

# Smart-Pixel OptoElectronic Connections (SPOEC)

**Heriot-Watt University (Co-ordinators)**

**Supelec, France**

**CSEM**

**University of Glasgow**

**Trinity College, Dublin**

email [A.C.Walker@hw.ac.uk](mailto:A.C.Walker@hw.ac.uk)

[www.phy.hw.ac.uk/resrev/SPOEC](http://www.phy.hw.ac.uk/resrev/SPOEC)



Smart Pixel OptoElectronic  
Connections (*ESPRIT MEL-ARI*)

# SPOEC Partners and Responsibilities

**Heriot-Watt University, Edinburgh (Depts of Physics, Comp and Elec Eng)**

Project Co-ordination - Professor Andy Walker (Dept. of Physics)

Silicon design, Optics, Optomechanics, Micro-optics

**University of Glasgow**

InGaAs device design, growth and fabrication

**SUPELEC, Metz / Paris**

Silicon design, PCB design, Optics

**Trinity College, Dublin**

Advanced InGaAs device design

**CSEM, Zürich (formerly Paul Scherrer Institute)**

VCSEL design, growth and fabrication

AN ESPRIT-LTR PROJECT - PART OF THE MEL-ARI OPTO CLUSTER



Smart Pixel OptoElectronic  
Connections (*ESPRIT MEL-ARI*)



# The European Scene

## MEL-ARI Opto Cluster of Projects 1996-1999

|          |                                       |
|----------|---------------------------------------|
| OIIC     | Polymer waveguide interconnects       |
| RODCI    | Reconfigurable planar interconnects   |
| SIBLE    | Silicon light emitters, quantum dots  |
| MONOLITH | Conformal growth of GaAs on Si        |
| SPOEC    | 3-D Free Space Crossbar with Tbit i/o |



Smart Pixel OptoElectronic  
Connections (*ESPRIT MEL-ARI*)

# The SPOEC Project

**A free-space optically connected crossbar demonstrator with Tbit/s io to Si**

## **Motivation**

**Interconnect Bottleneck**

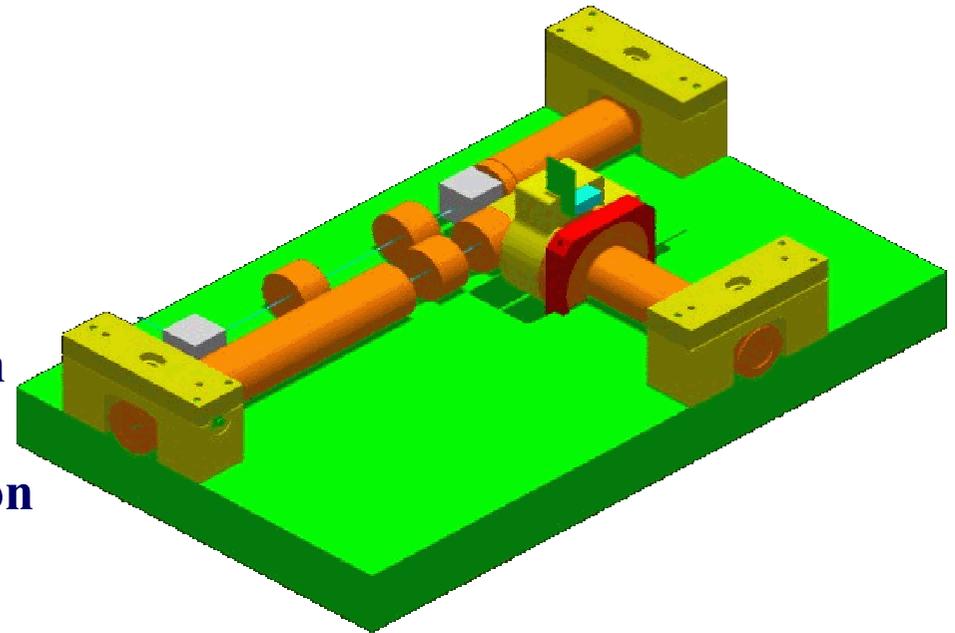
## **Features**

**hybrid Si/InGaAs  
smart-pixel logic**

**Optical clock distribution**

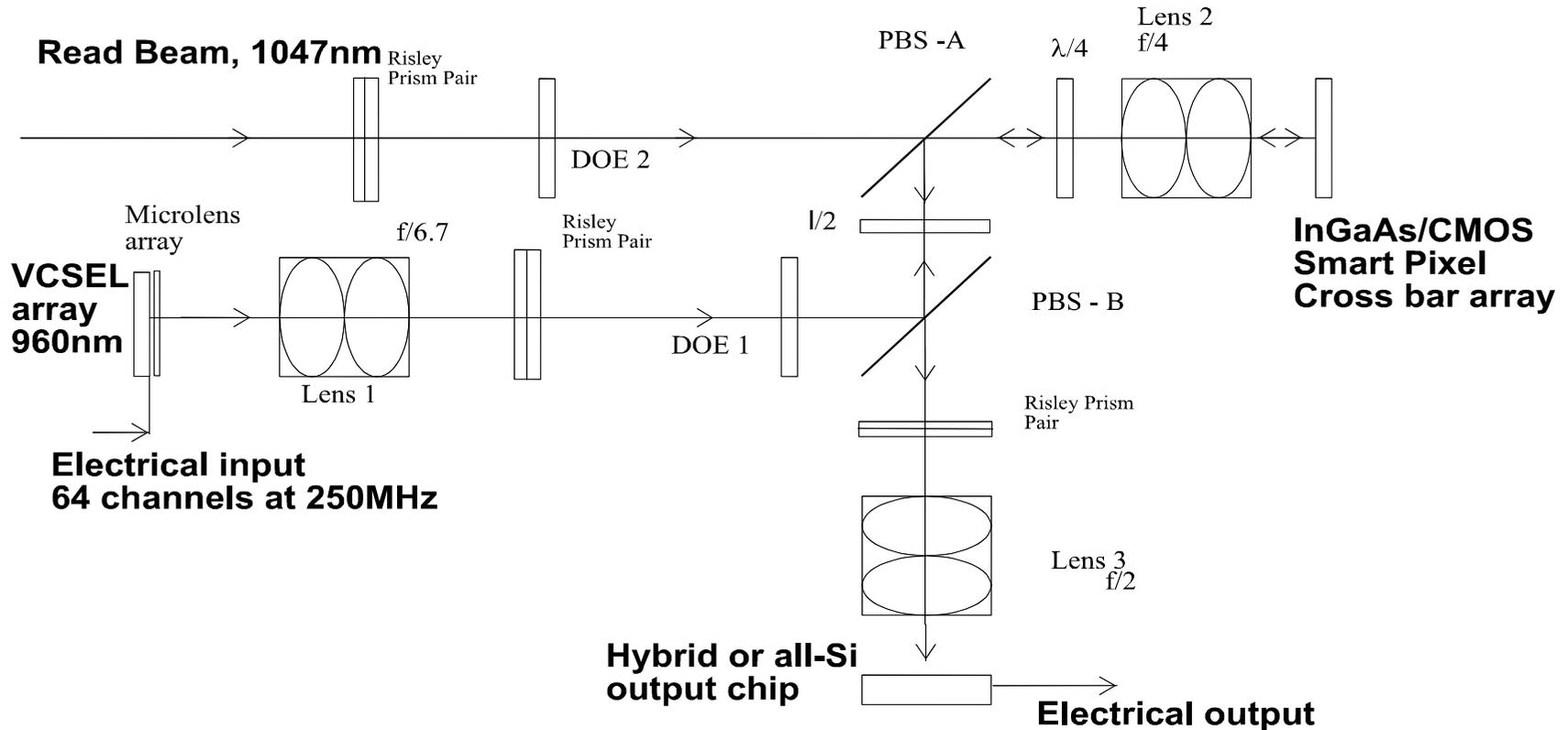
**Header decoding in Silicon**

**8x8 VCSEL array input**



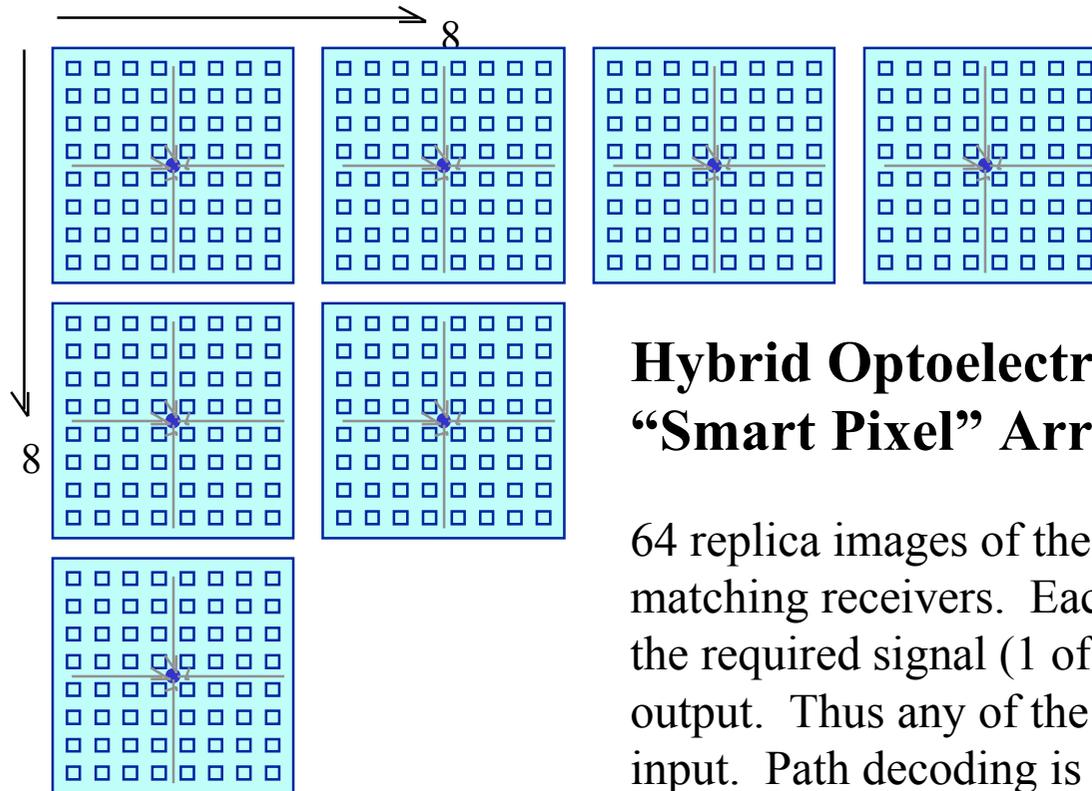
Smart Pixel OptoElectronic  
Connections (*ESPRIT MEL-ARI*)

# SPOEC - A System Overview



Smart Pixel OptoElectronic  
Connections (*ESPRIT MEL-ARI*)

# SPOEC Crossbar Operation



## Hybrid Optoelectronic “Smart Pixel” Array

64 replica images of the 64 inputs are incident on matching receivers. Each block electronically routes the required signal (1 of the 64 inputs) to its optical output. Thus any of the 64 outputs can select any input. Path decoding is carried out within each block, electronically, according to the header.



Smart Pixel OptoElectronic  
Connections (*ESPRIT MEL-ARI*)

High contrast input devices for SPOEC

MOVPE at **CSEM Zurich**

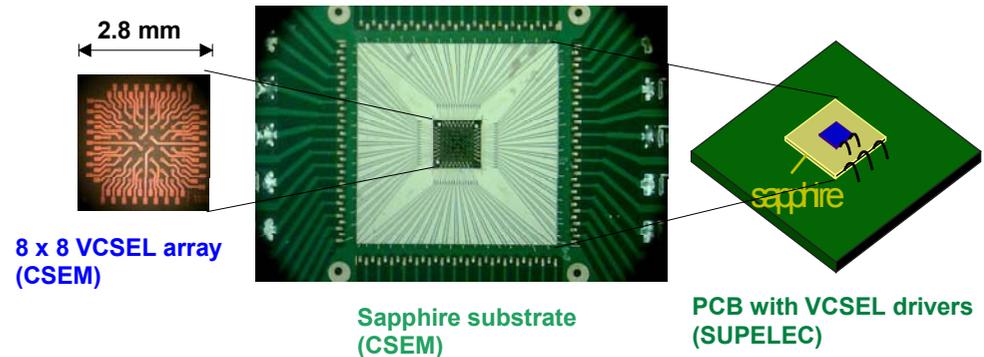
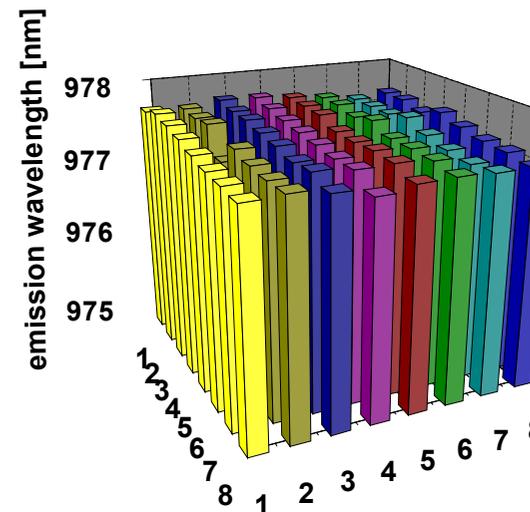
Strained AlGaAs/GaAs/InGaAs

250 $\mu$ m pitch, 10 $\mu$ m aperture

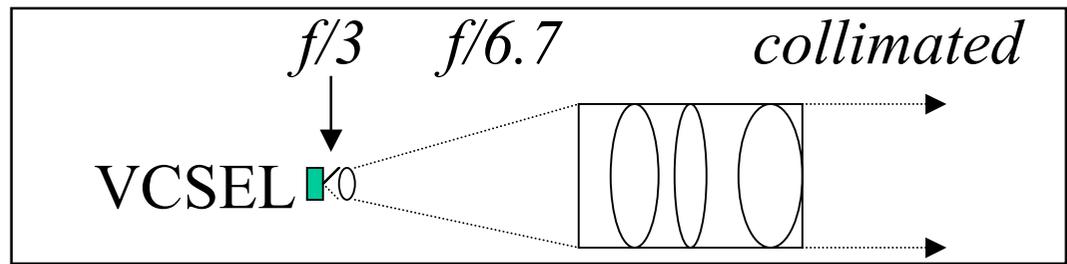
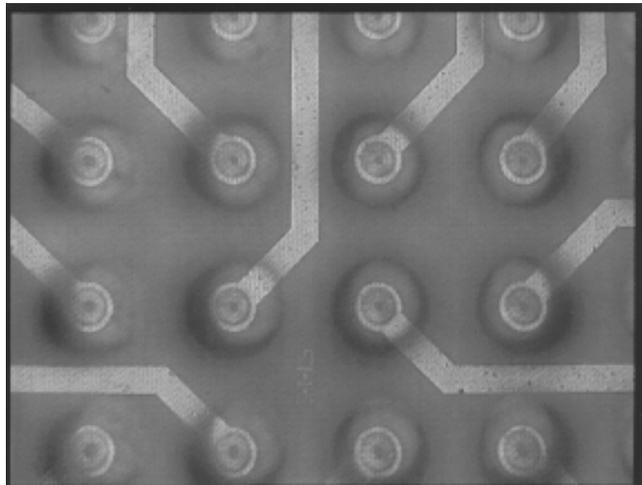
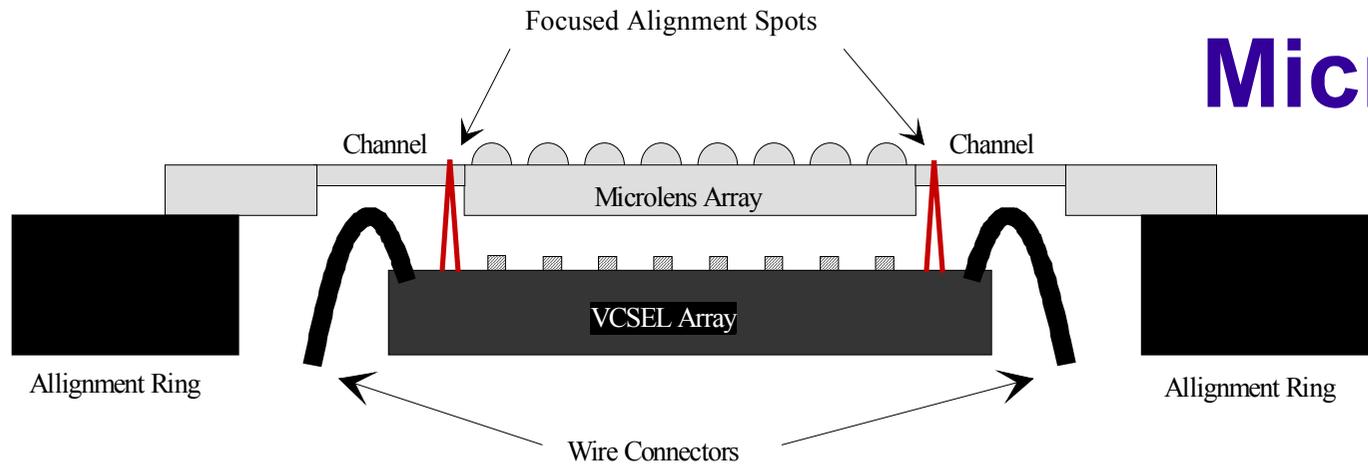
Performance

- 8x8 array,  $\lambda=960\text{nm}$
- >500Mbit/s
- $\Delta\lambda < 0.4\text{nm}$  (ie 0.1%)
- cw power of >1.5mW per device
- $V_{\text{th}}=1.9\text{V}$ ,  $I_{\text{th}} 2.6\text{mA}$

# VCSELS



# Micro-Optics



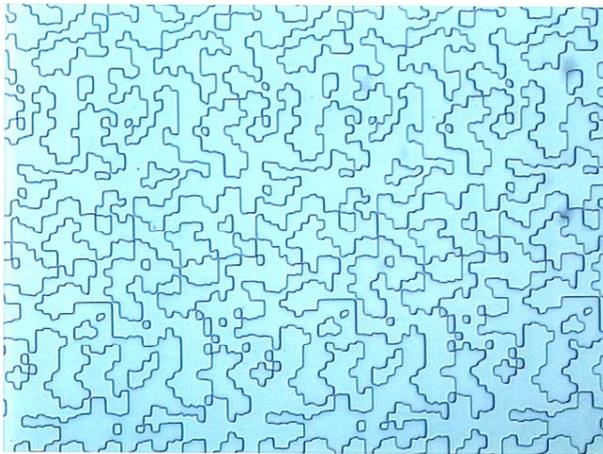
- Efficient collection of divergent VCSEL emission
- Refractive microlenses (Heriot-Watt University)



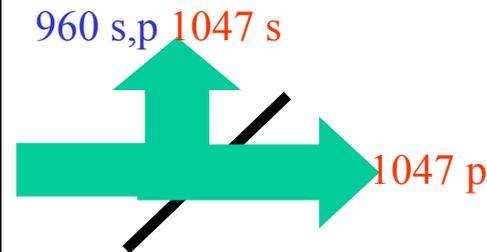
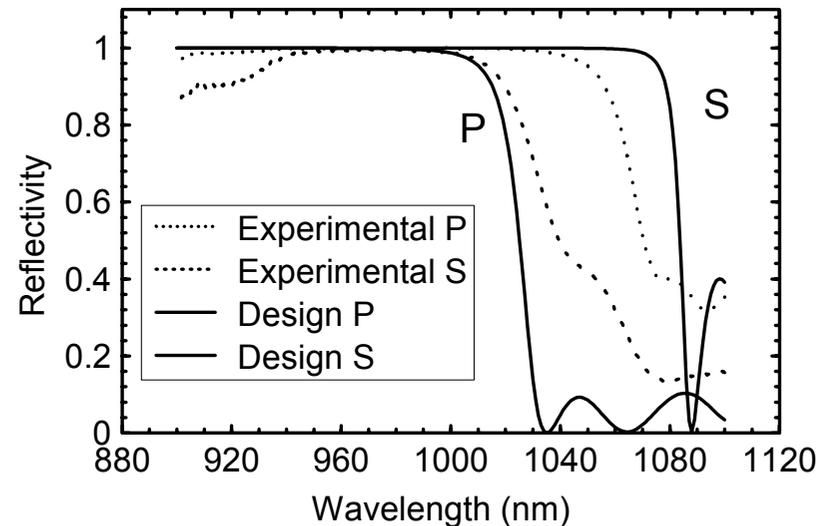
Smart Pixel OptoElectronic  
Connections (*ESPRIT MEL-ARI*)

# Fan-out and Beam Steering

- Binary DOEs for 8x8 and 8x16 fanout
- Uniformity to within 2%
- Low zero-order (<0.1%) to reduce xtalk

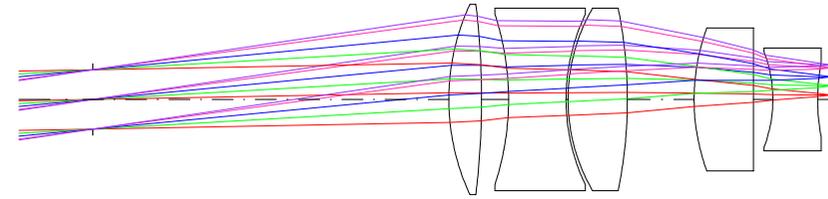
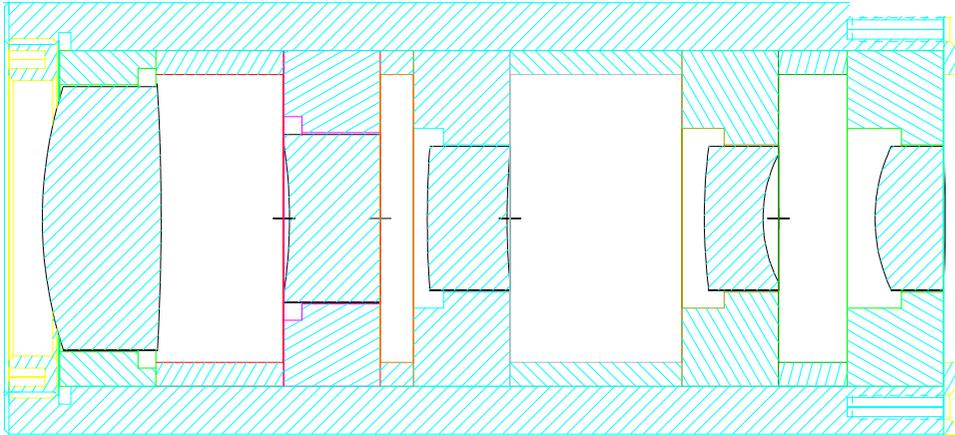


- 27 layers of TiO<sub>2</sub> and SiO<sub>2</sub> at 45°

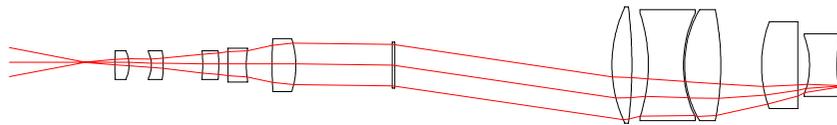


- Incident Angle  
> ±7.5°

# Bulk Optics



- Custom Multi-Element Lenses designed using CodeV
- Custom Optomechanical Lens Assembly and Baseplate

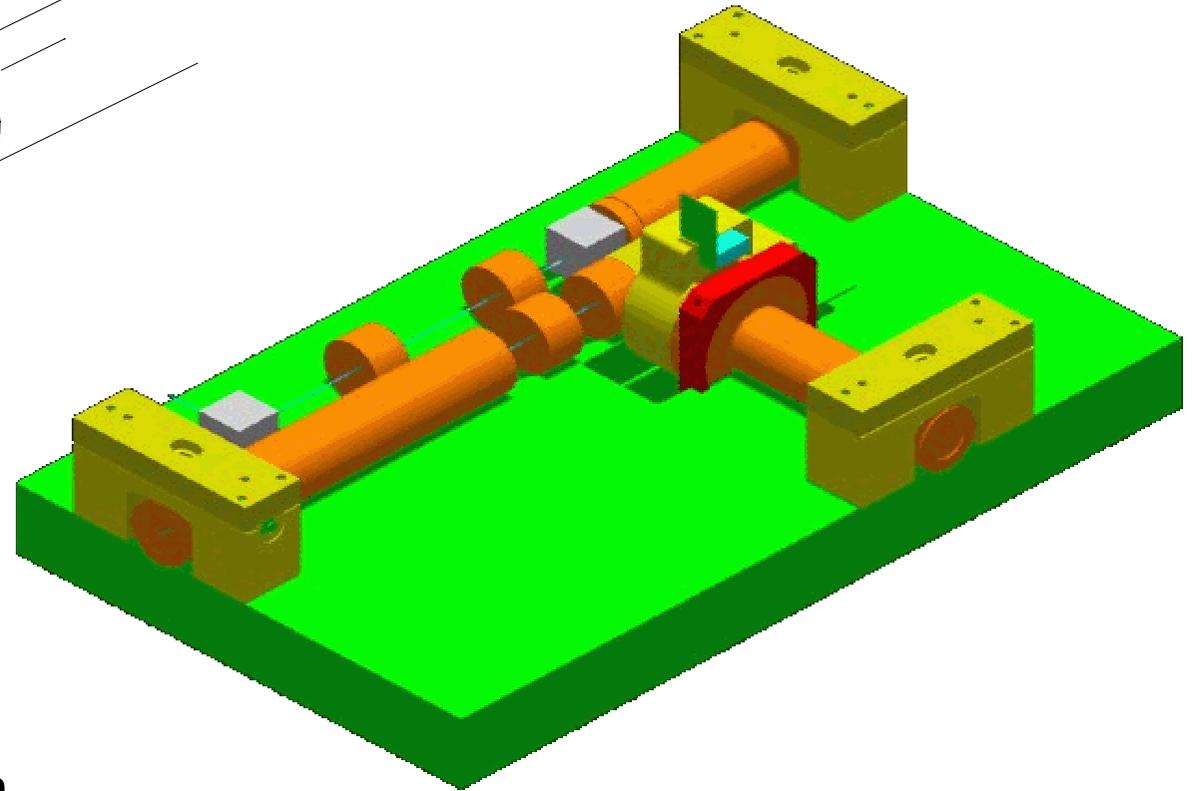
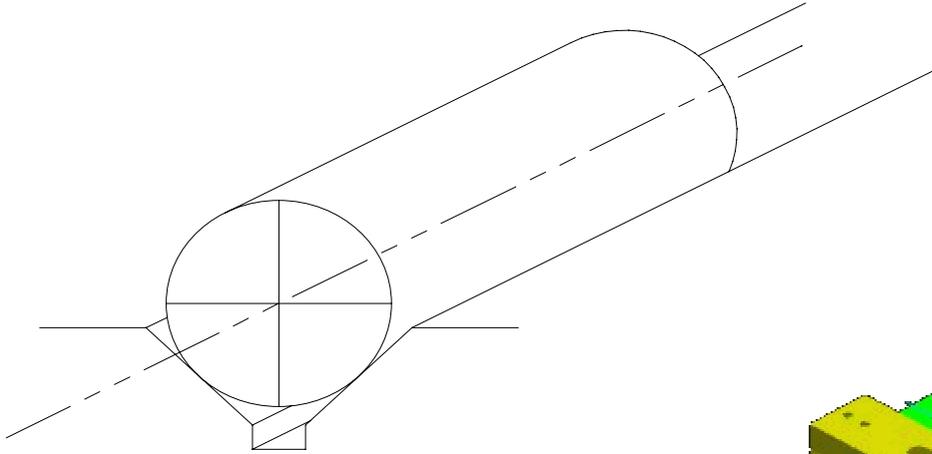


- Image field 17.5mm (Lens 2)
- Near-diffraction limited
- Barrel mounted for stability
- Dual-wavelength (Lens 2)



Smart Pixel OptoElectronic  
Connections (*ESPRIT MEL-ARI*)

# Optomechanics

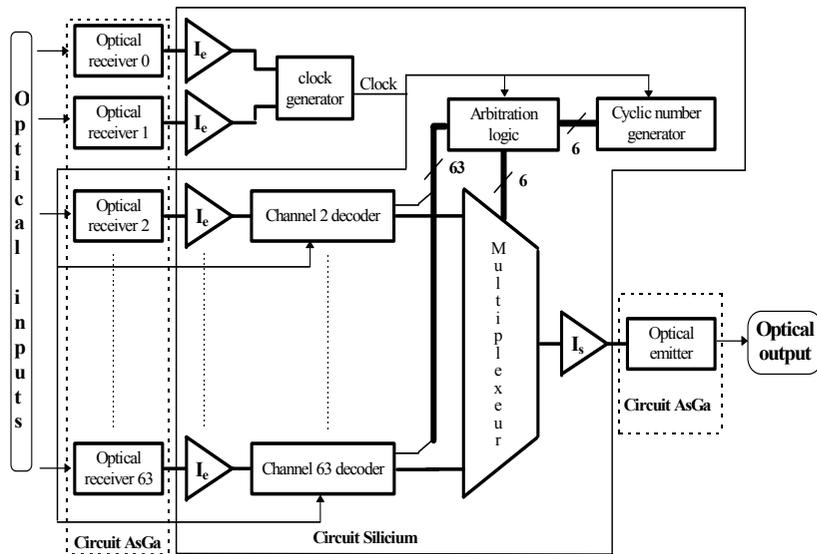


Stable mounting system  
Semi-kinematic slot plate  
system with magnets  
Components are centred in  
cells



Smart Pixel OptoElectronic  
Connections (*ESPRIT MEL-ARI*)

# Smart Pixels - Silicon CMOS



HWU/Supélec

- 0.6 micron CMOS (AMS)
- optical clock input
- header decoding
- Analogue design  
- sensitivity  $5 \mu\text{A}$  optical input  $\sim 10 \mu\text{W}$
- Clock receivers based on transconductance-transimpedance amp.  
Forbes and Walker *Electron Lett* 34(6) 1998

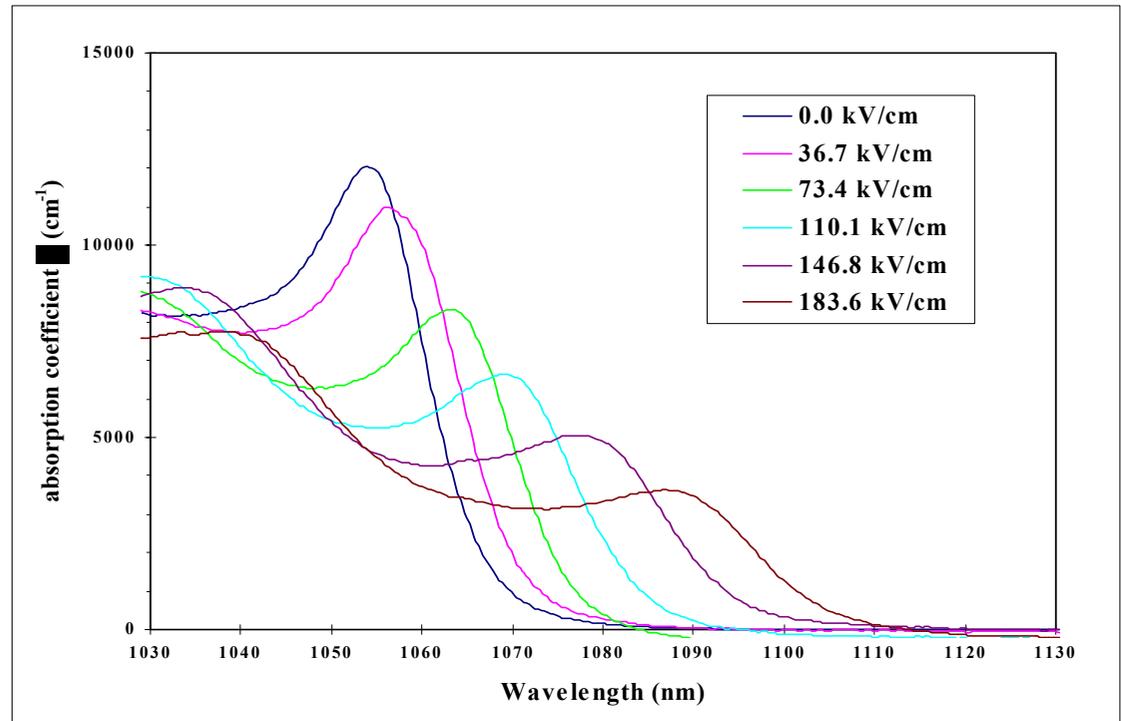


Smart Pixel OptoElectronic  
Connections (ESPRIT MEL-ARI)

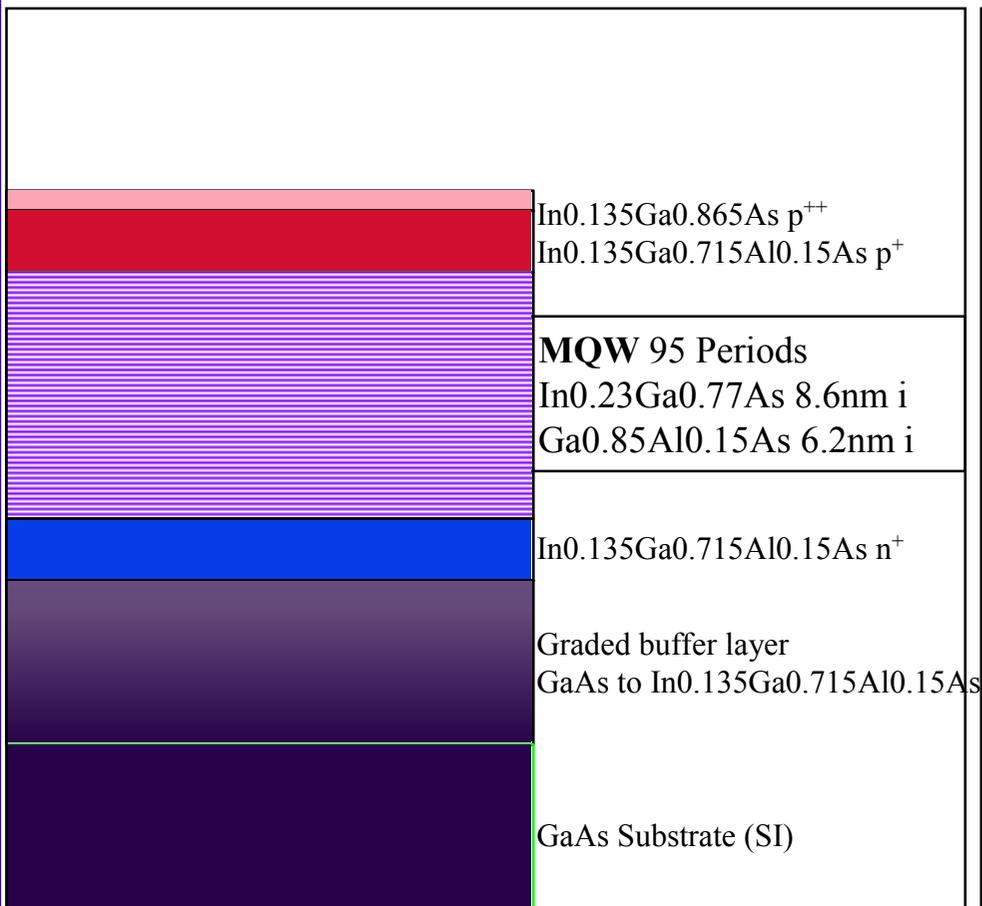
# Smart Pixels - Modulators

Quantum Confined Stark  
Effect Electro-absorption  
Modulators

(Thanks to Lucy Wilkinson for  
these example results)



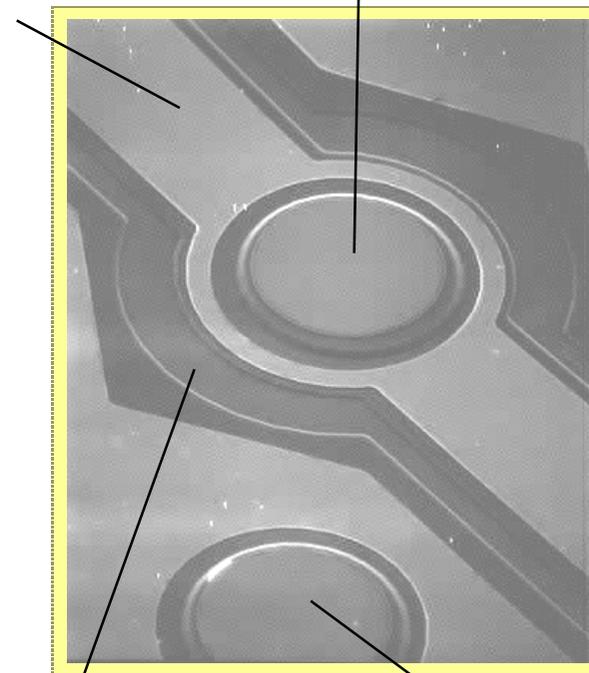
# InGaAs-based devices



(Univ. of Glasgow)

$n^{+}$ -contact rail  
to modulators

Modulator



Isolation trench

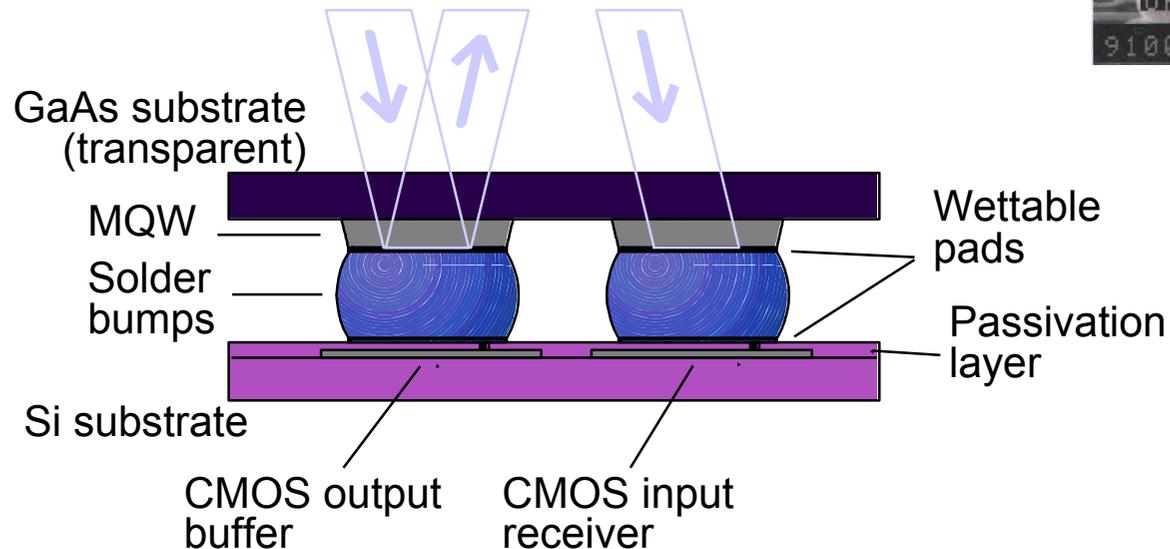
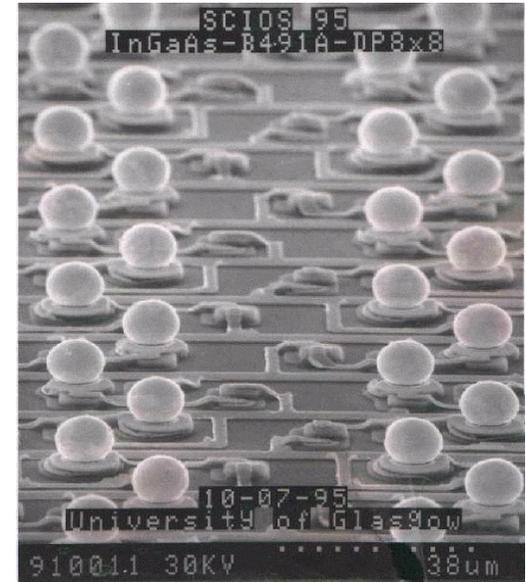
Detector



Smart Pixel OptoElectronic  
Connections (*ESPRIT MEL-ARI*)

# Flip-Chip Integration

Flip-Chip solder-bump bonding  
(GMMT Caswell)



Smart Pixel OptoElectronic  
Connections (ESPRIT MEL-ARI)

# Future Work and Related Research

- Flip-Chip Integration of Smart Pixel chips (end 1998)
- Opto-mechanical assembly (end 1998)
- Initial Construction (early 1999)
- Full System Operation (mid 1999)

## Development Work

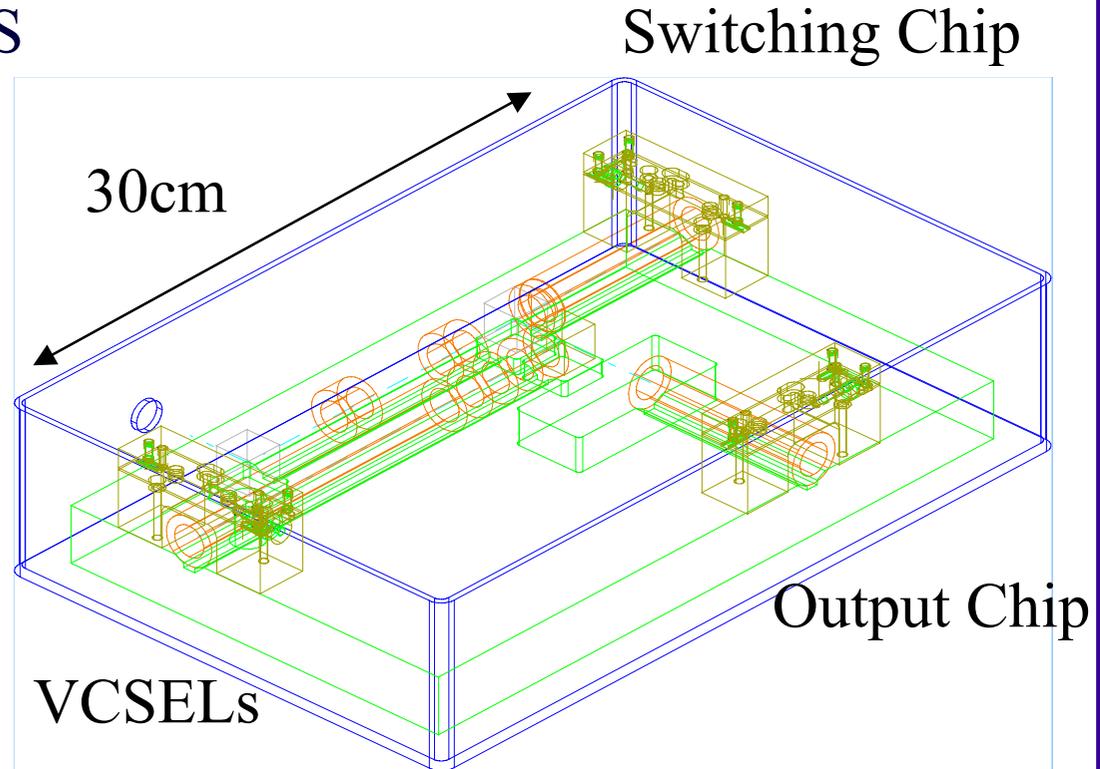
- Optimised Modulators (Trinity College/ Glasgow Univ)
- Improve modulator performance using AFPM
- Design finalised, testing ongoing



Smart Pixel OptoElectronic  
Connections (*ESPRIT MEL-ARI*)

# Summary and Acknowledgements

- Target is optical i/o to Si-CMOS chip at  $\geq 1$  Tbit/s.
- Data input by 960nm 8x8 VCSEL arrays at 250 MHz.
- Optical distribution of clock signals to smart pixel cells.
- Decoding of header routing data in Silicon.
- Operation of a 64 x 64 optoelectronic crossbar.



AN ESPRIT-LTR PROJECT - PART OF THE MEL-ARI OPTO CLUSTER



Smart Pixel OptoElectronic  
Connections (*ESPRIT MEL-ARI*)