NRC·CNRC

Institute for Microstructural Sciences

The Path to Manufacturing Nano-Photonics Components

Canadian Photonics Fabrication Center – CPFC

De-risking Technology & Investment
Enabling Commercialization

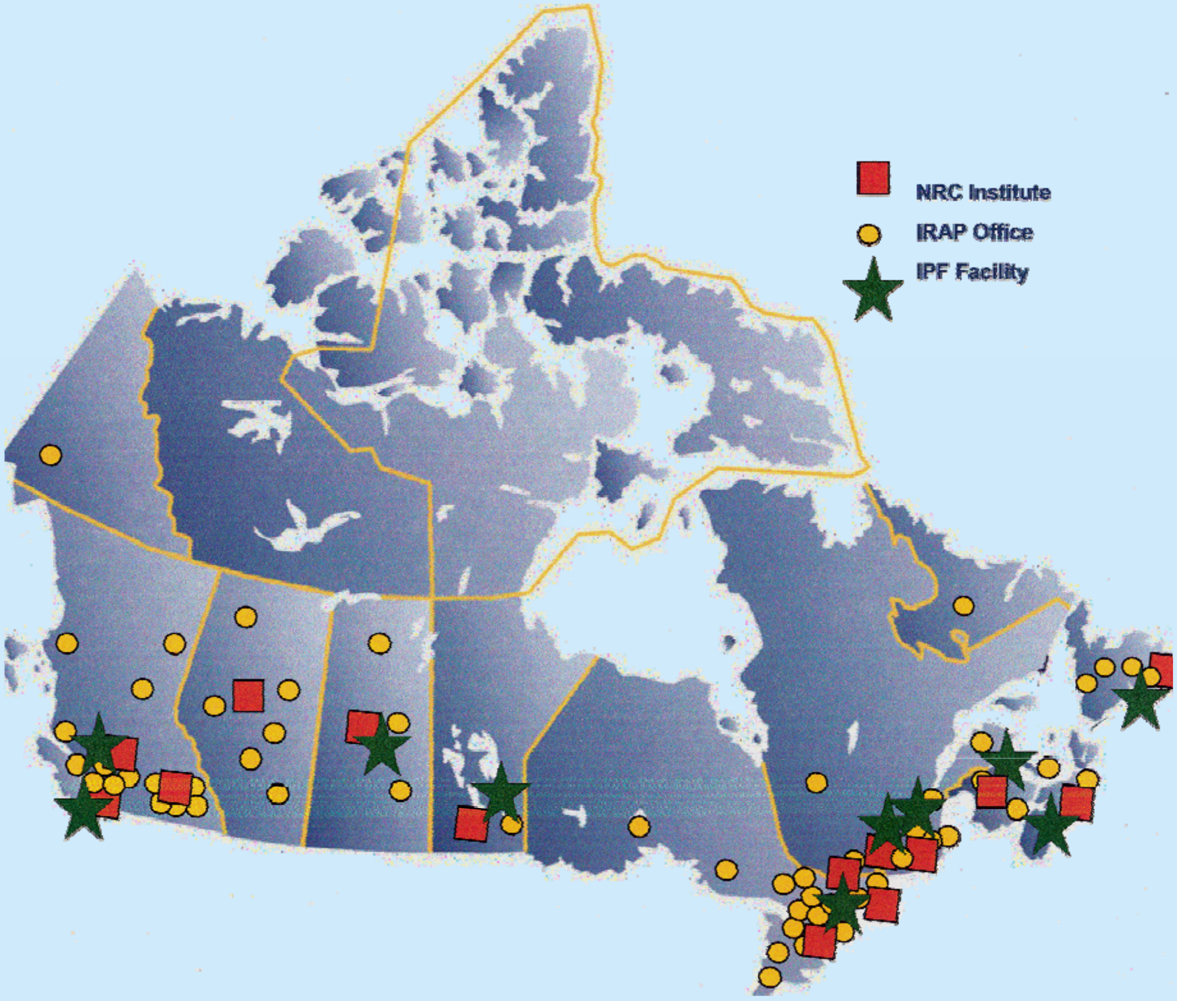
Sylvain Charbonneau
Director, Applications Technologies

Arizona's Second Annual Nanotechnology Symposium, March 23rd, 2007

National Research Council Canada | Conseil national de recherches Canada

Canada

NRC: A National Institution



- National organization, federal government agency
- Provides essential elements of national S&T infrastructure
- 4,116 employees
- 1,446 visiting / guest workers
- Labs and facilities across the country
- Total expenditures 2005-06: $767M
- Income 2005-06: $103M

Major Research Thrusts

- Information and communications
- Biotechnology
- Nanotechnology
- Manufacturing
- Aerospace, construction and ocean technologies
- Metrology
- Astronomy

IMS Mission

- *To play a pivotal role in the creation and development of photonic, optical and quantum devices*
- *Ensure diffusion into the Innovation System*
- *Communications, Health, Environment, Energy and Security*

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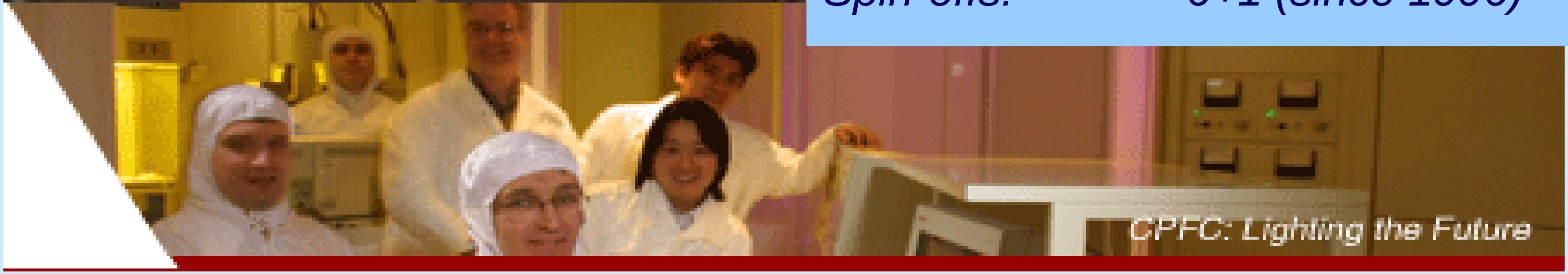
IMS at a glance

Locations: Ottawa
M50, M23-A, M36

Budget - IMS: $14M (+$5M)
- CPFC: ($43M/5yrs)

Staff: ***160 (~95PhD)***
Guest workers: ~40
Publications: ~180/year

Technologies: ~100
Spin-offs: 6+1 (since 1996)



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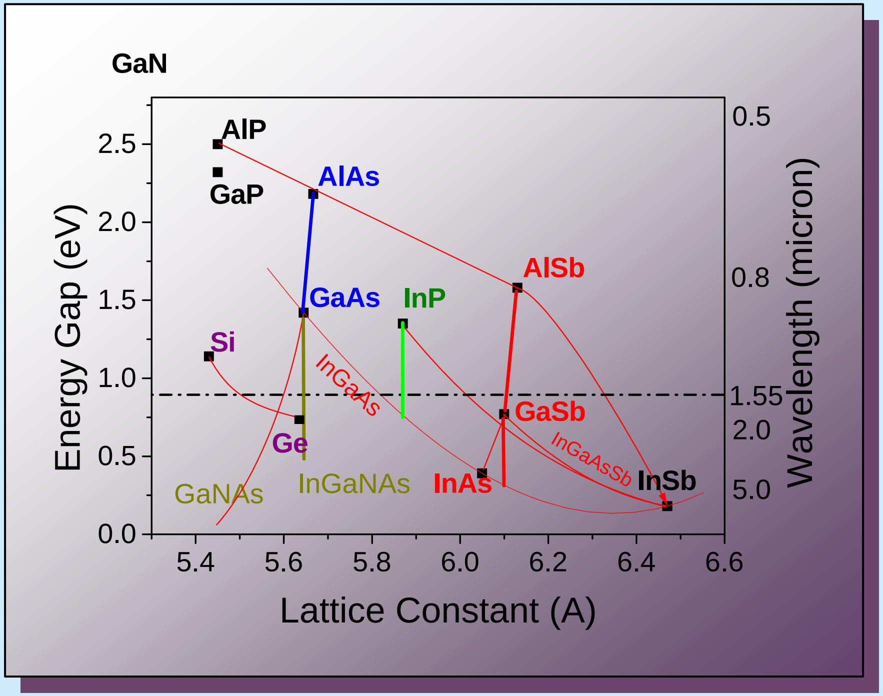
Core Competencies

- Semiconductors: inorganic & organic
- Nanofabrication

- Photonic & Quantum Devices
- PIC & Component Prototyping
- Optical Interference Coatings
- Optics Shop
- Acoustics



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IMS activities 2007

	THz & Imaging	Optoelect Devices	Organic Devices	Quantum Physics	Quantum Theory	Epitaxy & MultiLayer	Surfaces / Interfaces	NanoFab	Optics	Photonic Systems	CPFC	Acoustics	Example partnersr
COMMUNICATIONS													
QI: Nanoelectronics				◆	◆	◆	◆	◆			◆		DARPA
QI: Nano-Photonics				◆	◆	◆	◆	◆			◆		CIAR
CNTs for EL-FETs				◆	◆		◆	◆					Japan S&T
GaN HFETs		◆				◆	◆	◆			◆		CSA
High Contrast OLEDs			◆		◆	◆							industry
Wavelength Mtg				◆		◆				◆	◆		DND
HEALTH													
THz & Imaging	◆				◆	◆	◆	◆			◆		GHI
BioFETs					◆		◆	◆					GHI
Micro-Photonics		◆				◆	◆	◆			◆		GHI
Optical Probes			◆				◆		◆				CIPI
Hearing Aids												◆	industry
ENVIRON & ENERGY													
Mid-iR Lasers	◆	◆		◆	◆	◆	◆	◆			◆		industry
PhotoVoltaics			◆		◆	◆	◆			◆			ICPET
TECH PLATFORMS													
Acoustics												◆	industry
Device Prototyping											◆		industry
Optical Thin Films						◆							industry

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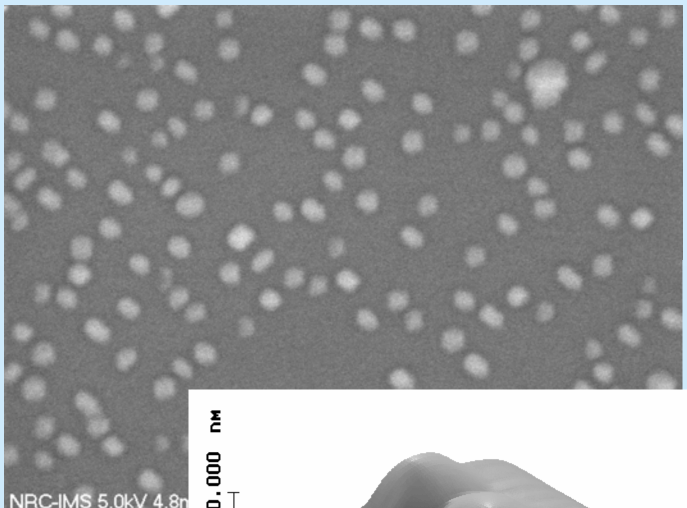
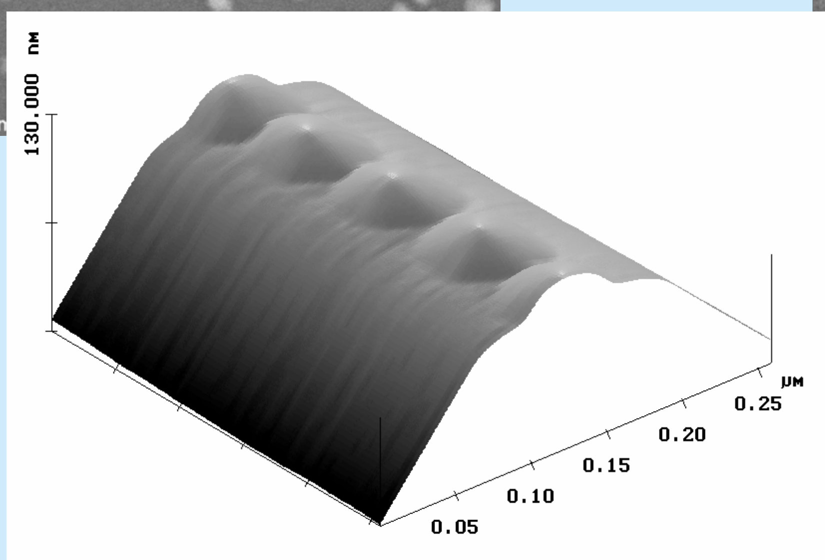
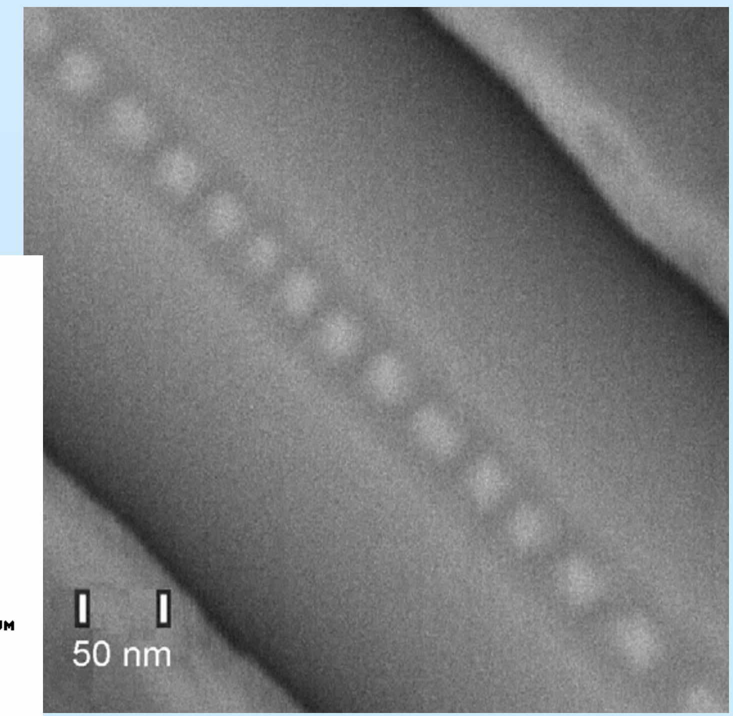
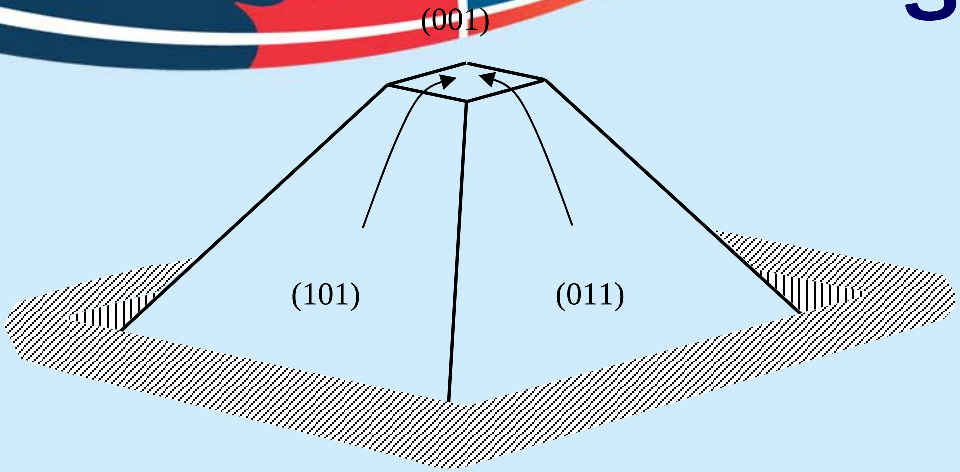
Self-Assembled Quantum Dots (SAQD)

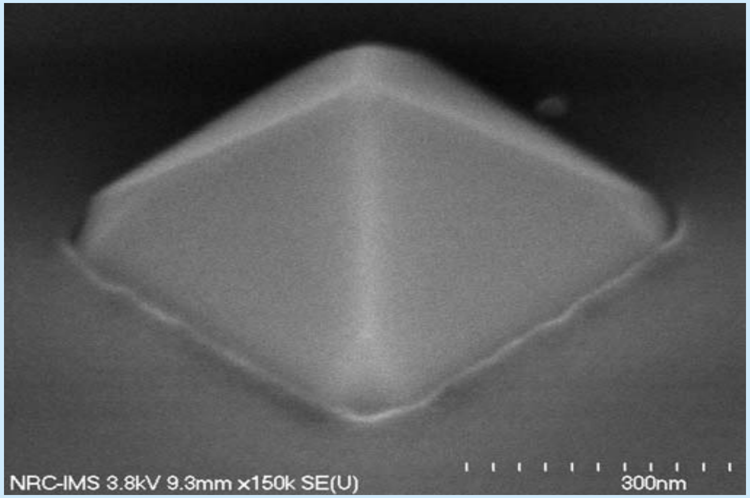


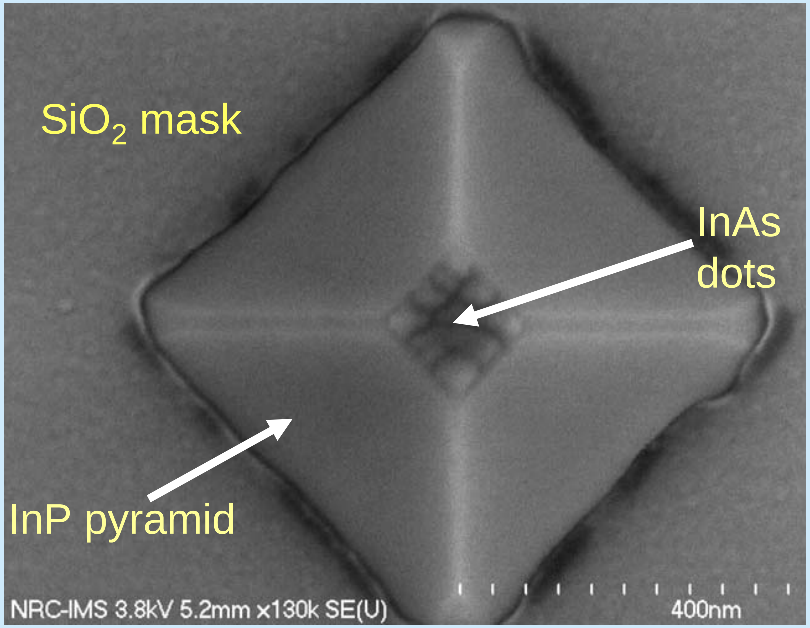




SAQD - Basis for Single Photon Emitter



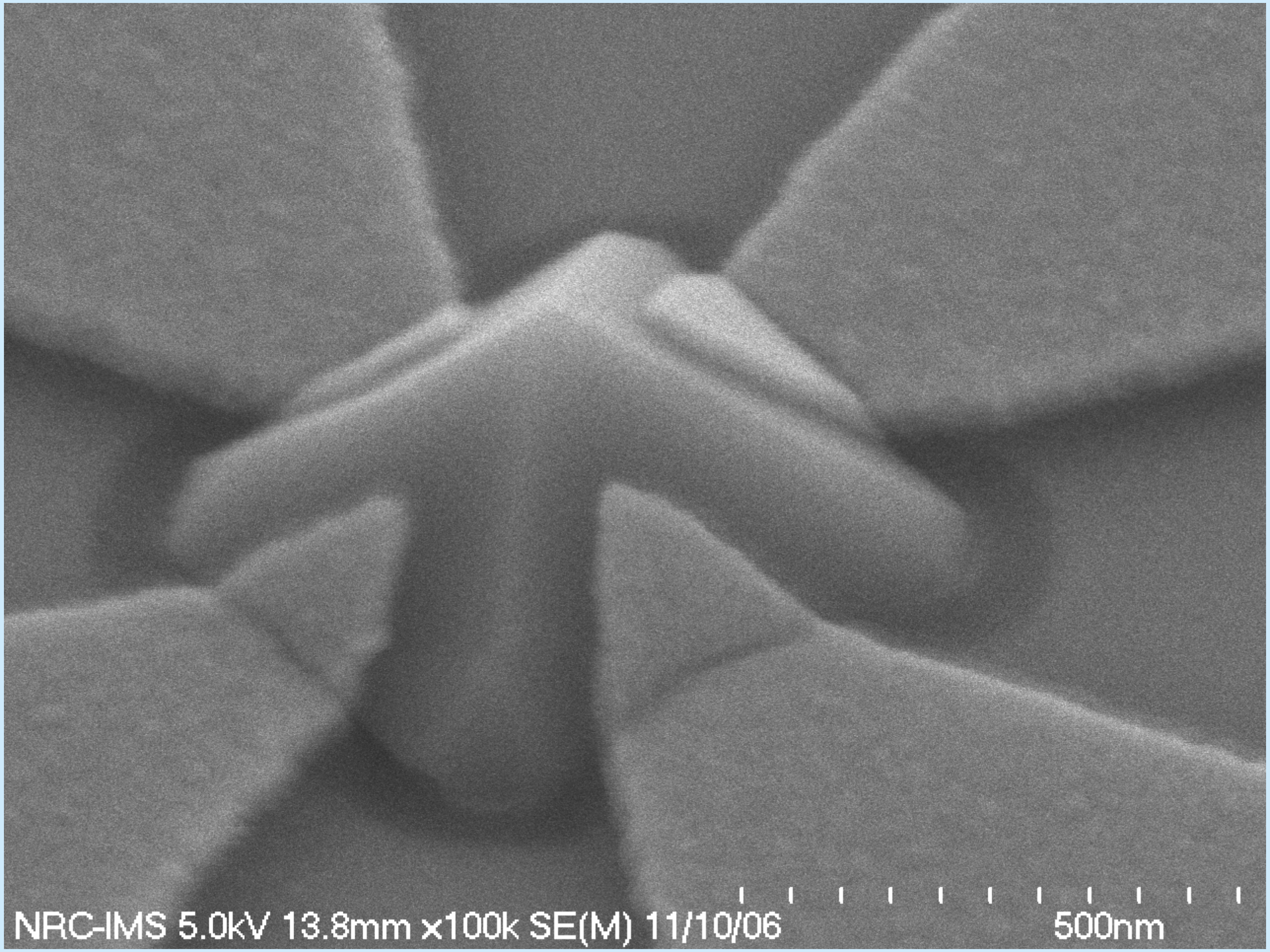




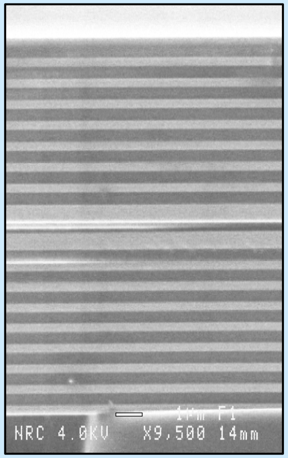
Advantages:

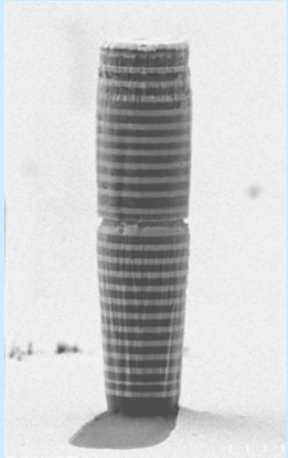
Fully in-situ development of structures for single dot spectroscopy.

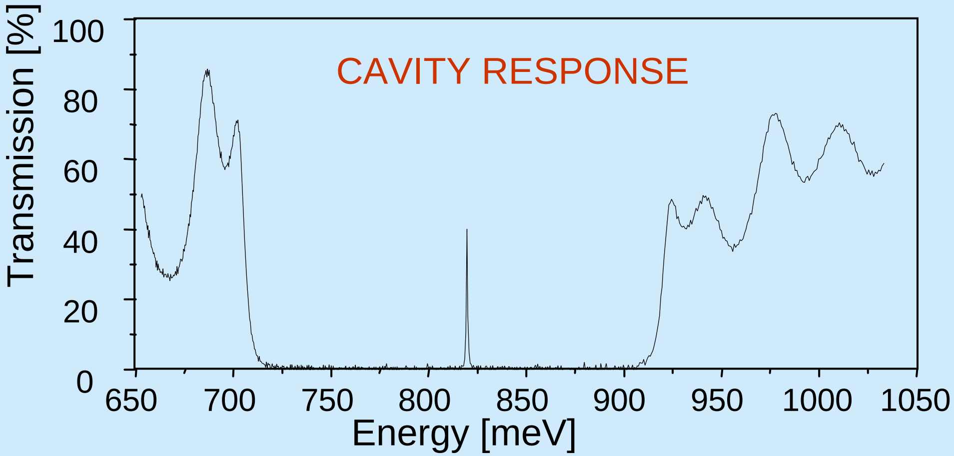
Electrical connection of Single QDs

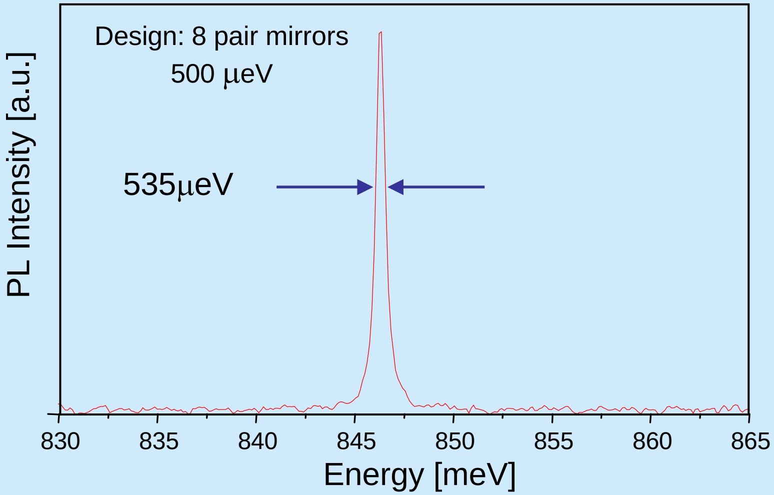


Single Photon Gun









Nano Electronics - controlling electrons on the nanoscale

Challenge:

How to control one out of many?

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1995 NATO Workshop

Increased miniaturisation:

"The writing is on the wall"

(but it is getting smaller!)

Why smaller features?

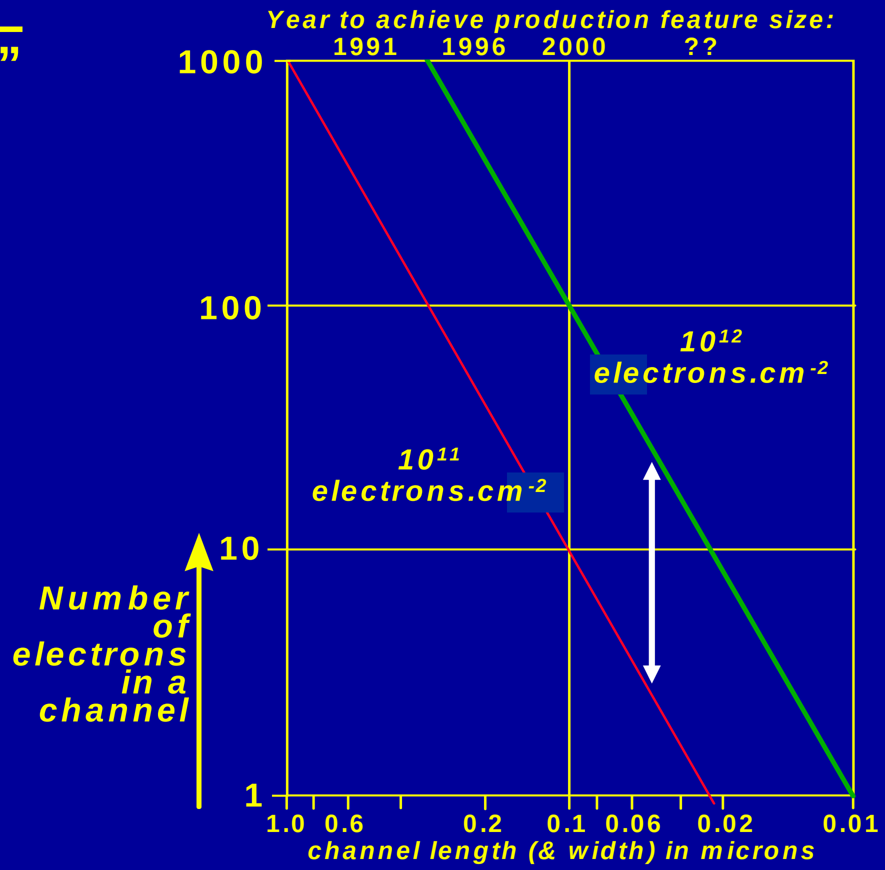
- lower cost
- faster performance
- lower power
- higher integration

Lithographic limits:

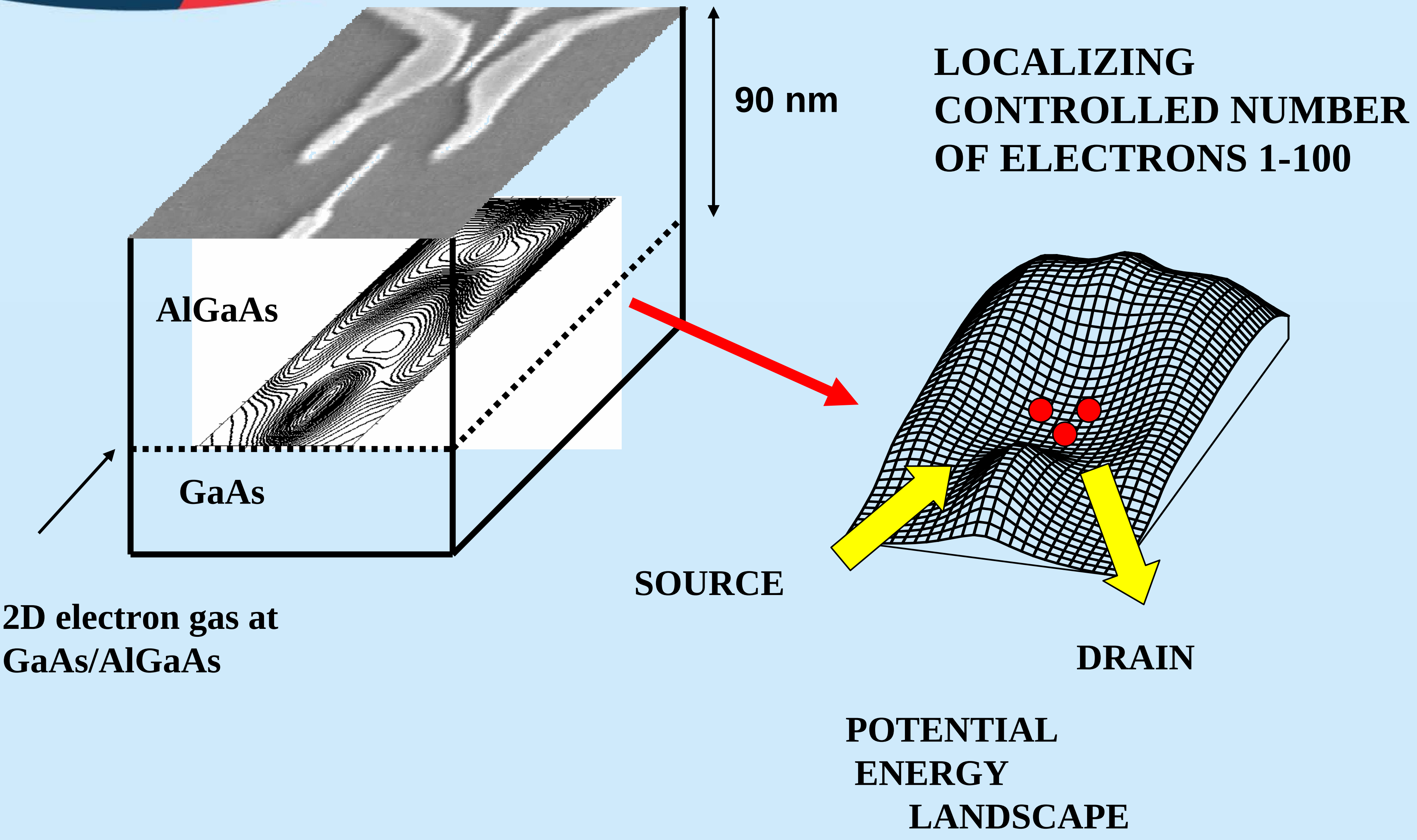
- driven by eg RAMs
- devices and interconnect

Physical limits:

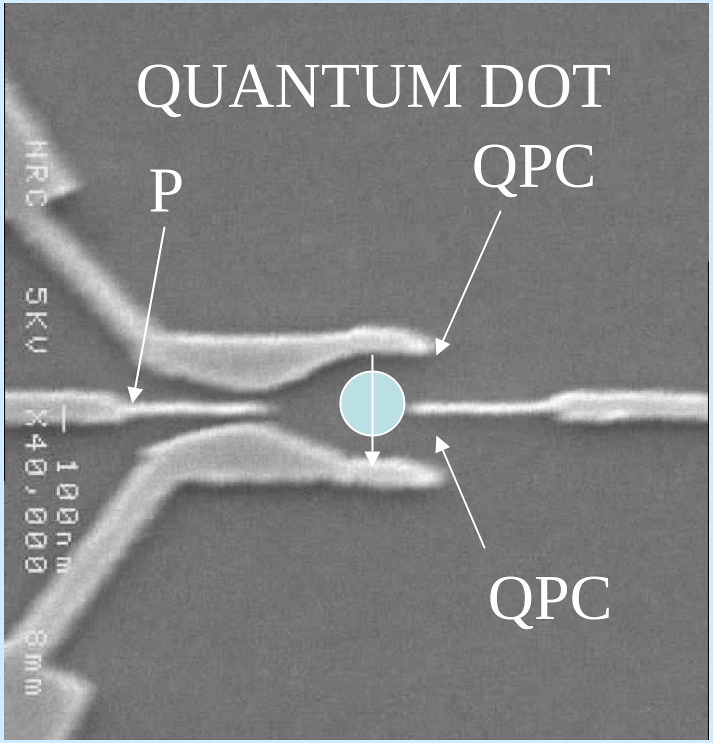
- 'handful of electrons'
- upset resilience
- interconnect delay

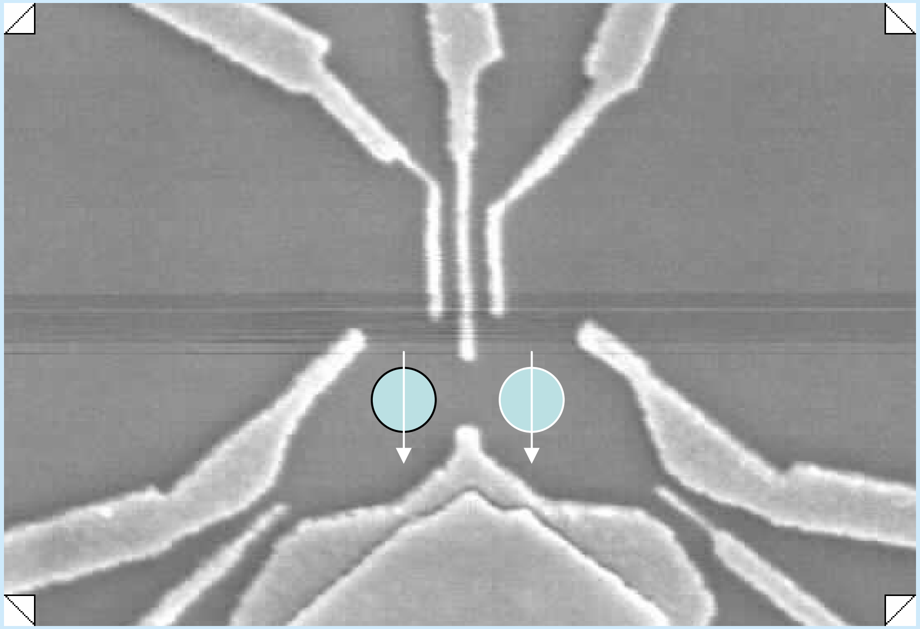


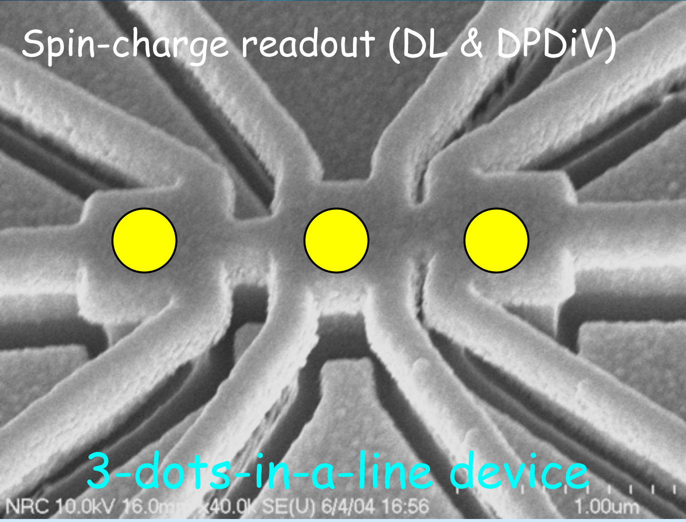
Single Electron Transistor: Surface Gates

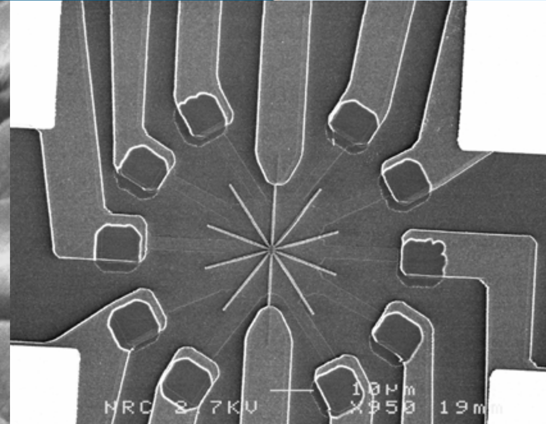


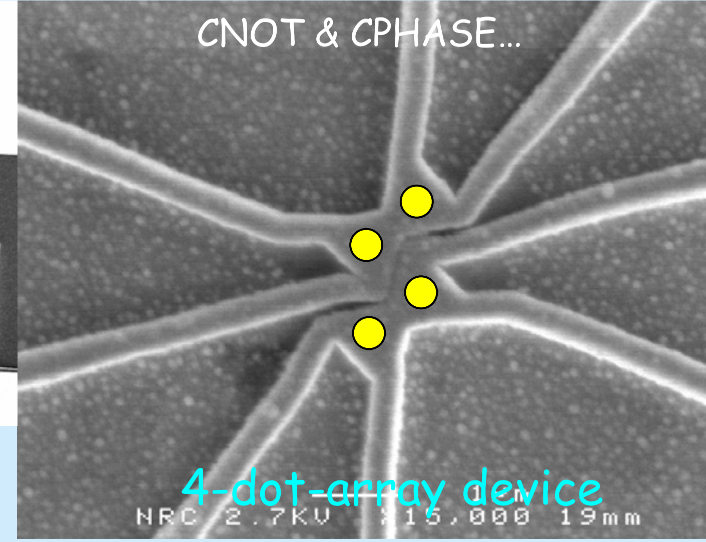
Artificial Atoms and Molecules

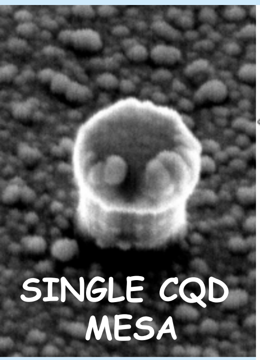


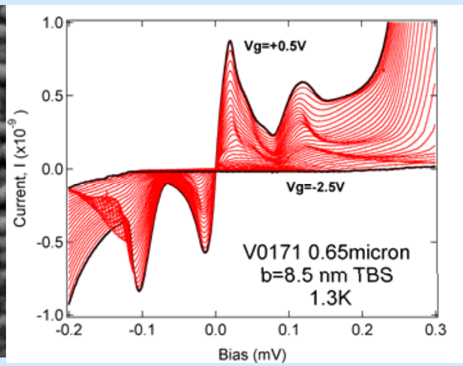






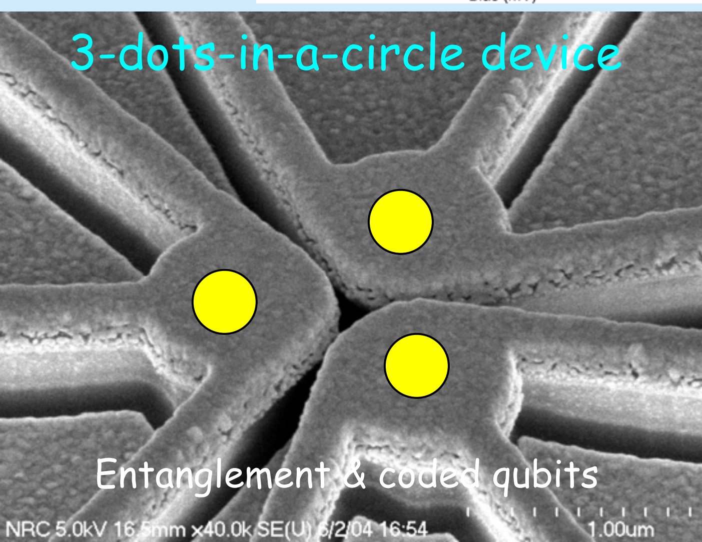


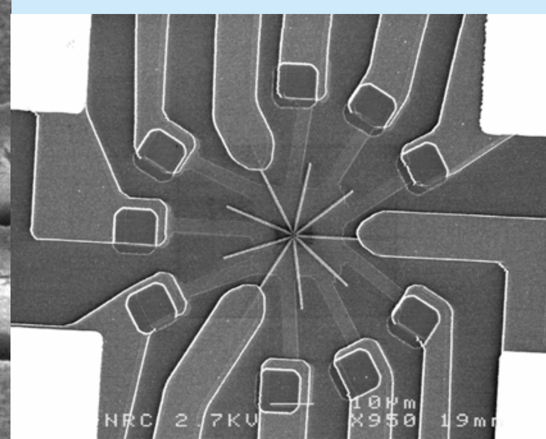


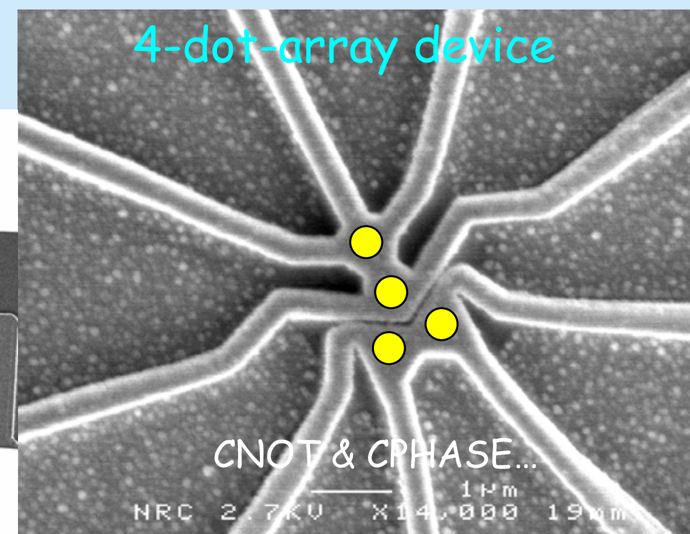


DARPA QuIST project (2001-06):

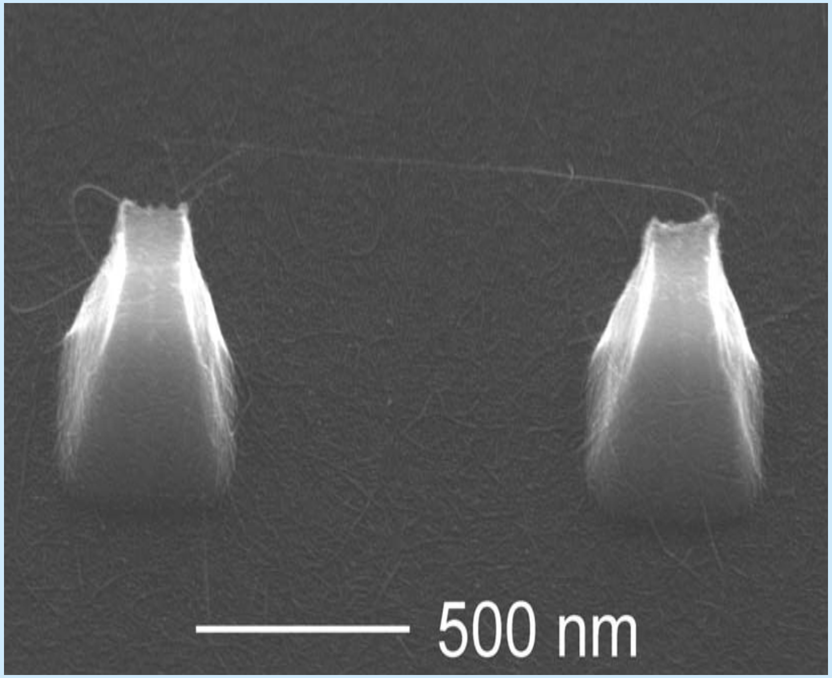
"NRC-IMS: 3- & 4-laterally coupled vertical semiconductor quantum dots for spin-qubit circuits"

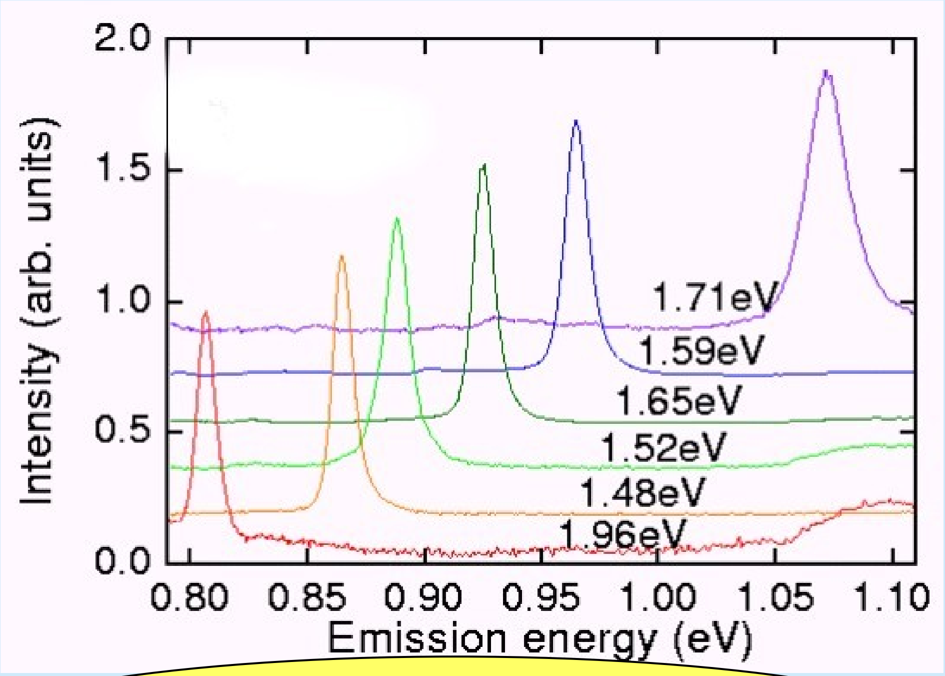






Single Wall – Carbon Nanotubes

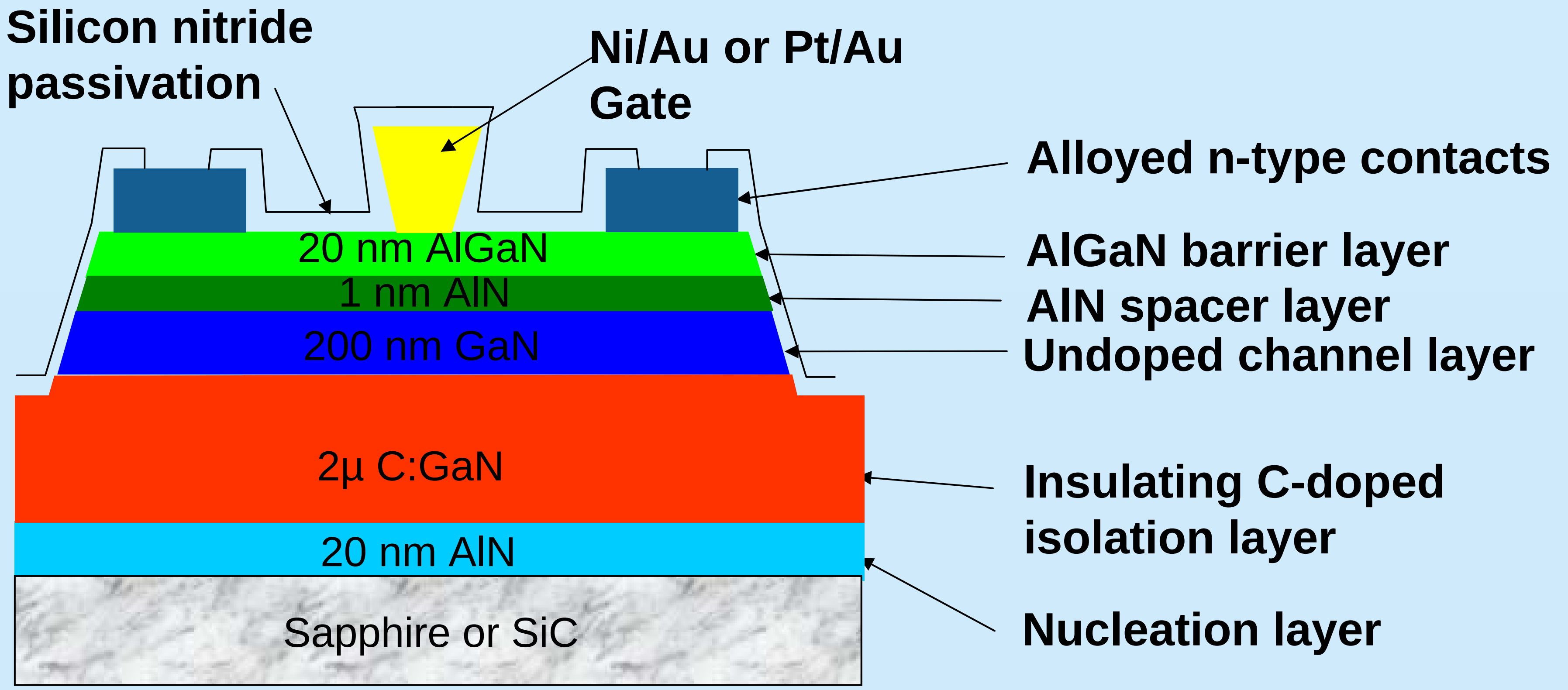




Single SWNT PL
-strong, polarized, sub-$k_B T$ width
-diameter dependent peak position

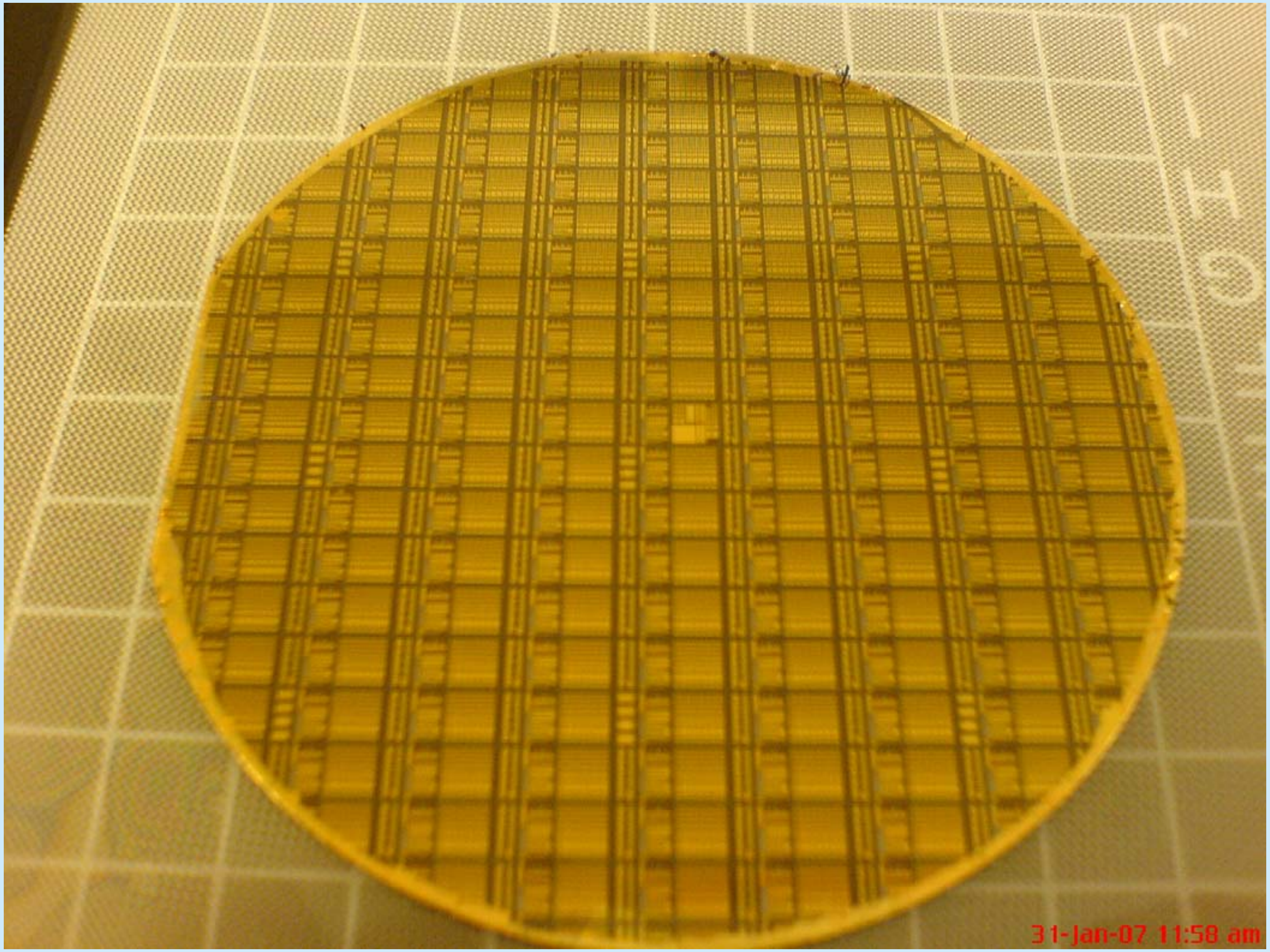
see J. Lefebvre *et al.* PRB **69** 075403 (2004) & PRL **90** 217401 (2003)

Primary Focus: GaN power transistors (HFETS)

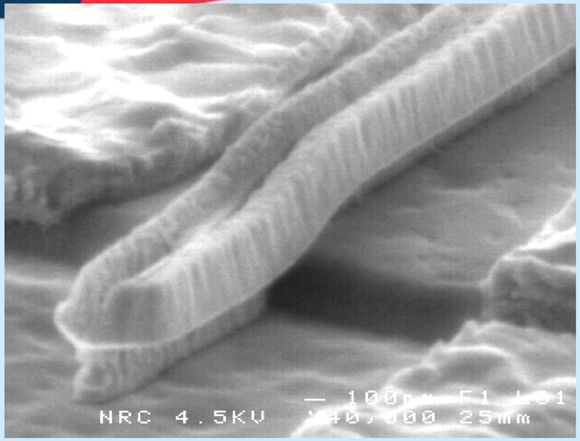


Robust and well-established fabrication sequence yielding 0.8µ optically defined gates

Fully processed 2 inch GaN on SiC wafer

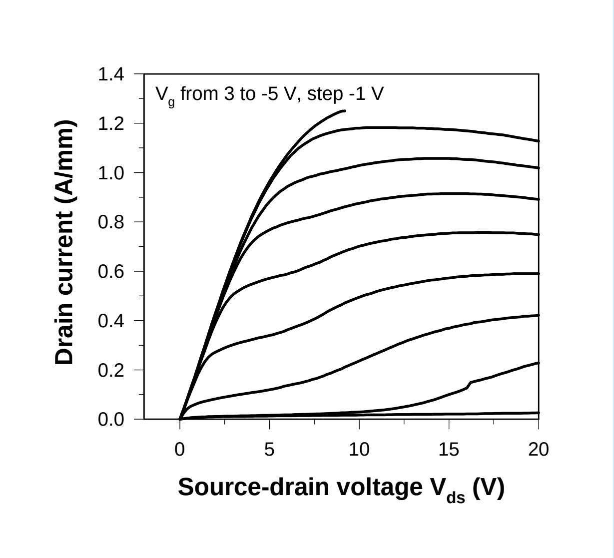


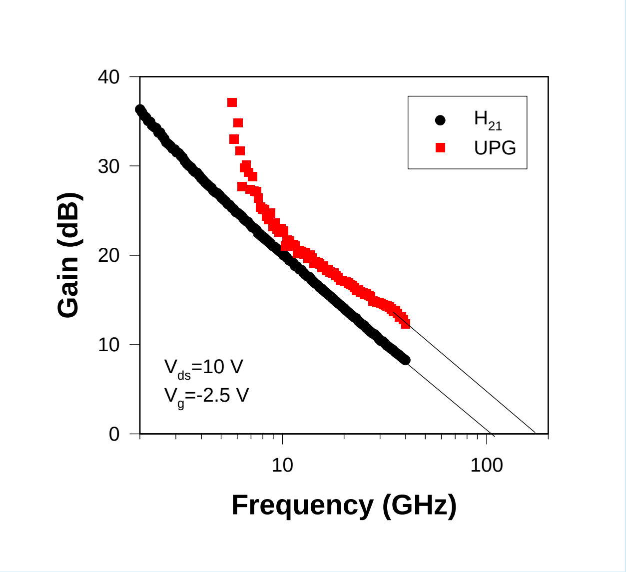
GaN power transistors (HFETS) - DC and RF results



E-beam written T-gates; 0.15 µm gate length on SiC

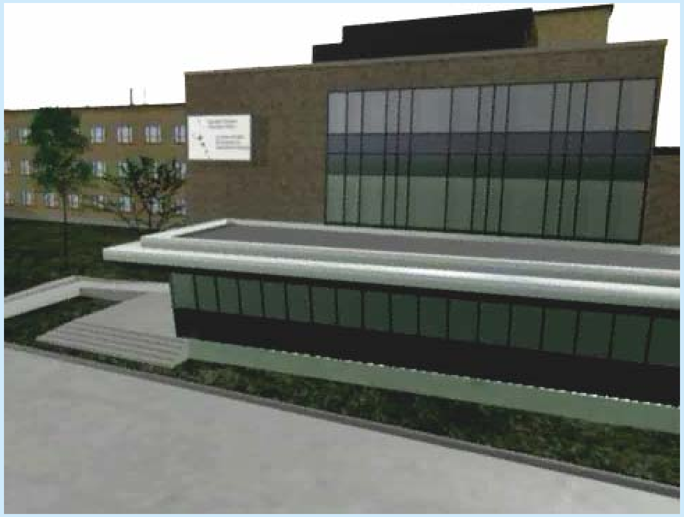
f_T=103 GHz, f_{MAX}=170 GHz





Ottawa Photonics Valley

Canadian Photonics Fabrication Centre (CPFC)

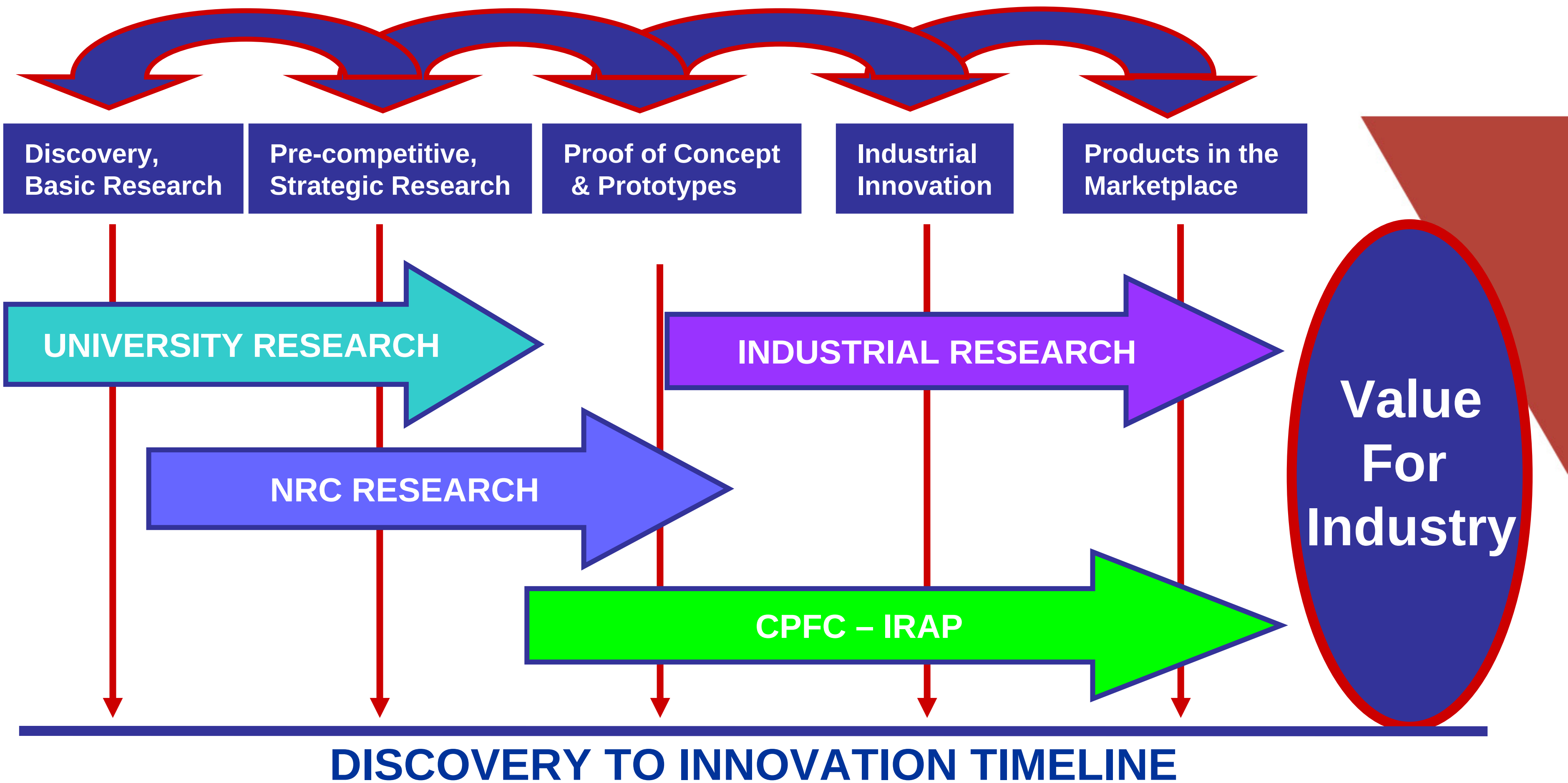


- Pure-play foundry service
- Prototyping & Small Production
- Unique facility in North America for industry and universities
- Component and device fabrication
- Linking photonics clusters to NRC's national facilities, networks, competencies and incubation services

CPFC:
Lighting
the Future

CCFDP :
Pleins feux
sur l'avenir

NRC: Bridging the innovation gap



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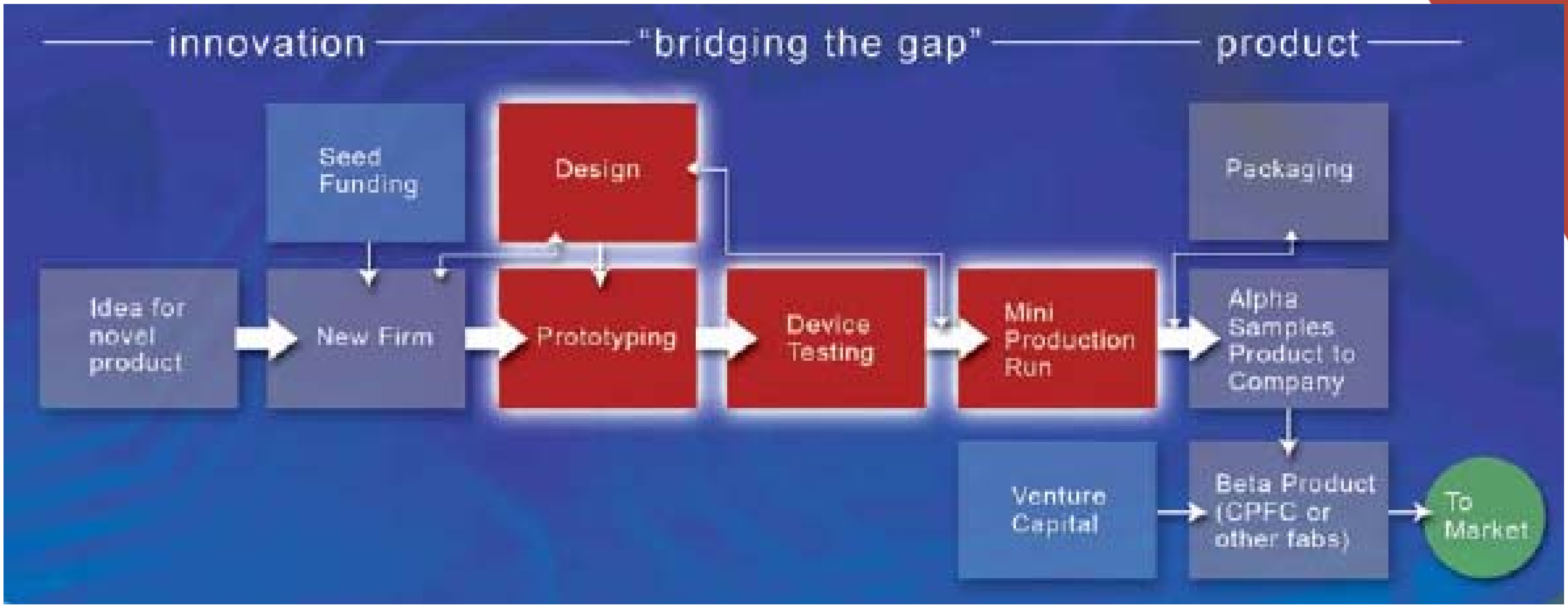
What is the Gap?



CPFC: Lighting the Future

CCFDP : Pleins feux sur l'avenir

CPFC Mission

Mission

- *To facilitate the commercialization and de-risking of photonic technology and investment by providing a world class industrial grade facility that bridges the gap from innovation to product.*

Core Technologies

III - V Core Technology

Competencies

- **Design**
- **Epiwafers**
- **Processed wafers**
- **Bars, Chips**
- **Chip test**

Applications

PASSIVES & ACTIVES

Telecom & Data

FP Lasers, DFB lasers, PIN's, Mux, Demux, TOS, OADM's, R-OADM's, Tuneable lasers, Modulators, Integrated TX + Rx, OCM's, Spot size convertors

Biophotonics

Spectroscopy, Sensors, Imaging, Lasers

Defense, Environmental, Security, Consumer

Silicon

Competencies

- **Design**
- **Dielectrics & SOI**
- **Processed wafers**
- **Bars, Chips**
- **Chip test**

Applications

PASSIVES & ACTIVES

Telecom & Data

Mux, Demux, TOS, OADM, R-OADM, SOB's, Microfluidics, Splitters

Biophotonics

Spectroscopy, Sensors, Imaging

Defense, Environmental, Energy, Imaging, Security, Consumer

Strategy

- Establish technology platforms and re-usable process blocks in two materials sets
- Fill up the "tool box" by demonstrating selected devices
- Look for applications/clients in a broad range of markets (not just telecom)

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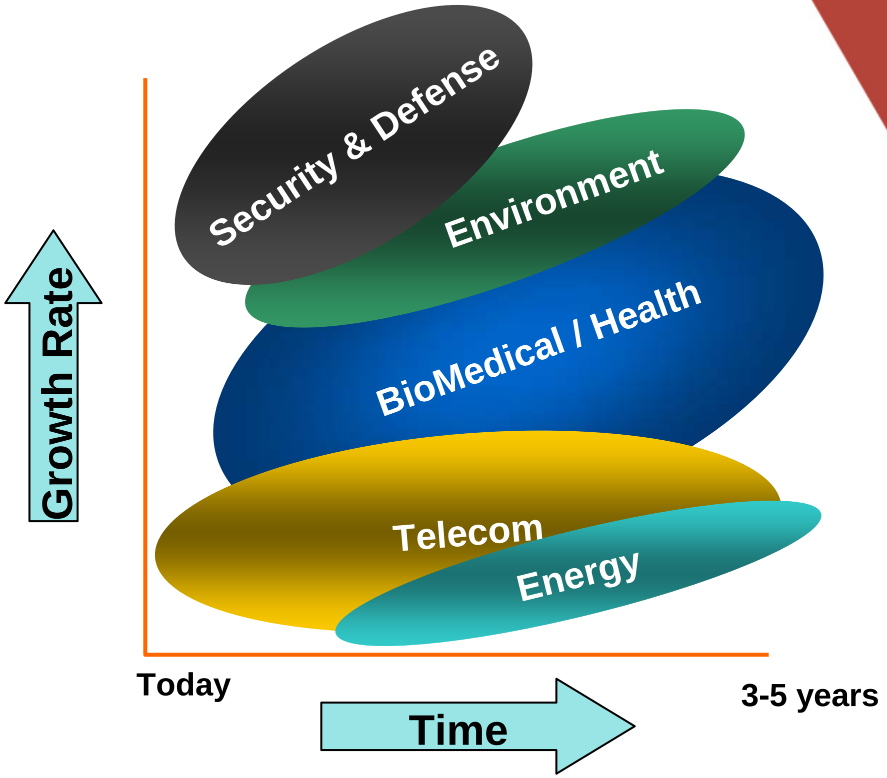
Marketing Roadmap

The CPFC has been engaging with a variety of customers representing a variety of markets. The distribution has been heavily weighted by telecom due to our location and the dependence telecom has for photonics. Other markets may represent higher growth potentials over the next few years.

1. Communications
2. Biomedical /Health
3. Defense and Security
4. Environmental
5. Energy and Space



CPFC:
Lighting
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CPFC Infrastructure

Size: 40,000 ft^2 lab and office space
Clean room : bay & chase configuration: total area 12,000 ft^2
Personnel: 18 fab engineers & staff at present

Epitaxy: *MOCVD Multi-wafer reactor (2", 3", 4", 6")*
InP & GaAs-based

Deposition: *PECVD, LPCVD, and Thermal grown oxides*
Thick SiO_2 (silica-on-silicon) & Thin SiO_2 + SiN

Lithography: *Stepper, mask aligners, e-beam & nano-imprinting*

Etchers: *Stand alone for deep oxide, Si & III-V*

Metallization: *e-beam & sputtering*

Leveraged on top of extensive existing IMS infrastructure:
Device physics, Design & Modeling, Test & Characterization, Surface and Interfaces, Nanofabrication

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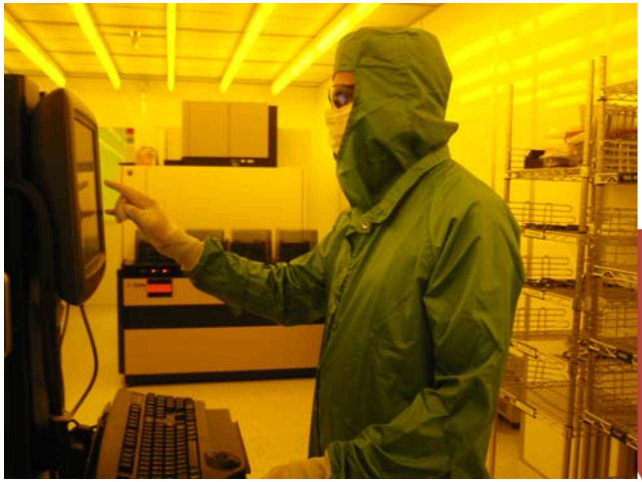
Lithography

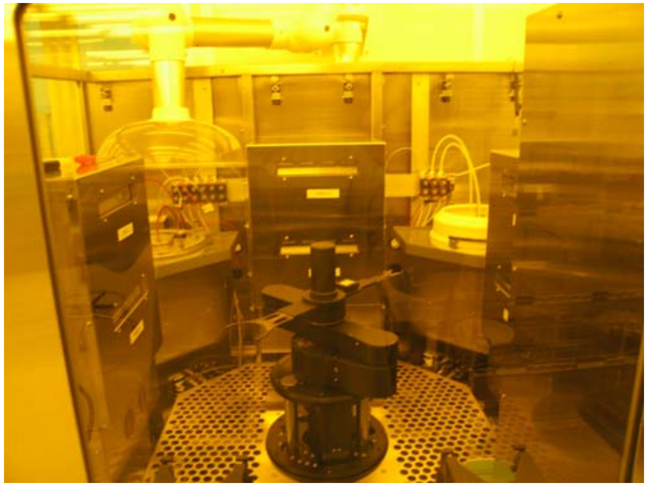
Complete suite of resist tracks and exposure tools including:

- Contact aligners (with backside alignment capability)
- i-line stepper (with ~0.35µm resolution)
- Holographic exposure tool (for uniform gratings to ~ 100nm resloution)
- E-beam lithography (resolution 25nm) – not SEM
- Nanoimprint lithography (resolution shown at 60nm)



All set up for full wafer fabrication to achieve:

- Uniformity
- Process control
- Reproducibility
- Automated alignment (stepper, nanoimprint, e-beam)



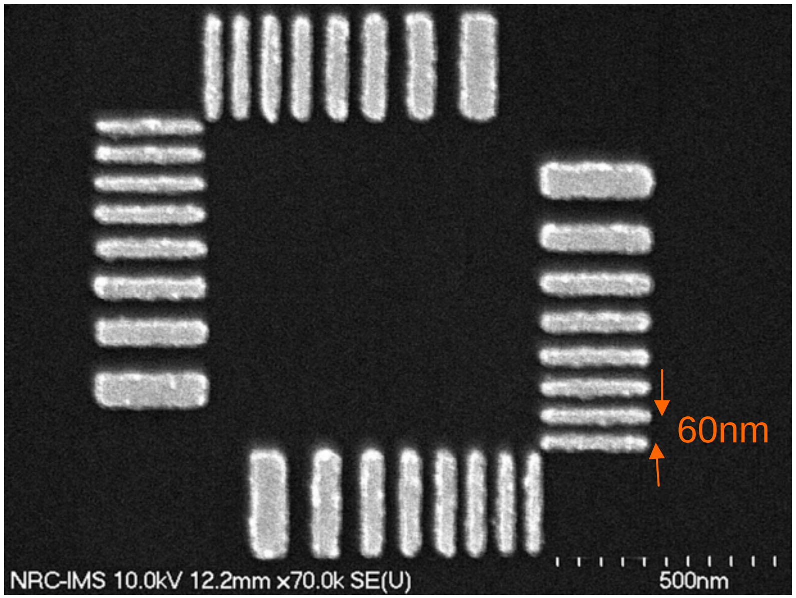
Emerging trend towards nanostructured devices

Electron beam lithography facility

JEOL JBX-6000 FS

- 5 nm diam. spot
- 20 nm lines
- 40 nm field stitching acc.
- 150 x 150 mm write area
- 200 mm wafers
- 6" masks

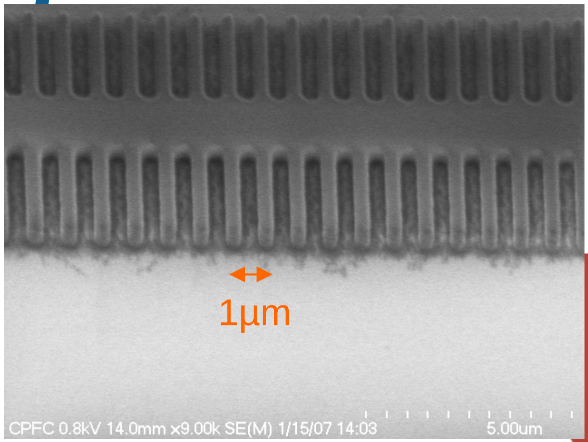
Lithography process examples



E-beam lithography

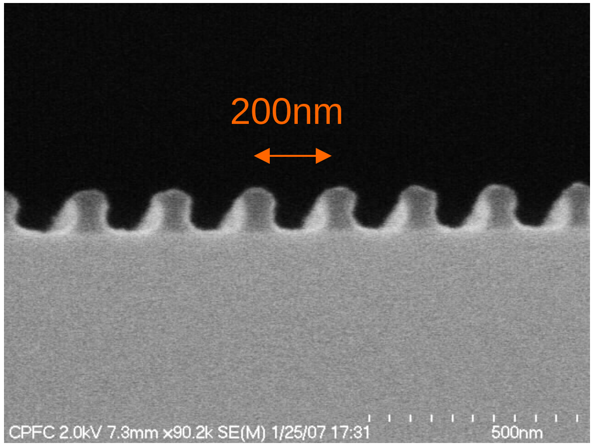
Low throughput

Stepper lithography



High throughput

Laser Holography



CPFC:
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the Future

CCFDP :
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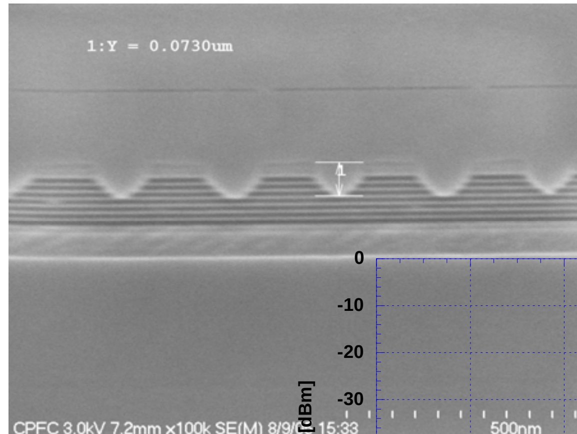
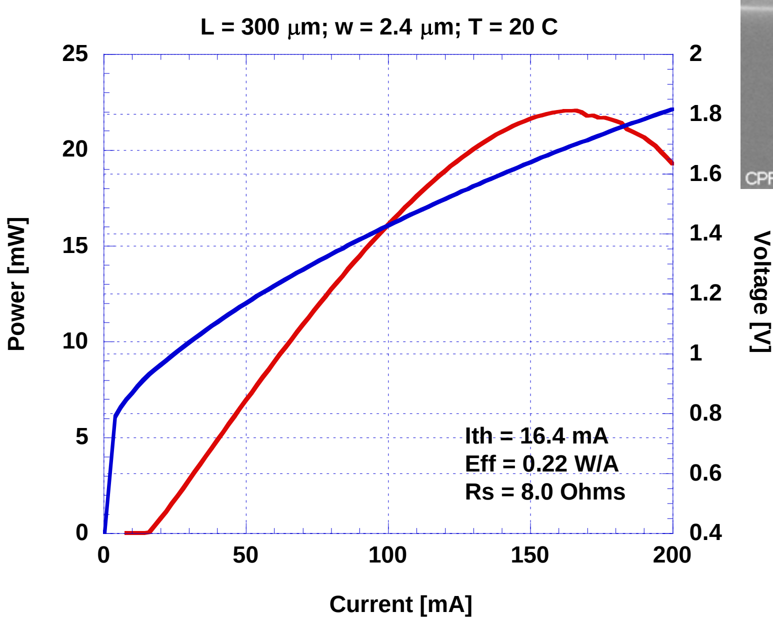
sur l'avenir

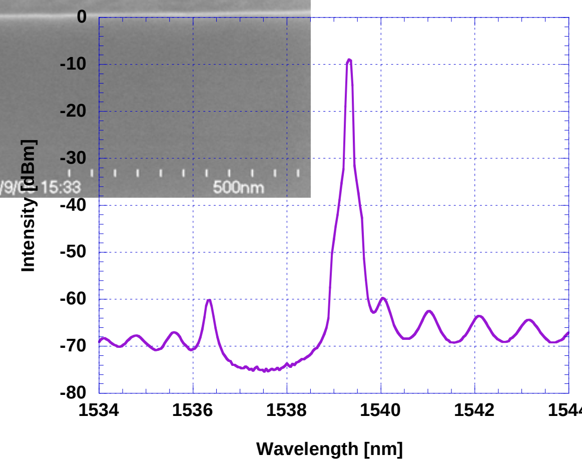
Fabrication of DFB lasers

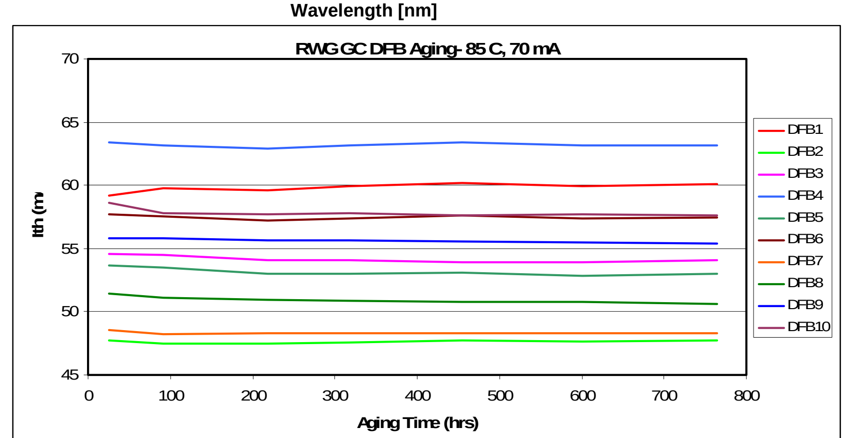
1st order holographic gratings



DFP Lasers







DFB laser (CL/AR bar),
W=2.4 μm, L=300 μm, T=20 °C, T_0=70 K
Spectra at 100 mA

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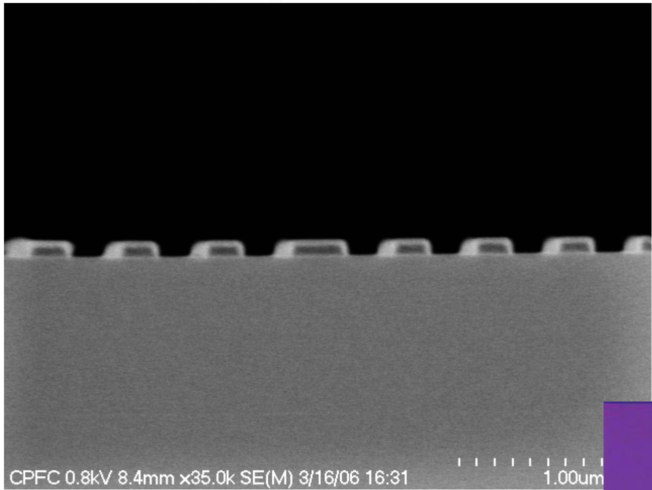
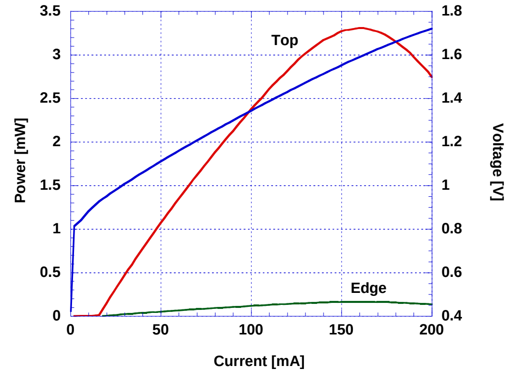
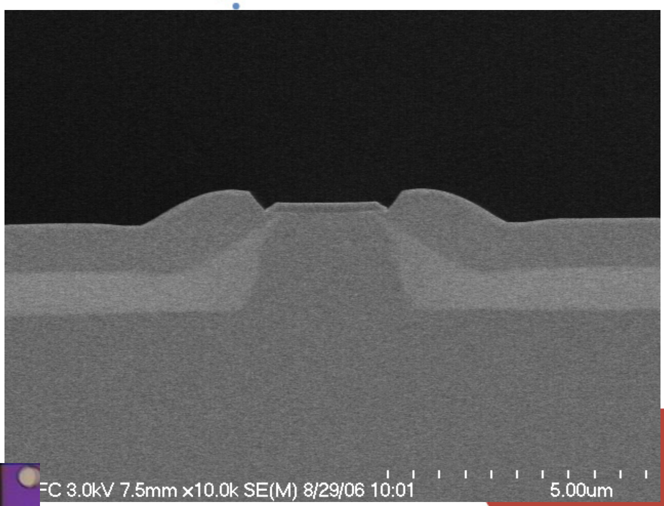
Surface Emitting BHET laser

CPFC: Lighting

CCFDP : Pleins feux

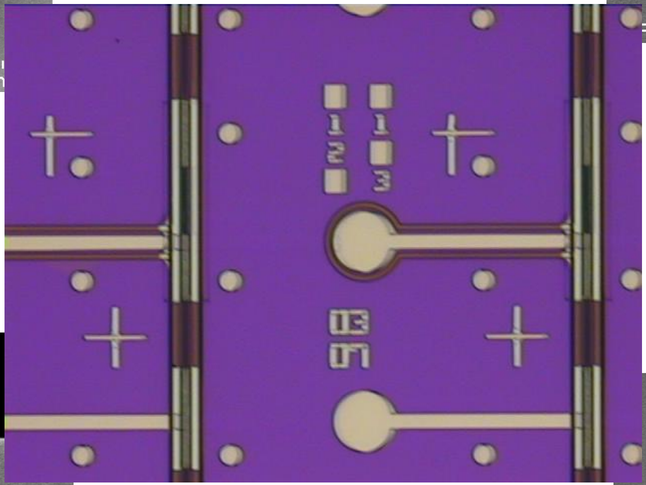




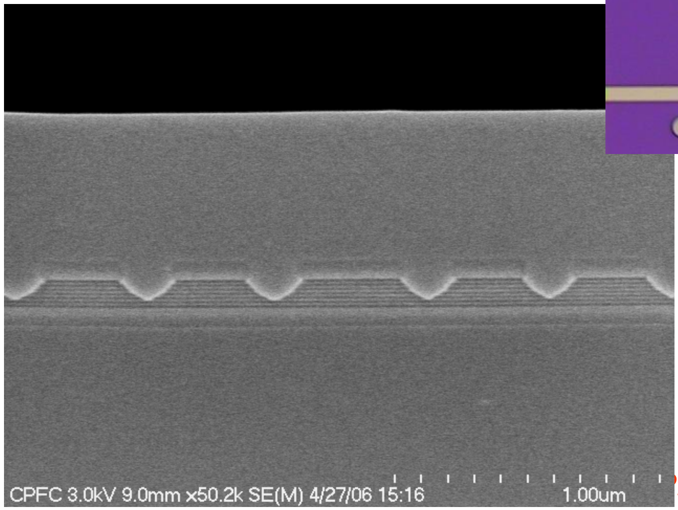


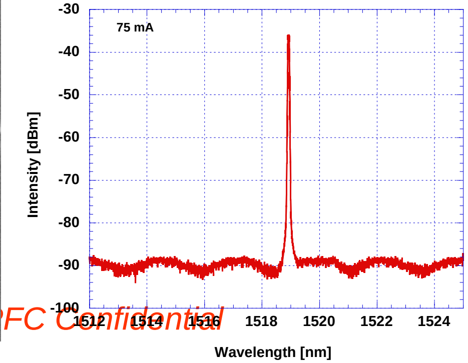
ICP etch, & MOCVD blocking layer selective regrowth

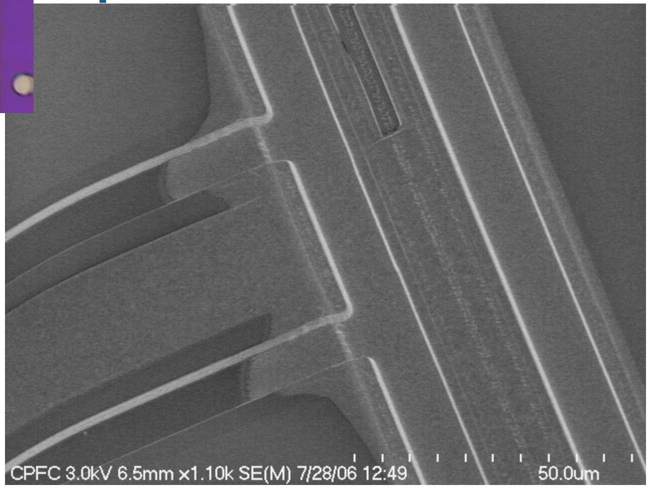
E-beam gratings, etch & MOCVD overgrowth



P-metal patterned around aperture







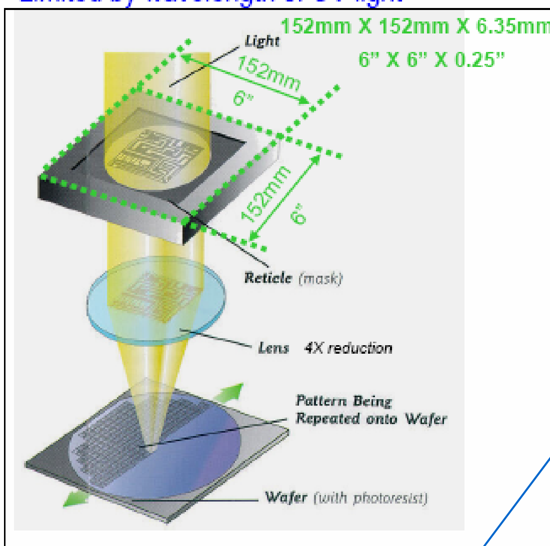
CPFC: Lighting the Future

CCFDP : Pleins feux sur l'avenir

CPFC's Gateway to Nanotechnology

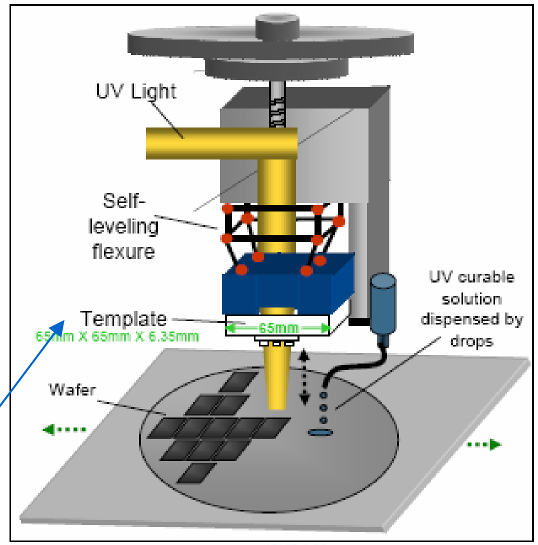
Standard Optical Lithography

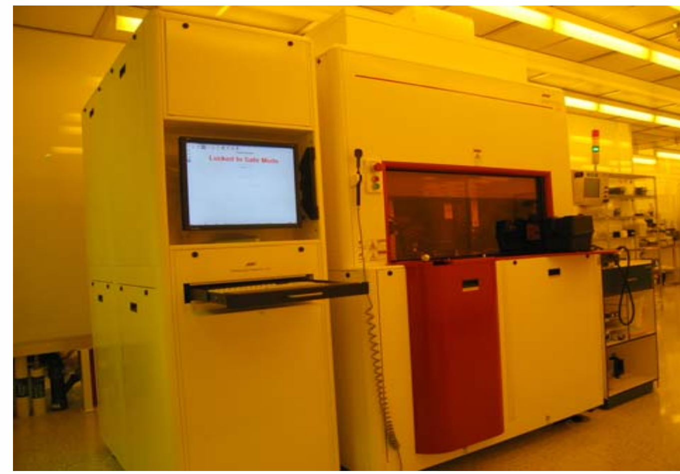
- Uses deep UV light to transfer circuit patterns
- Limited by wavelength of UV light

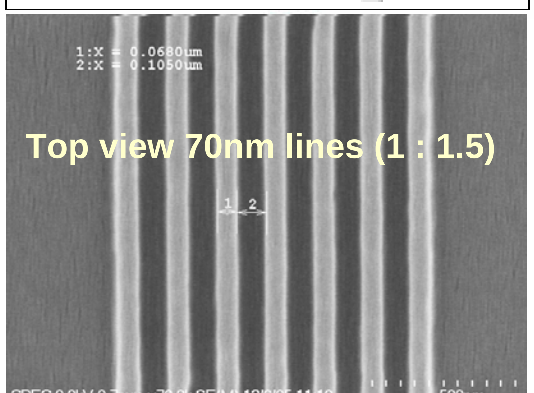


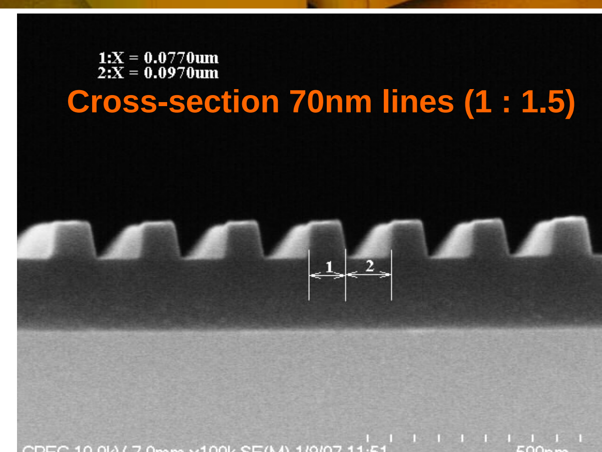
Imprint Lithography

- Uses molding to transfer circuit patterns
- Quality of template controls resolution









Template made by E-beam lithography and ICP etching

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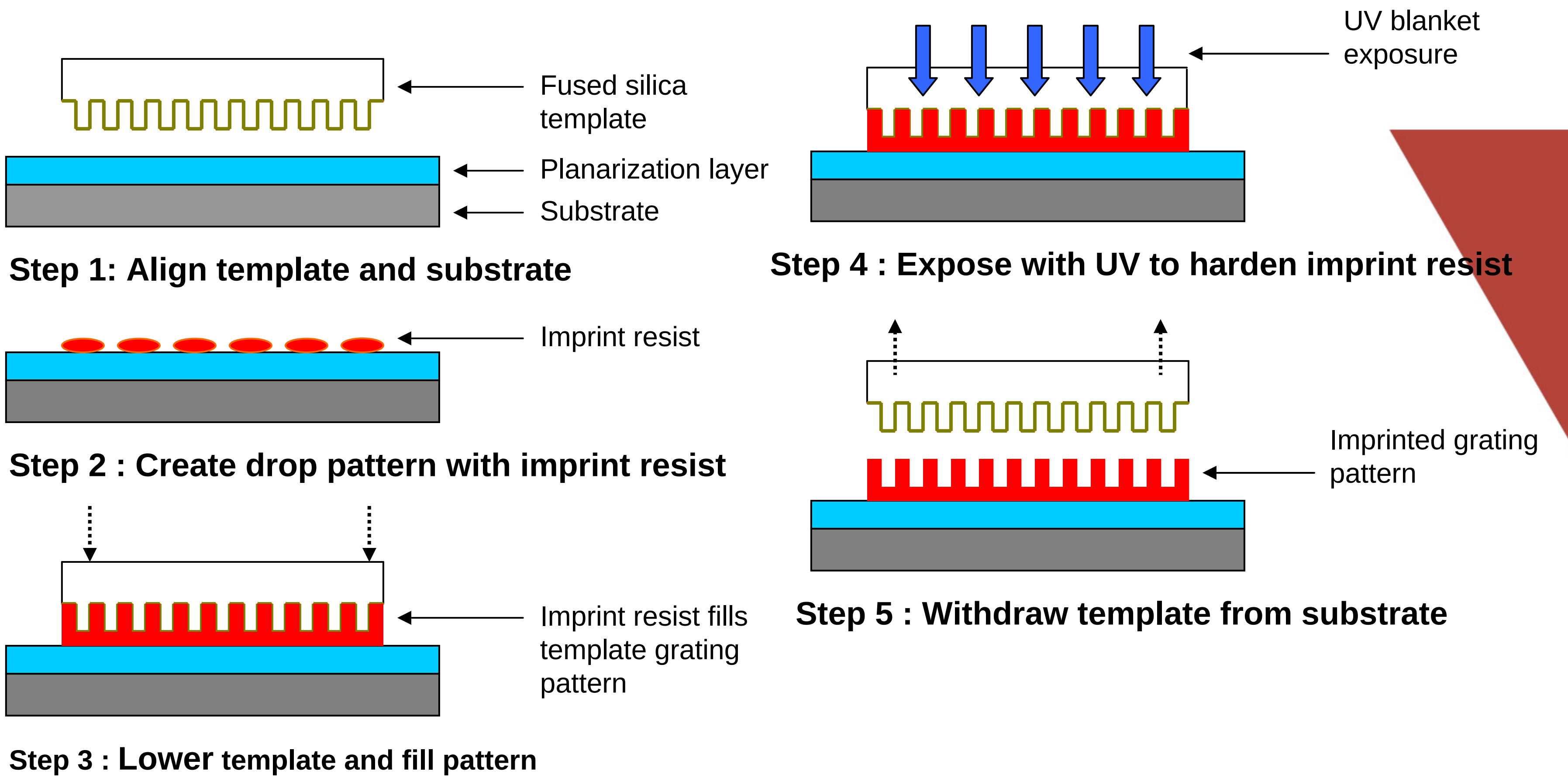
Gratings by nano-imprint lithography



Schematic showing step and flash imprint lithography (S-FIL)

NRC · CNRC

Advantages and disadvantages of grating fabrication by NIL

Advantages

- Takes advantage of the resolution offered by electron beam lithography to pattern the template.
- The resolution is only limited by the pattern resolution of the template.
- The template can be used many times either for multiple fields per wafer or for the whole wafer printed at once, therefore providing a higher throughput than e-beam direct write.

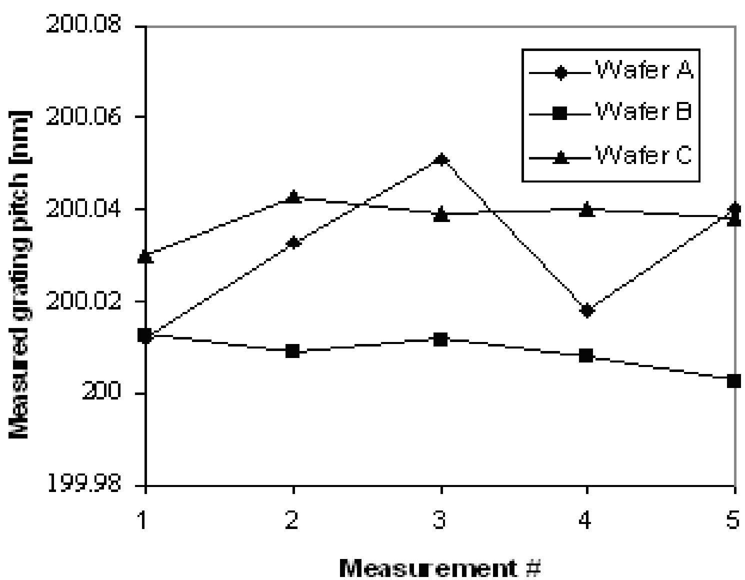
Disadvantages

- A template must first be fabricated to imprint the gratings.
- Imprinting is problematic on non-flat surfaces.

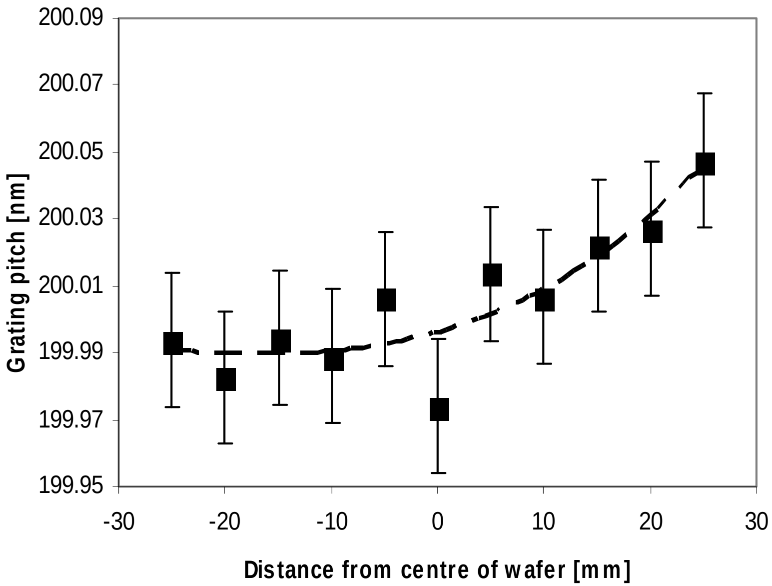
Grating metrology (pitch)

Grating pitch for holographic gratings was measured by finding the difference between the Littrow angle of the grating and the angle of normal reflection. A set of 5 trials were taken without removing the wafer from the stage, the standard deviation was found to be less than 0.02 nm.

The grating pitch uniformity for holographic gratings was assessed with measurements taken at 5 mm steps across a 3-inch wafer. There is a definite increase in grating pitch across the wafer, possibly caused by the wafer bending while held on the vacuum chuck.

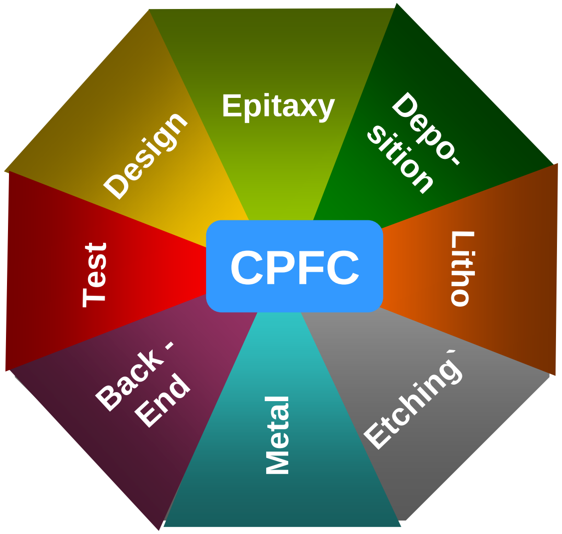


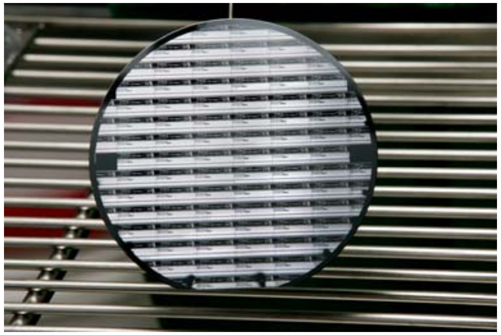
Holographic grating pitch repeat measurements taken from the centre of 3 separate 3-inch InP wafers.



Holographic grating pitch measurement as a function of position from the centre of a 3-inch wafer.

CPFC - Summary





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Complete Prototype Manufacturing:

- Design & Modeling
- Prototyping (controlled monitored processes)
- Fabrication (i.e. specialized deposition or etch)
- Specialty Masks & e-beam Lithography
- Development (process change)
- Epitaxial Services
- Materials and Device Testing and Analysis
- Consulting
- Technology Licensing & Training

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The CPFC will provide value by

- Reducing start-up costs
- Reducing time to market
- De-risking the technology
- De-risking the investment opportunity

Bridging the gap to commercialization!

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