
Compared to conventional bulk or quantum well (QW) lasers:

1) Complete inversion impossible in QW:



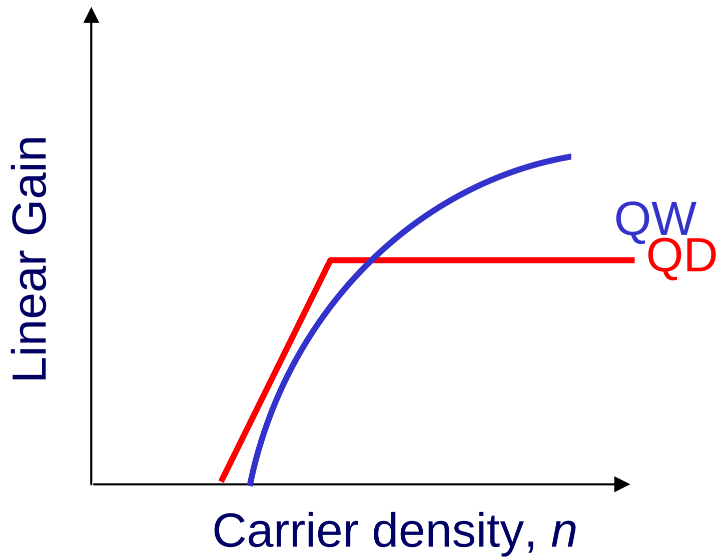
- but could be achieved in QD

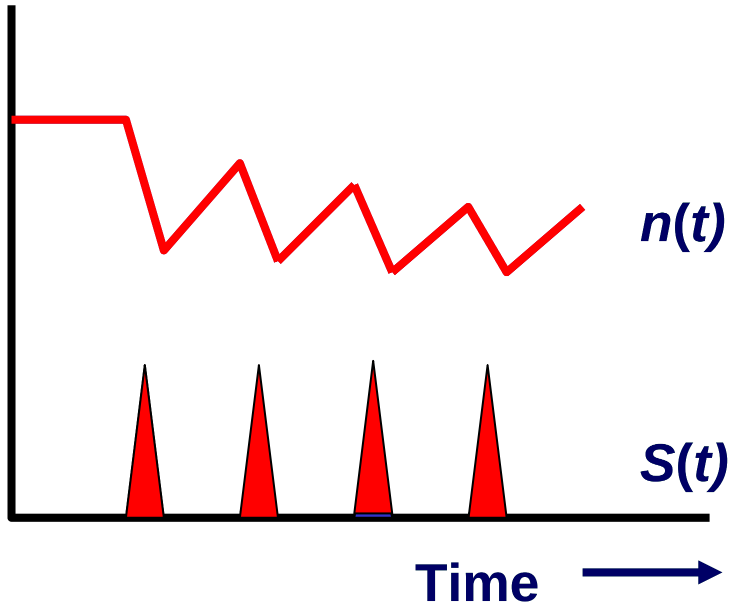
2) Carrier capture rate-limiting?



Capture rate into lowest electron level determines high-speed behaviour

Quantum dot optical amplifiers





Gain saturates at low carrier density:

- Pattern-free pulse amplification

  [A.V. Uskov *et al.*, Optics Comms., **227**, 363-369 (2003)]

- Potential key to pattern-free ultrafast switching

  [A. V. Uskov *et al.*, IEEE PTL **16**, 1265-1267 (2004)]

- Reduced sensitivity to laser feedback

  [O. Carroll, G. Huyet *et al*, Electron. Lett. **41**, 911 (2005)]

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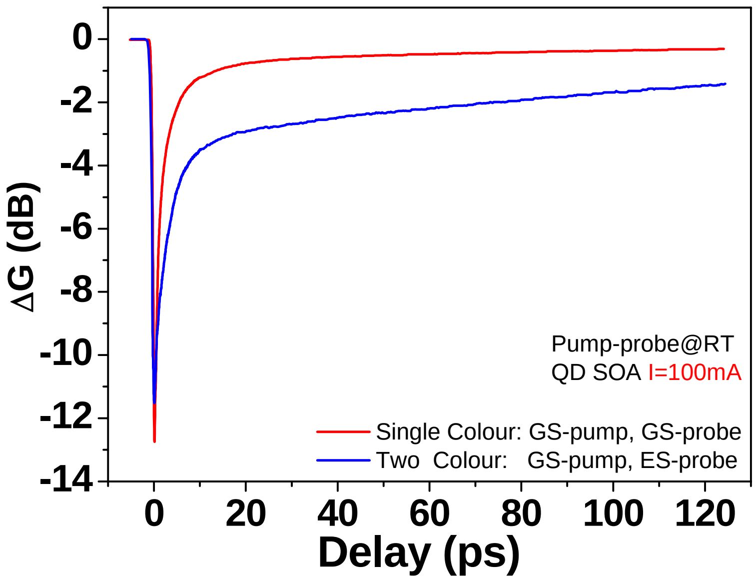
Carrier capture and gain recovery



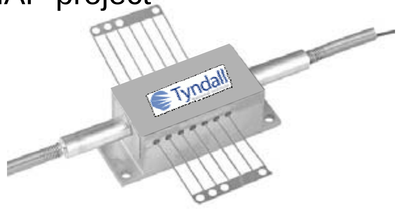
I. O'Driscoll, G. Huyet et al. Appl. Phys. Lett. (2007)

Fast recovery for pump ground state; probe ground state

Slow recovery for pump ground state; probe excited state

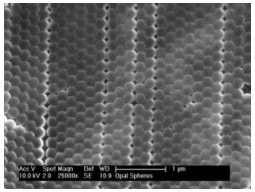
Patented system applications of QD devices

QD phase modulator to be fabricated by Tyndall under the NAP project

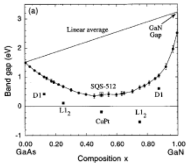


Photonics at Tyndall

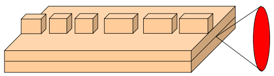
- Low-cost technologies



Opal thin films

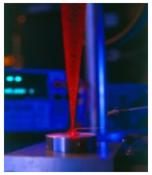


Dilute nitride alloys

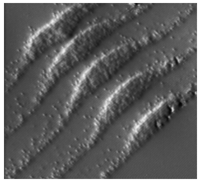


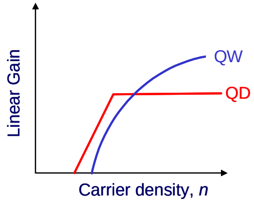
Single-mode Fabry-Perot laser

- Materials & devices



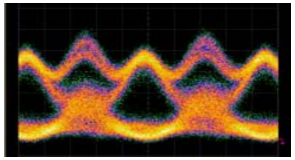
Red VCSL



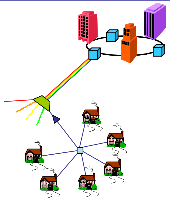


Quantum dot materials & devices

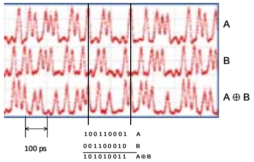
- **Systems**



Coherent WDM



Optical access



Ultrafast logic

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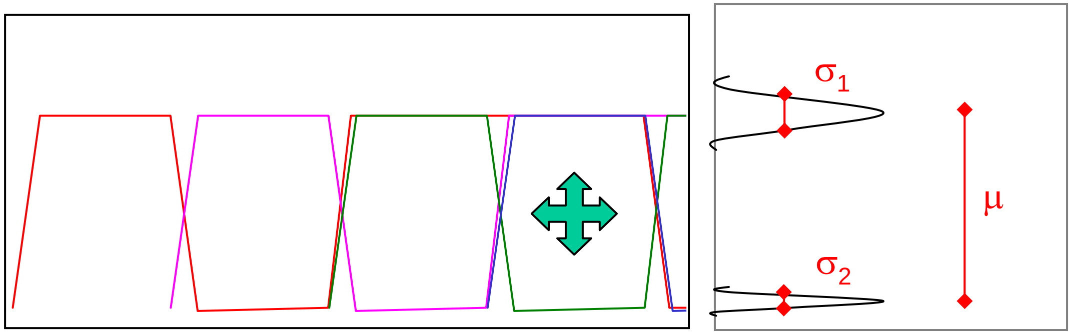
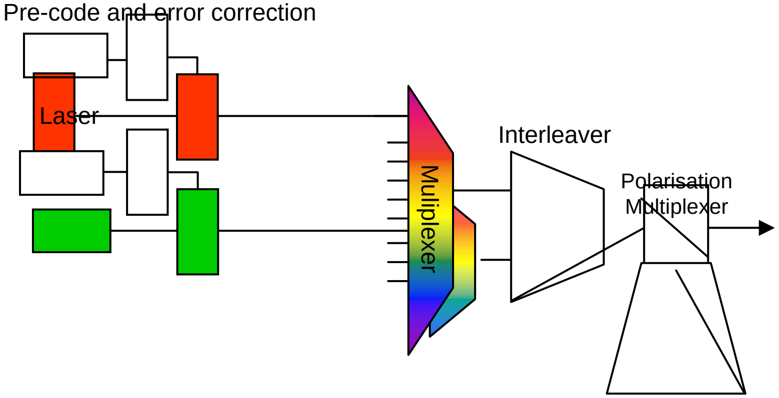
"Eye Diagrams" and "Q-Factors"

$$Q = \mu / (\sigma_1 + \sigma_2)$$

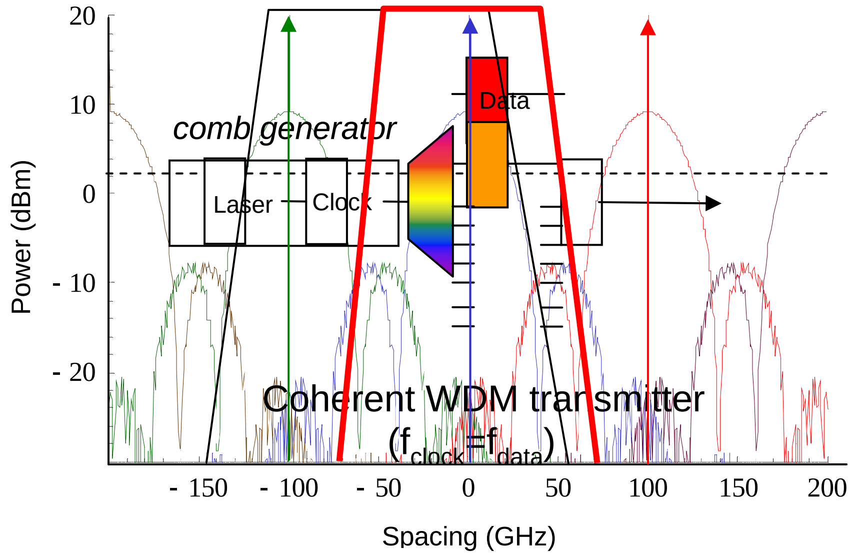


Coherent WDM - Principle[1]

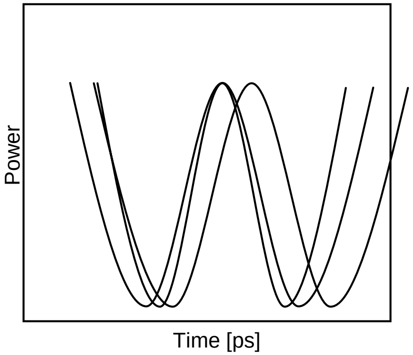


A typical high spectral efficiency transmitter

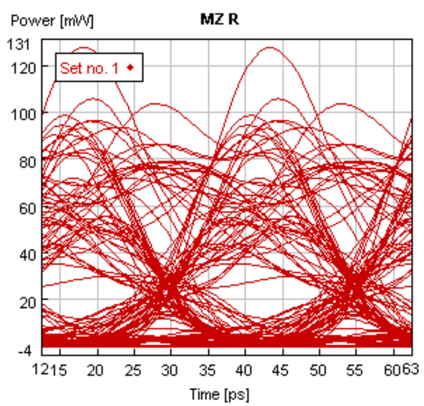
40 Gbit/s, 0.8 b/s/Hz



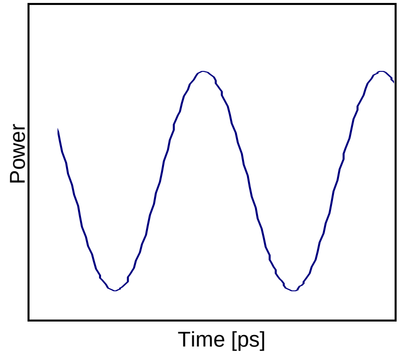
Sinusoidal beat signal between two cw signals



40 GHz channel spacing



Sinusoidal beat signal between two cw signals



1: A.D.Ellis et al, PTL **17** 2 pp504 (2005)

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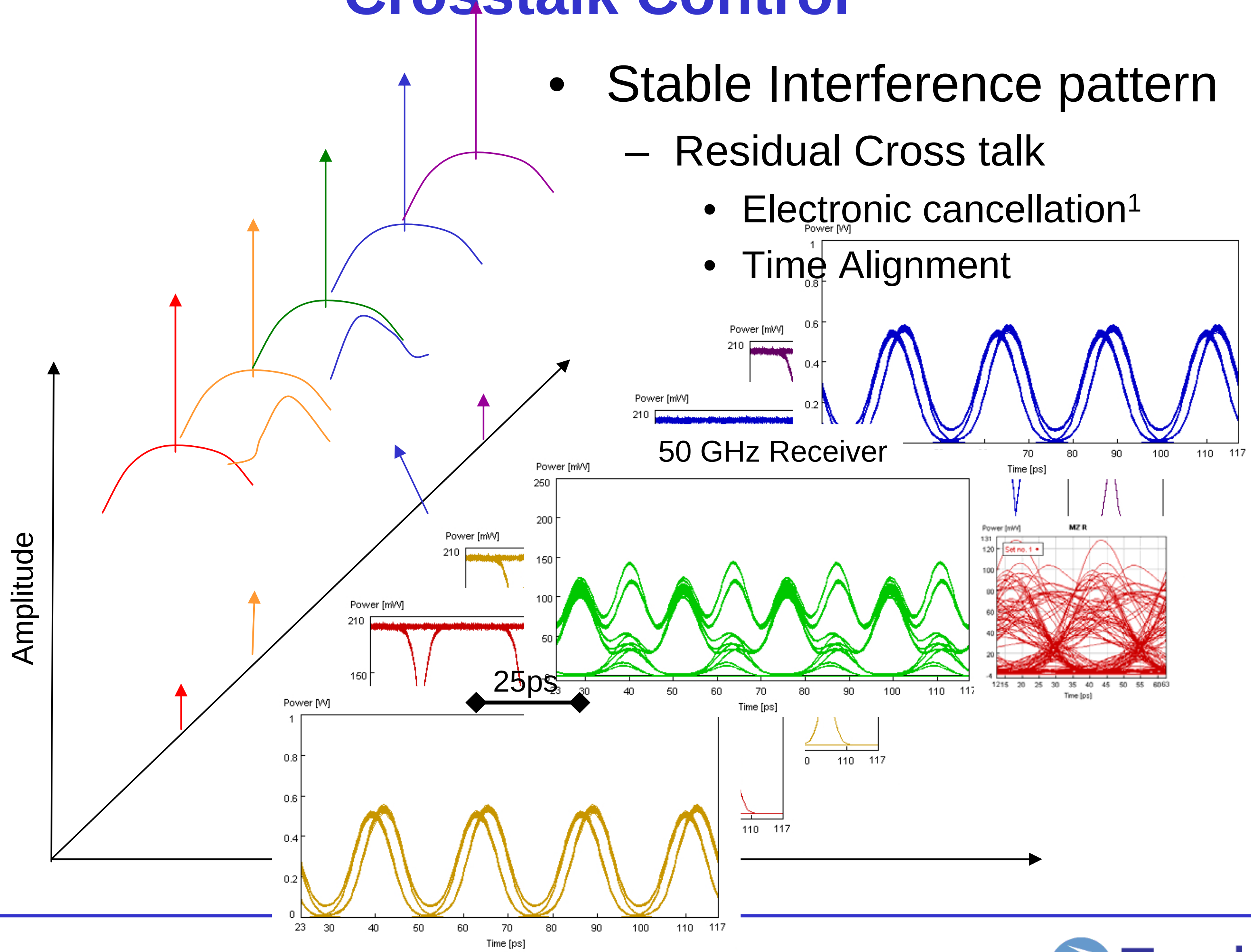
Crosstalk Control

- Stable Interference pattern
  - Residual Cross talk
    - Electronic cancellation[1]
    - Time Alignment



1. E.Yamazati et al, OFC 2006, JThB5

Conclusions

- Photonics ‘critical mass’ in Ireland
- Wide spectrum
  - *Expertise* in fundamental science, materials, devices, integration, systems
  - *Activities* in basic research, technologies, systems, services
- Wide range of times to commercialisation
  - 0 to 20+ years
- Extensive industry involvement in Ireland and beyond
  - HPSUs (including Tyndall/NMRC spin-outs) and multi-nationals
- International collaboration
  - Prominent players in EU collaborations


Thank you!
Any questions?