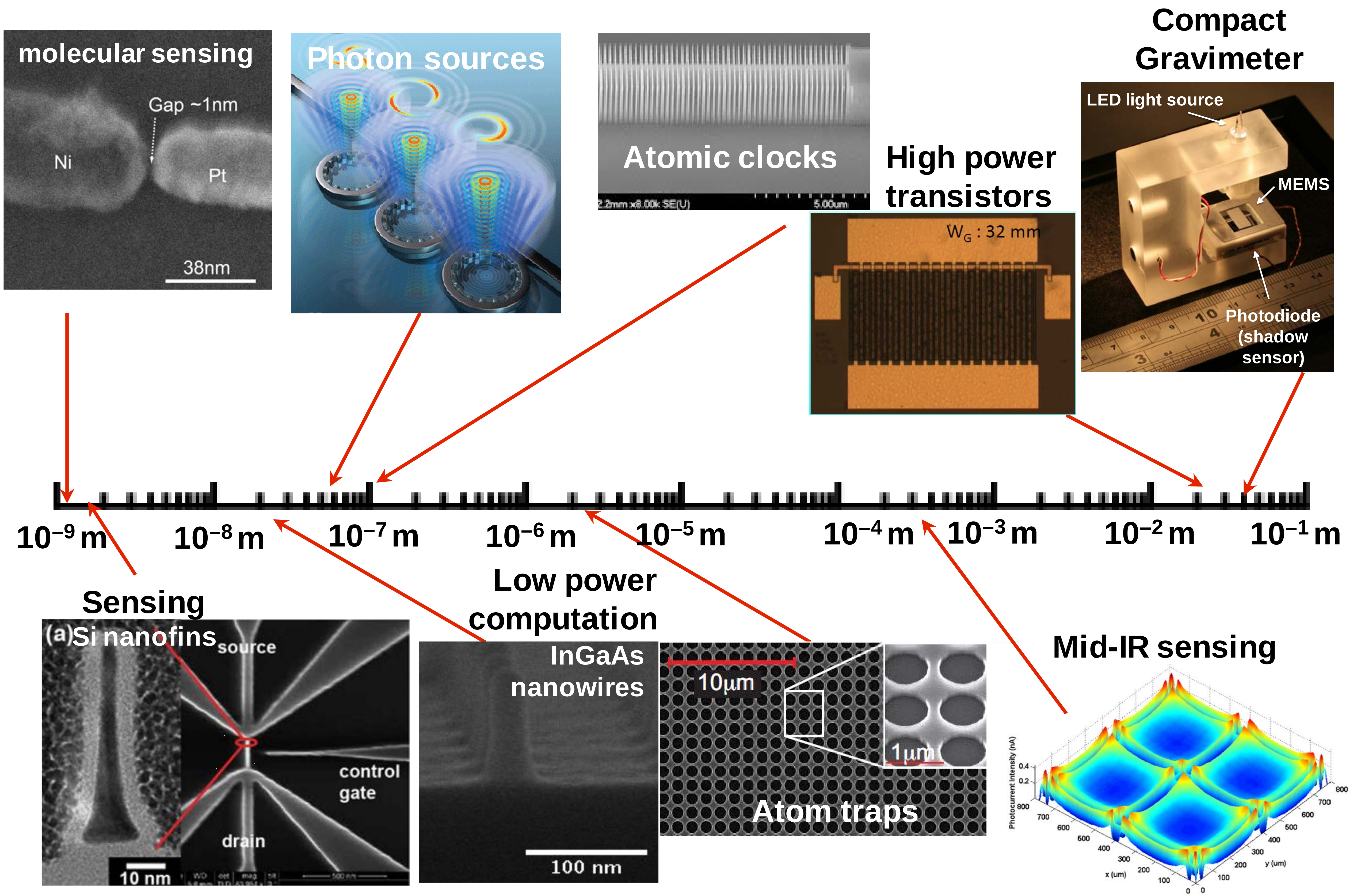
Micro and Nanotechnology from Glasgow



Some of the toolset..............

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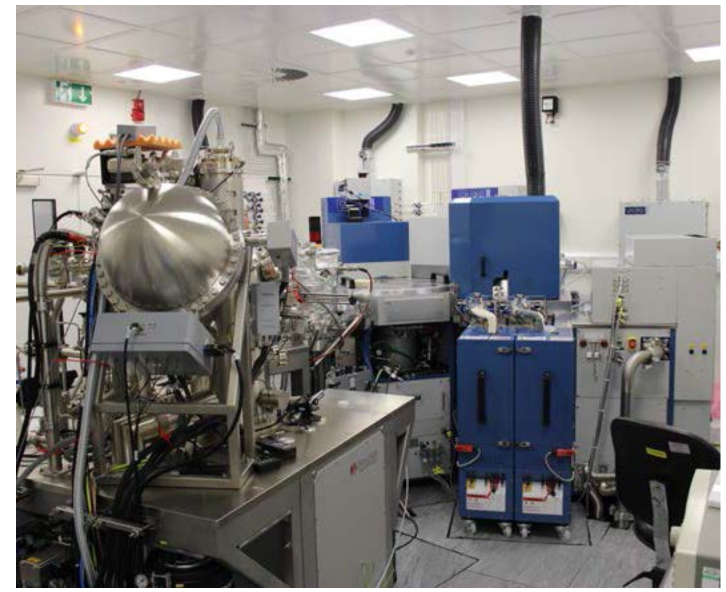
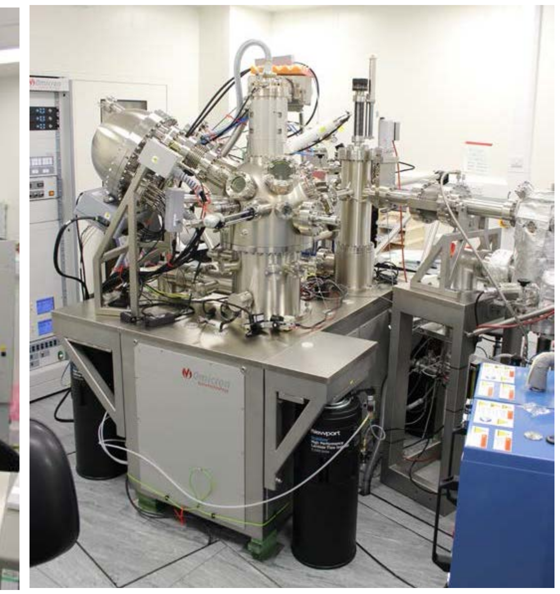
E-beam lithography

Raith VB6 & Nanobeam NB5

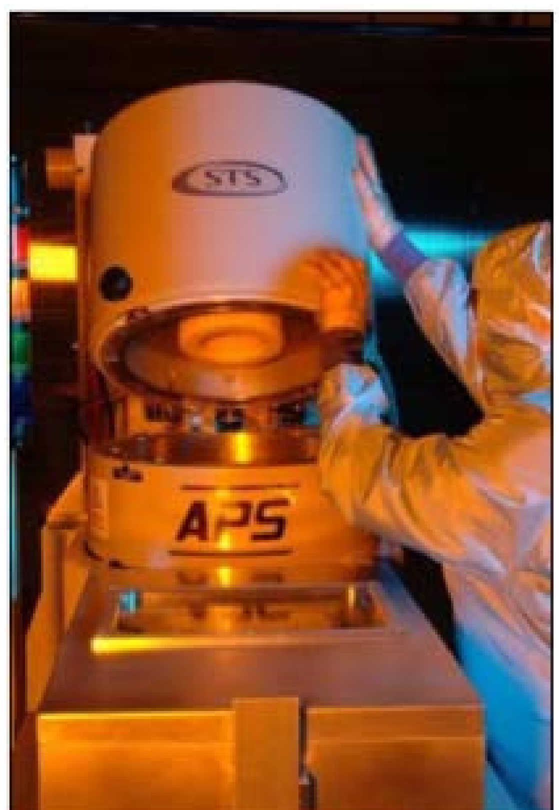
Clustered RIE/PECVD/ALD/Auger





EVG Nanoimprint

14 RIE / PECVD



6 Metal dep tools

5 SEMs

Furnace Tubes

Bruker Icon AFM

Materials we currently work with

Conductors

Can deposit and pattern conductors

Cu, Ni, Pt, Al, NiCr, Au, Ge, Ti, TaN, Pd, Mo, TiN, Nb, VO_5

Insulators/dielectrics

Can deposit and pattern insulators

SiO_2, SiN, Al_2O_3, HfO_2, AlN, diamond

Semiconductors

Can define patterns in a range of semiconductors

Si, Ge, GaAs, InP, GaSb, GaN

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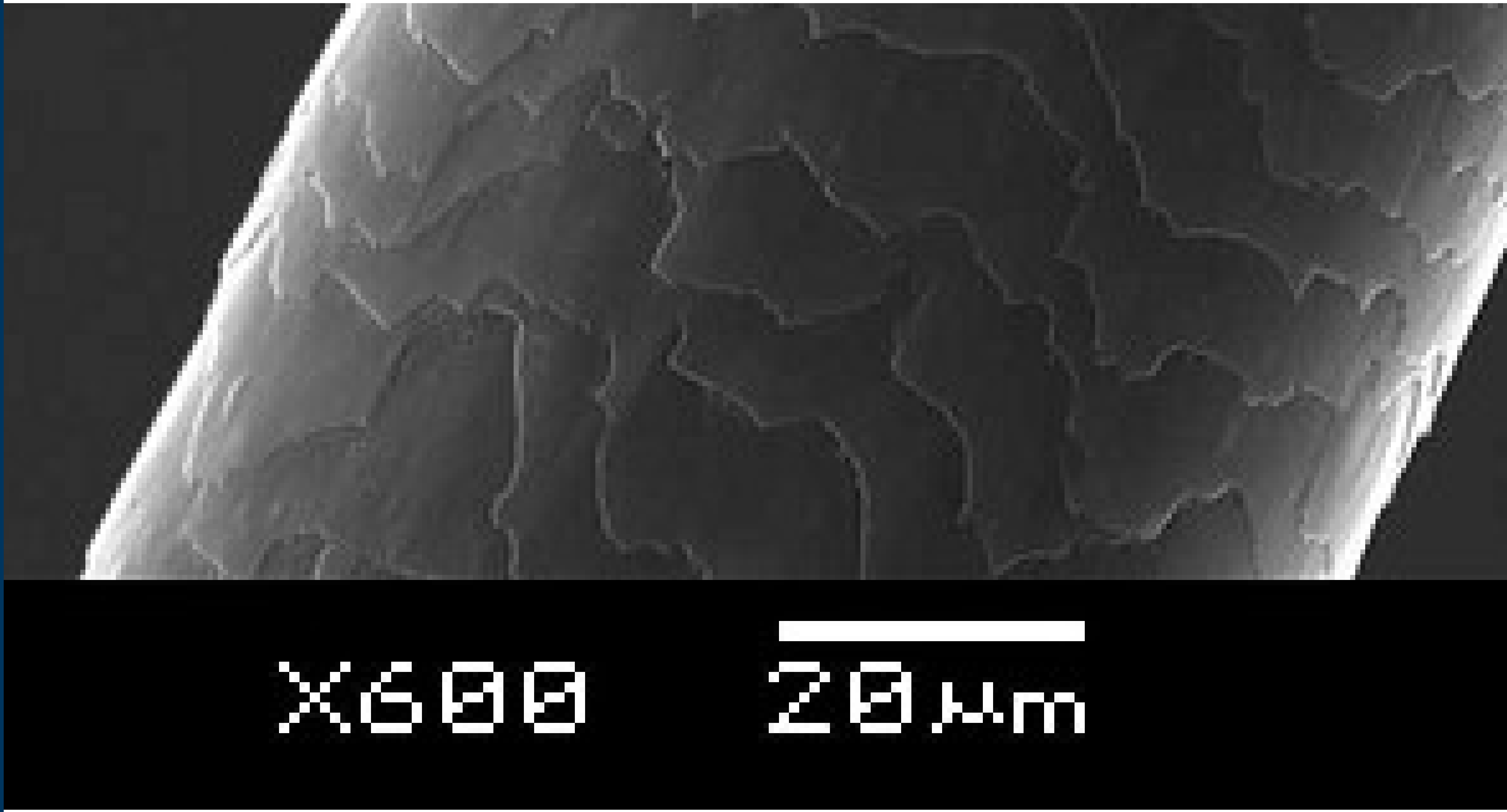
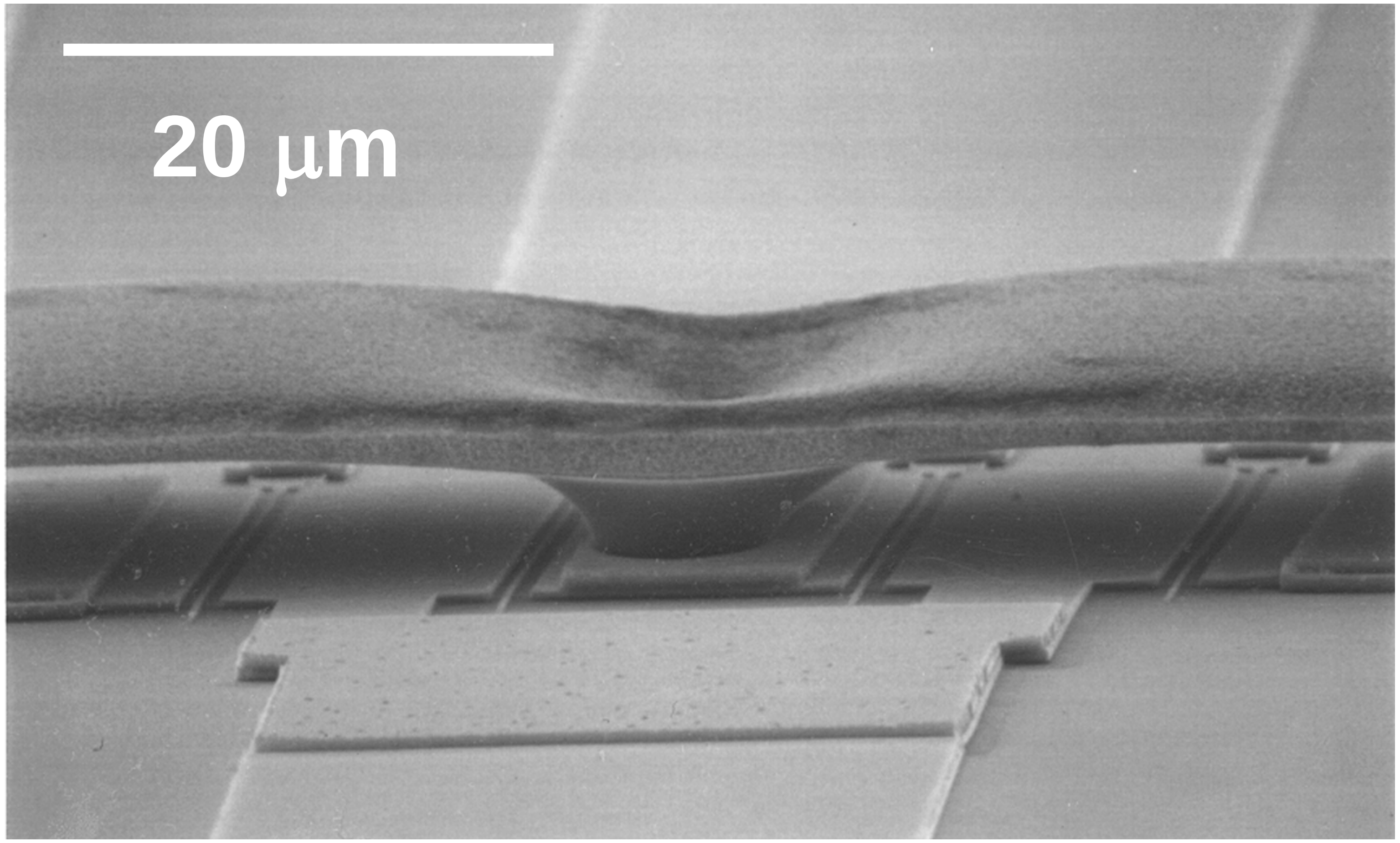
Some Examples

The following are some examples of devices that have recently been produced in the JWNC using the extensive nanofabrication toolset

Some idea of lengthscales

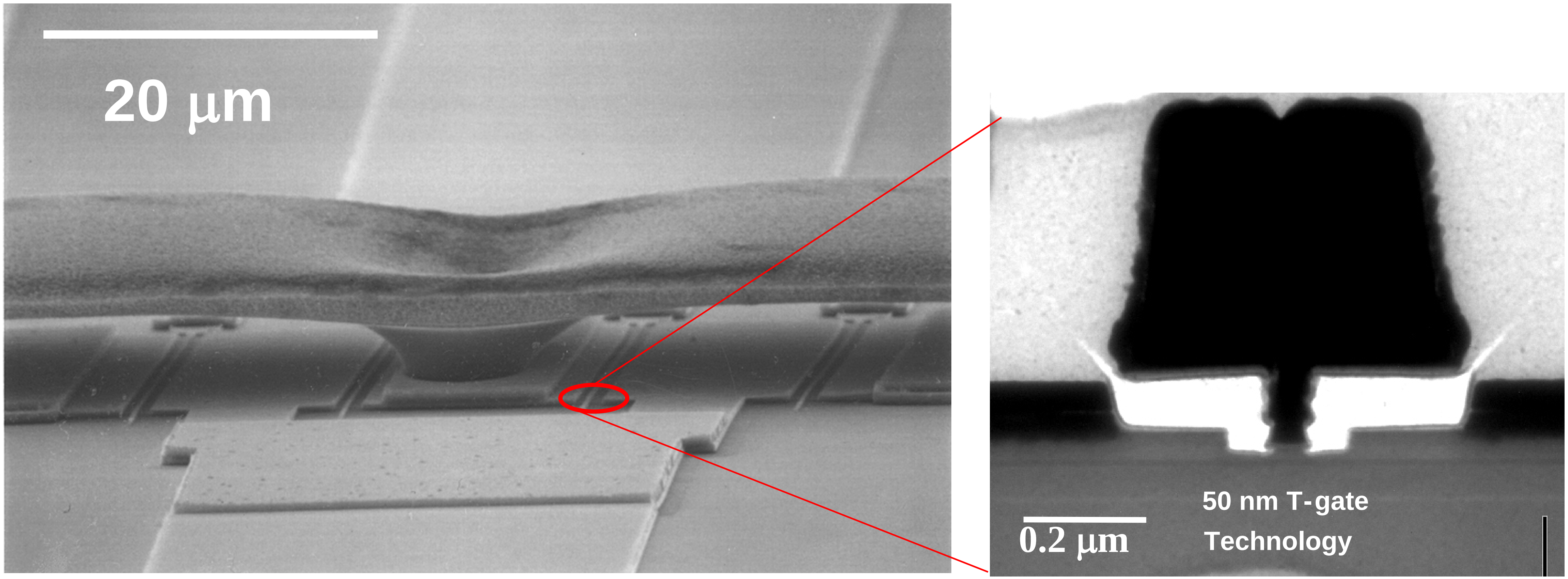


Electron Micrograph of a transistor

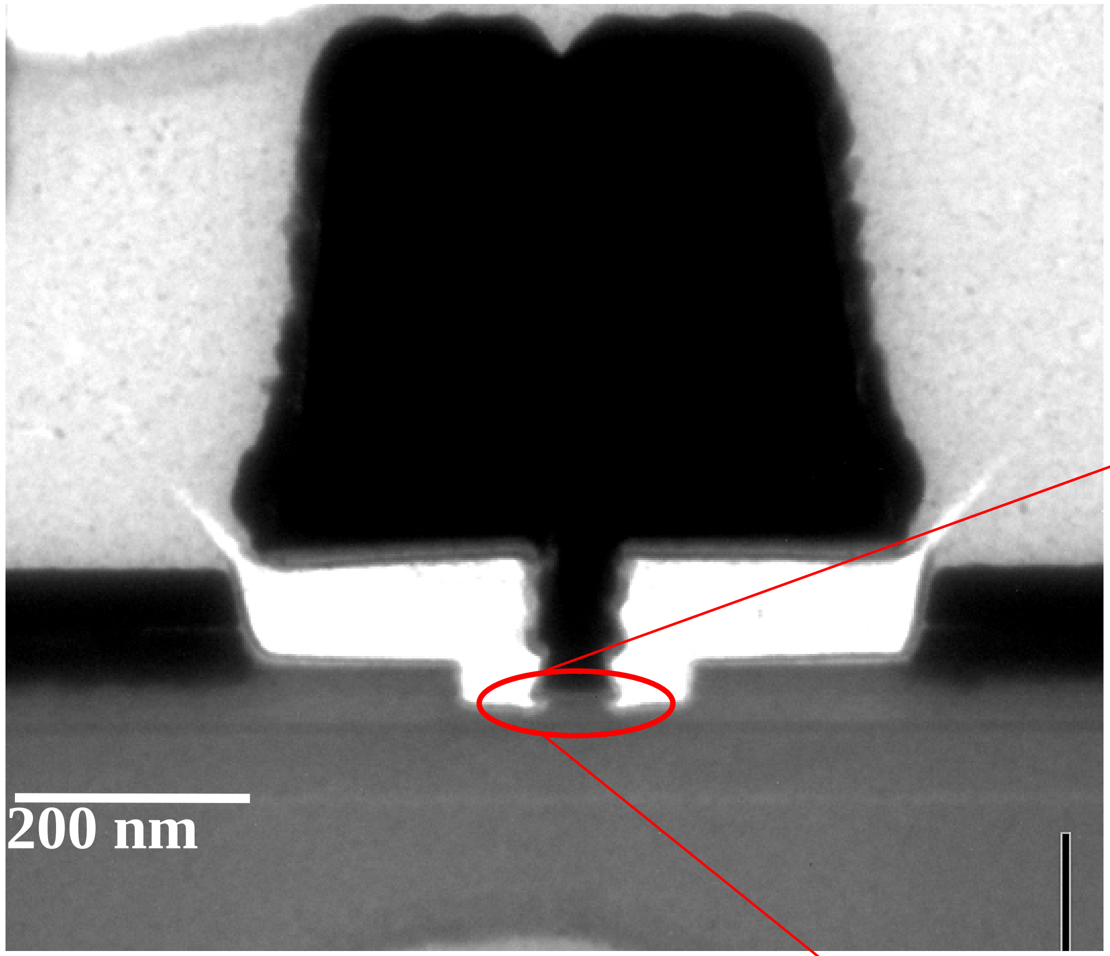


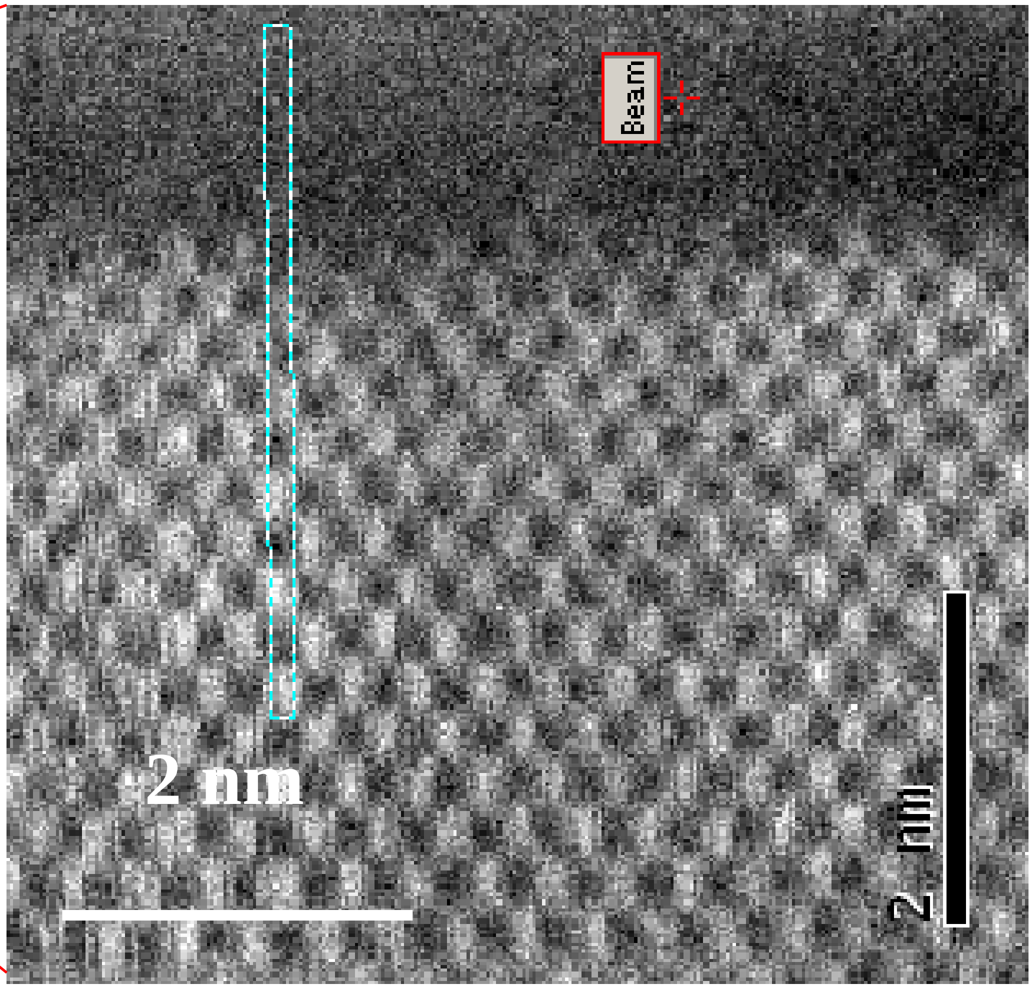
Same scalebar size as previous image

Zoom in by ~400x

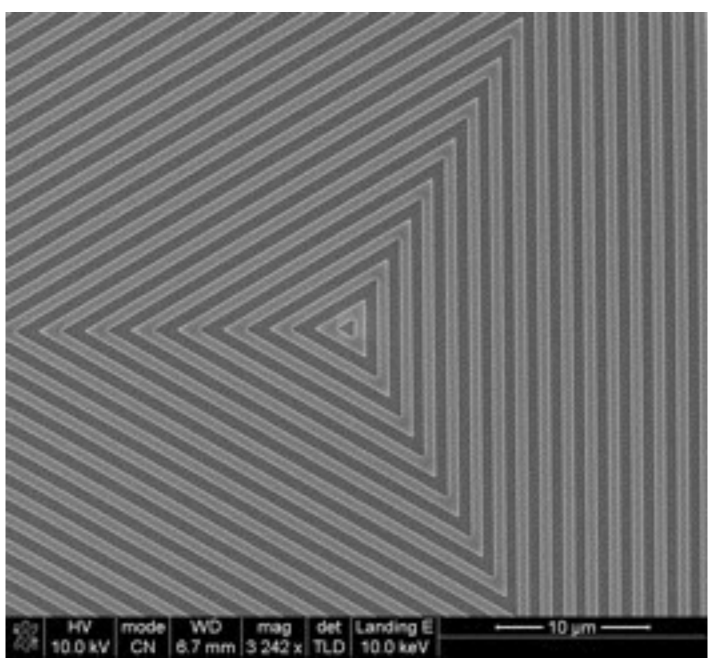


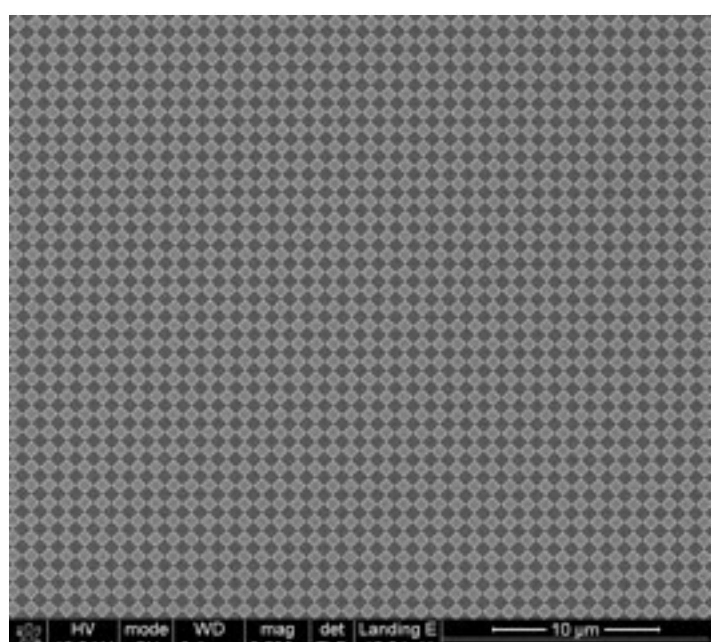
Zoom in by ~100x

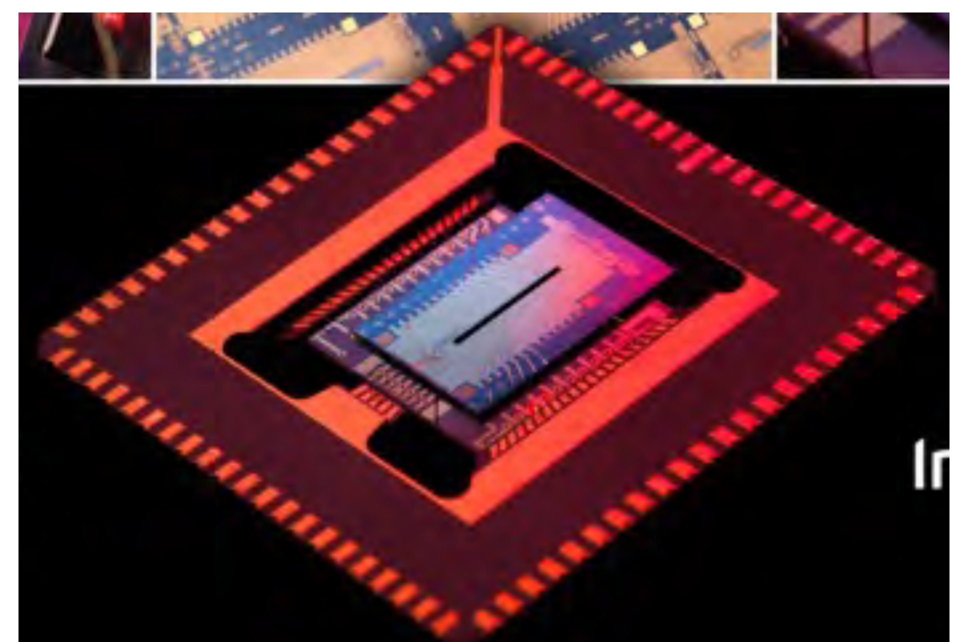




Magneto Optical Traps and Paul Ion Taps







C.C. Nshii et al. Nature Nano. 8, 321 (2013)

UK NATIONAL QUANTUM TECHNOLOGIES PROGRAMME

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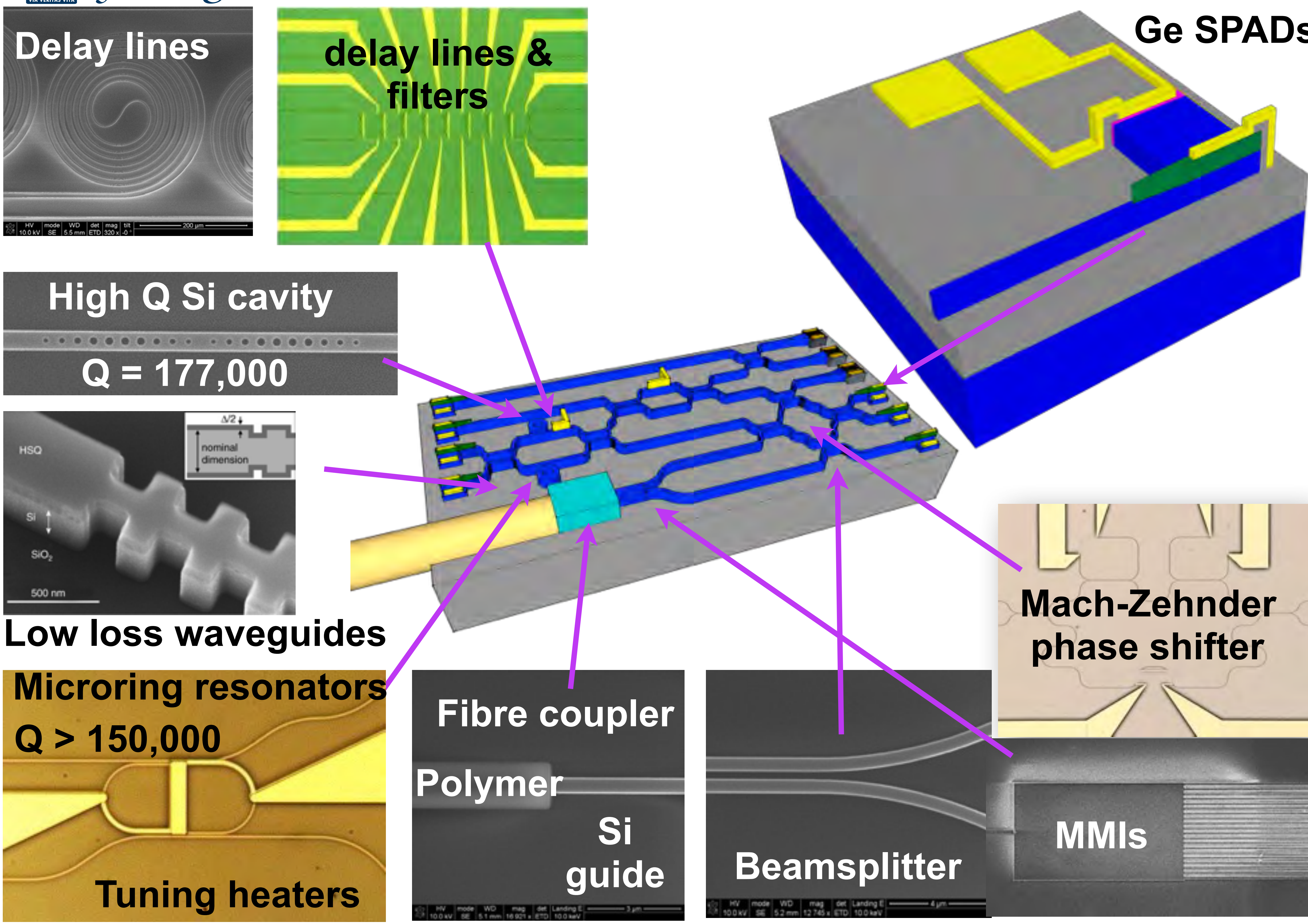
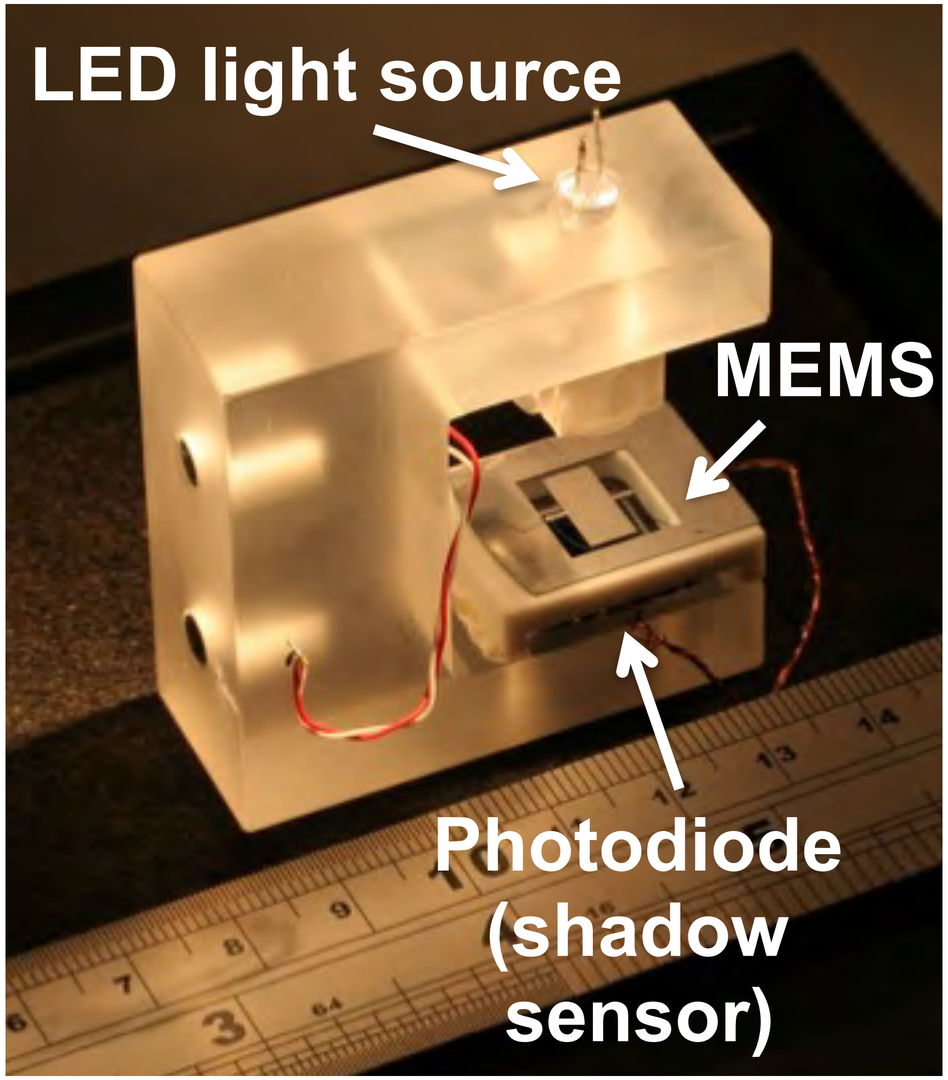
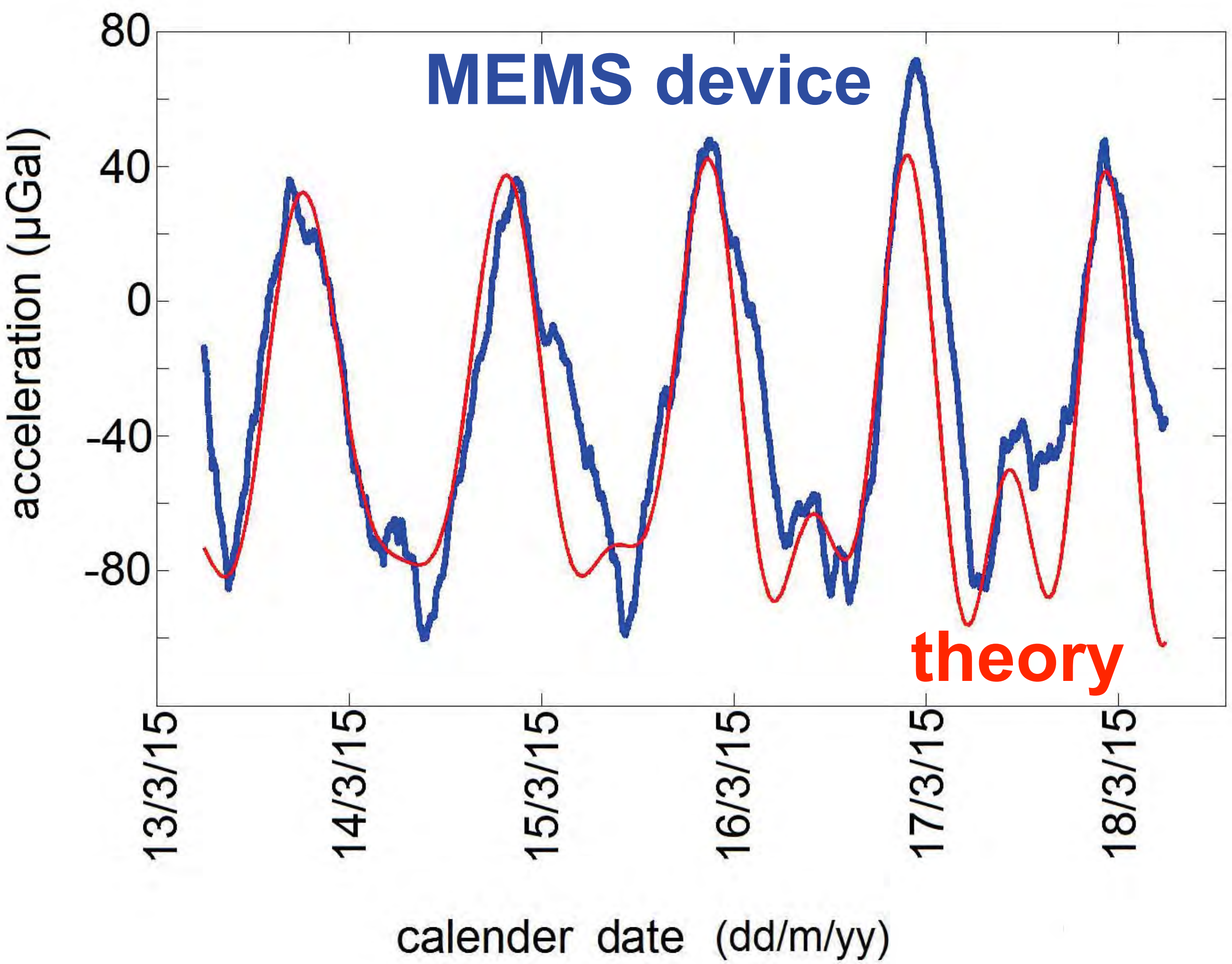
University of Strathclyde Science

Integrated Silicon Photonics



MEMS Gravimeter





R.P. Middlemiss et al. Nature 531, 614 (2016)

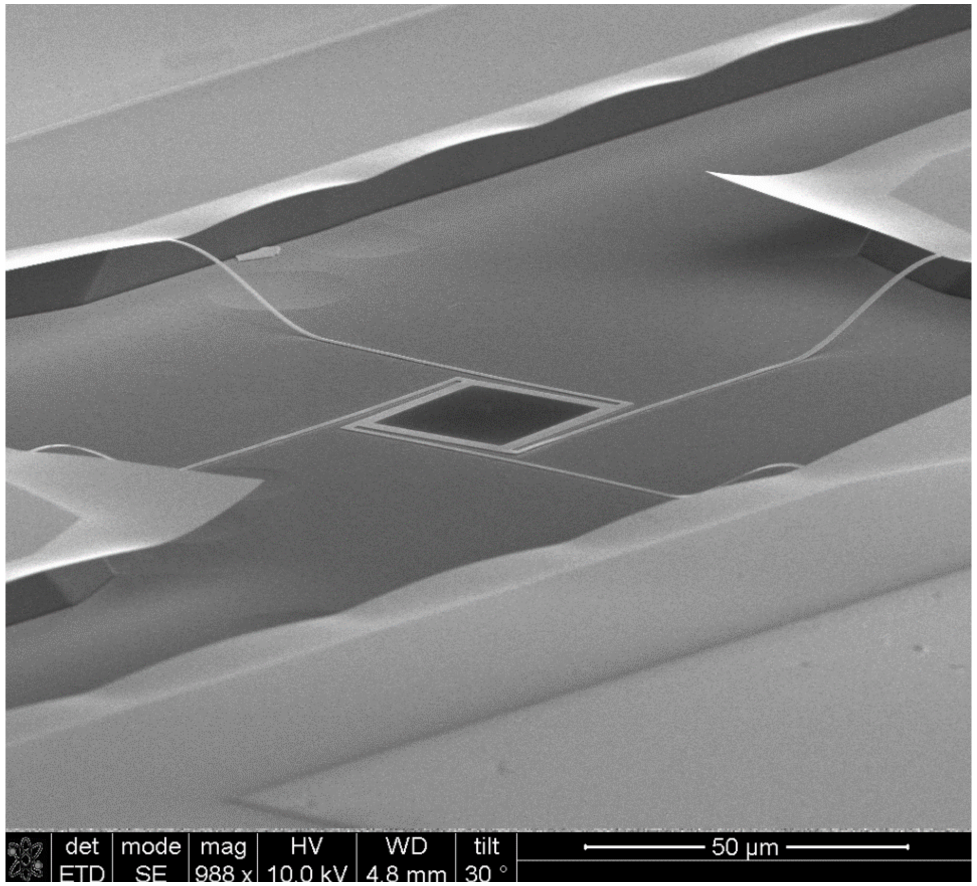
Aim: ≤10 ng/√Hz relative gravimeter with integrated squeezed light interferometer

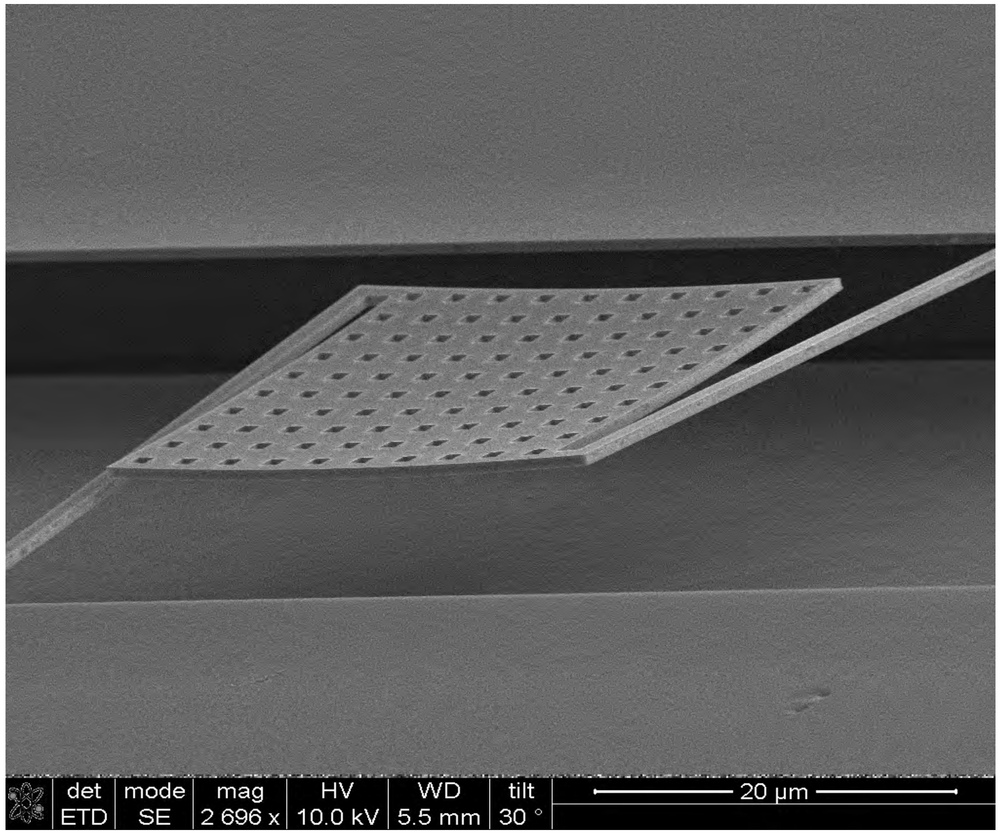
- **40 ng/√Hz gravimeter achieved**

Engineering and Physical Sciences Research Council

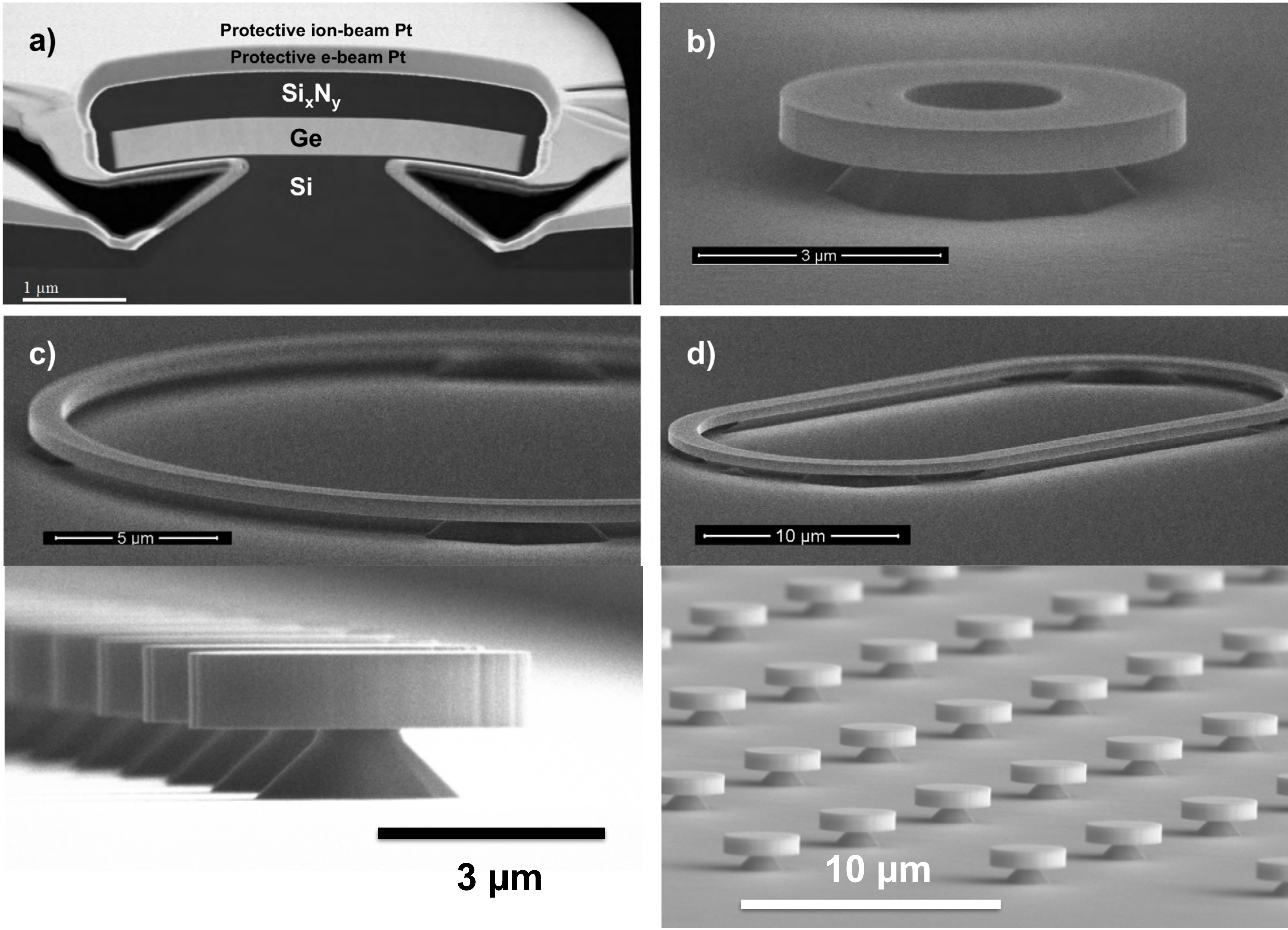
Ge Plasmonics Challenges

- **Monolithic integrated plasmonic sensor**
- **Agressive μ-bolometer scaling**
- **Surface normal Ge QWIP ~ 10 μm**
- **Cheap & integrable MIR Source**
- **3 to 5 μm gas detection window**





Ge & GeSn Lasers: Cavities



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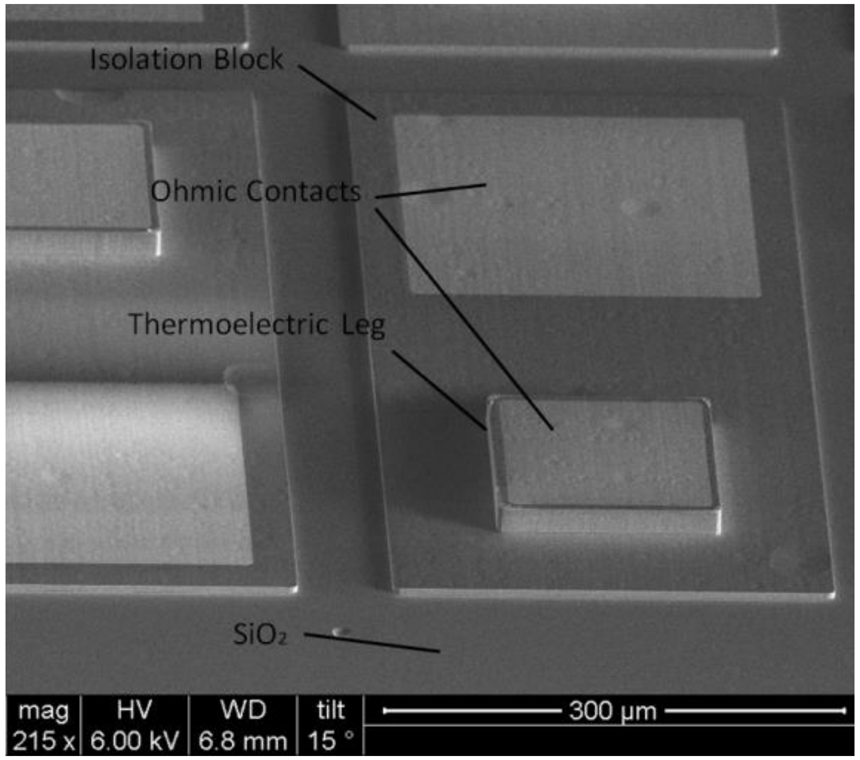
Thermoelectric Process

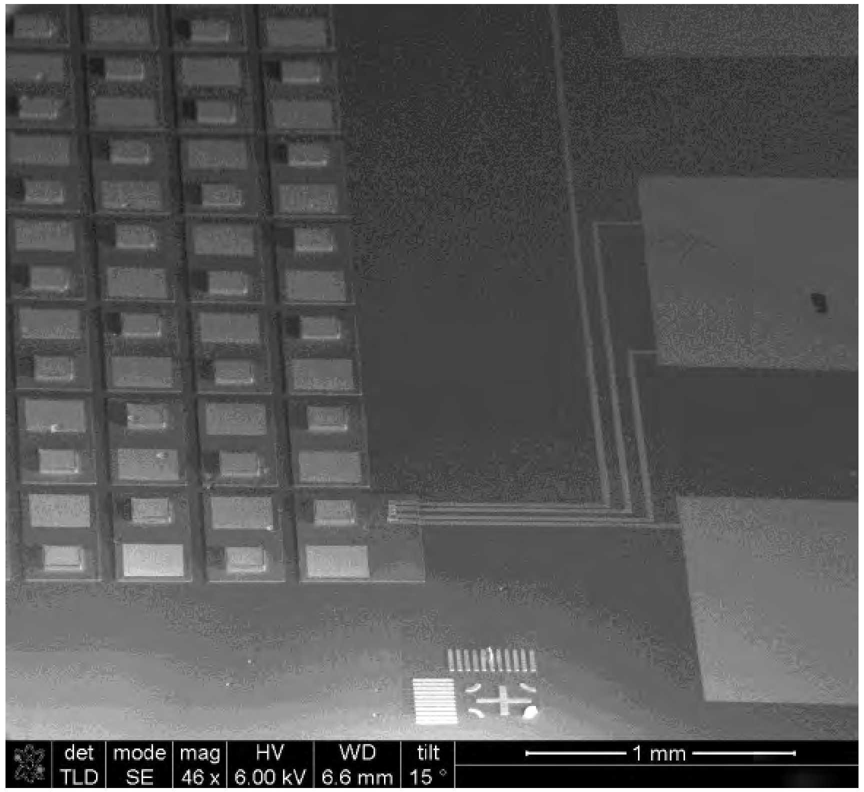
Separate n- and p-type few cm^2 substrates

- ≥ 10 µm photolith
- ≥ 20 µm SiGe SF_6, C_4F_8 ICP-RIE
- Ohmic metal (Ni or Ag(1% Sb), TiN, W / Cu)
- PECVD Si_xN_y
- ≥ 0.5 µm photolith / EBL
- Thermometers: Ti/Pd / Ti/Pt

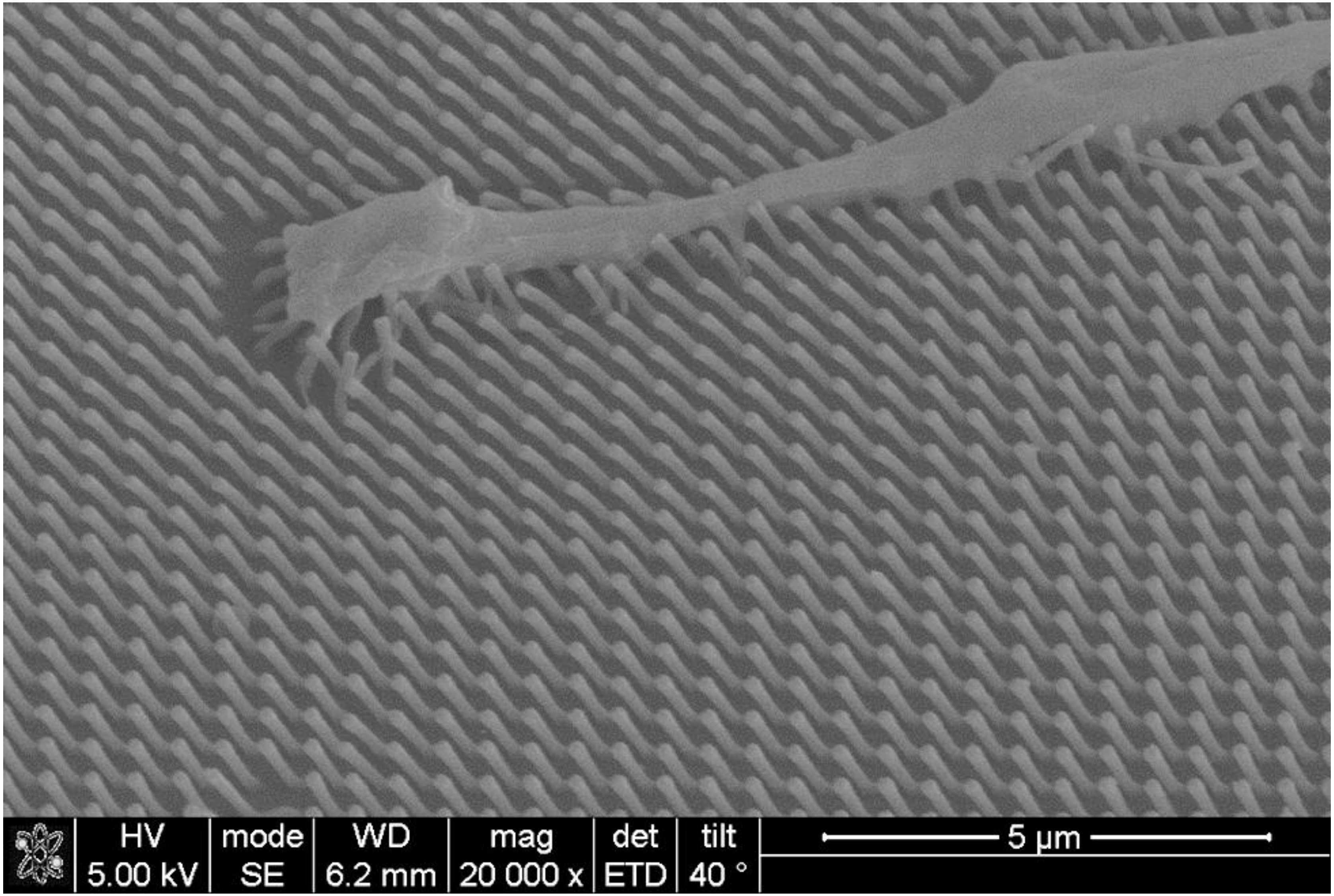
heaters

- ≥ 10 µm photolith
- Metal bond pads (Al)
- Bumps: ≥ 10 µm photolith, In evaporation
- Flip-chip-bond: alignment ≤ 20 µm, 120 ˚C



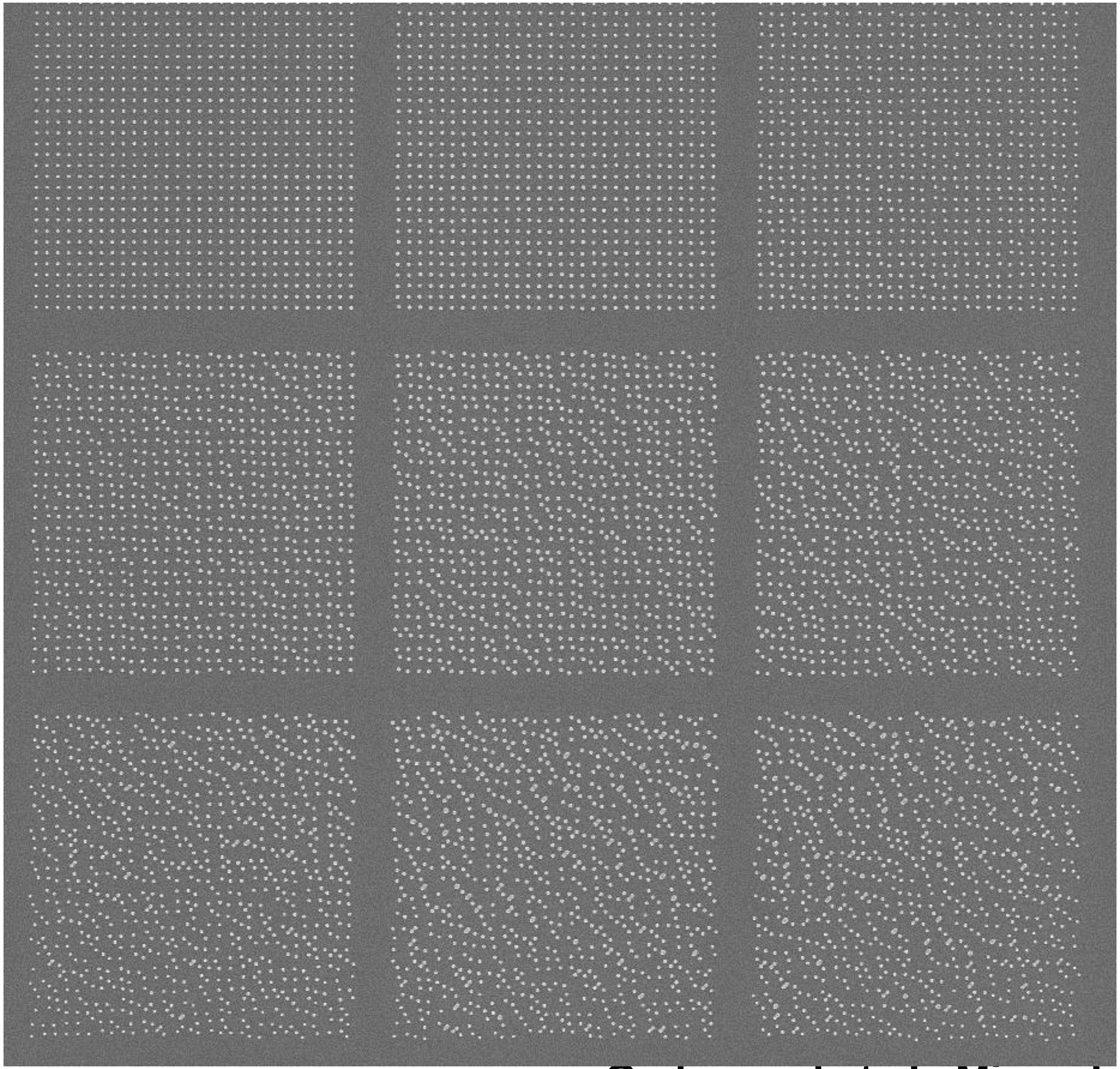


Nanoscale force measurements



Nikolaj.Gadegaard@glasgow.ac.uk

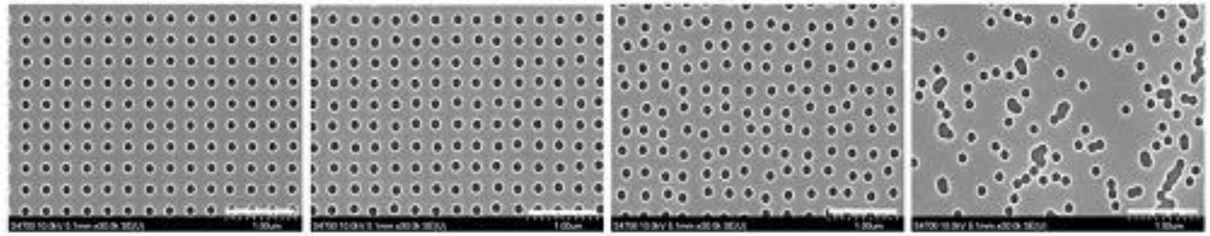
Nanolithography of dots – an ideal model system

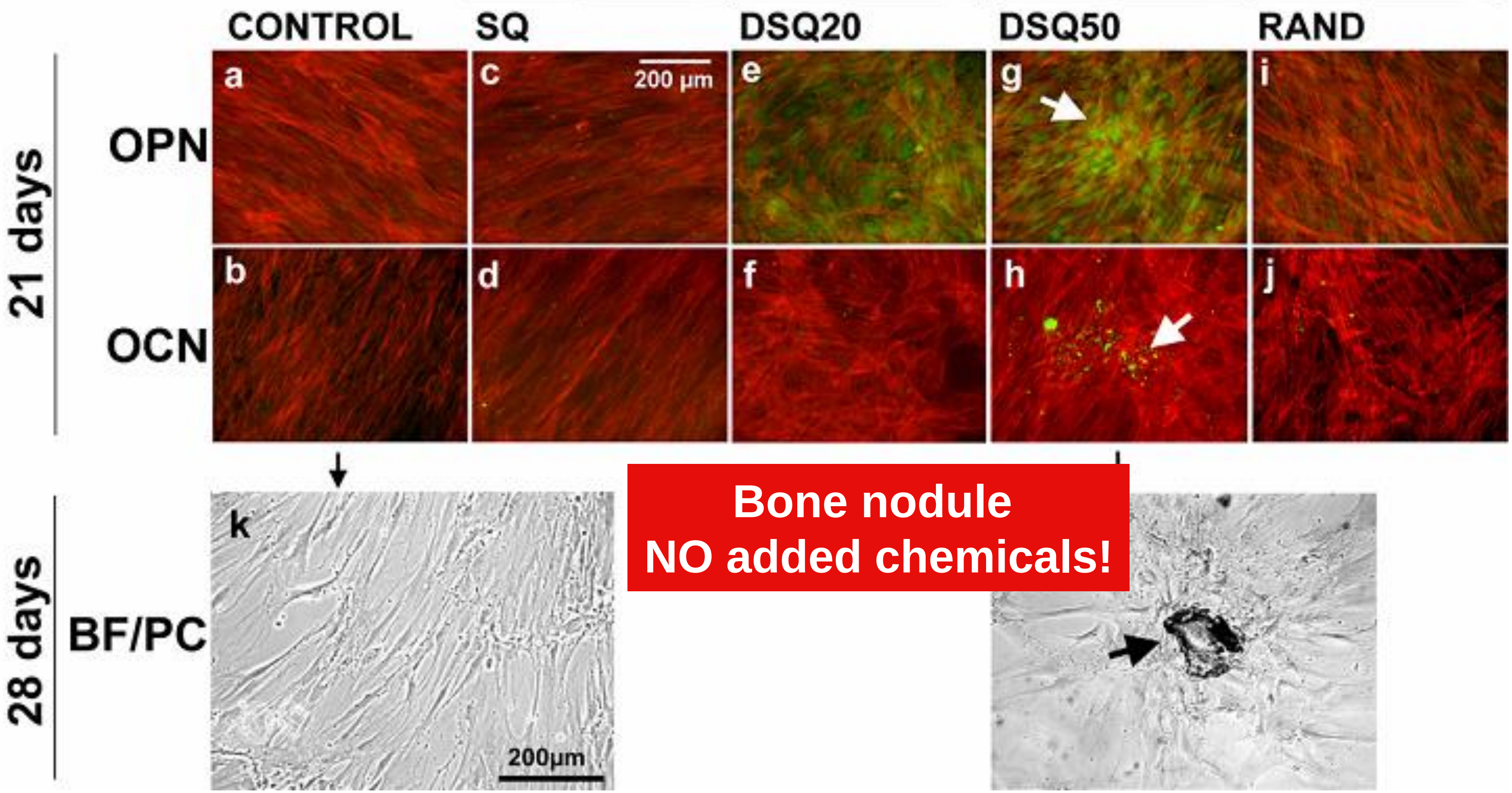


Gadegaard et al., Microelec Eng 2003

Nikolaj.Gadegaard@glasgow.ac.uk

Topographical control of stem cell fate





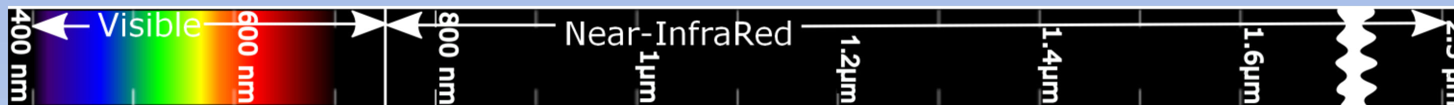
Bone nodule
NO added chemicals!

Dalby and Gadegaard et al., Nature Materials 2007

Nikolaj.Gadegaard@glasgow.ac.uk

Photon-counting technology

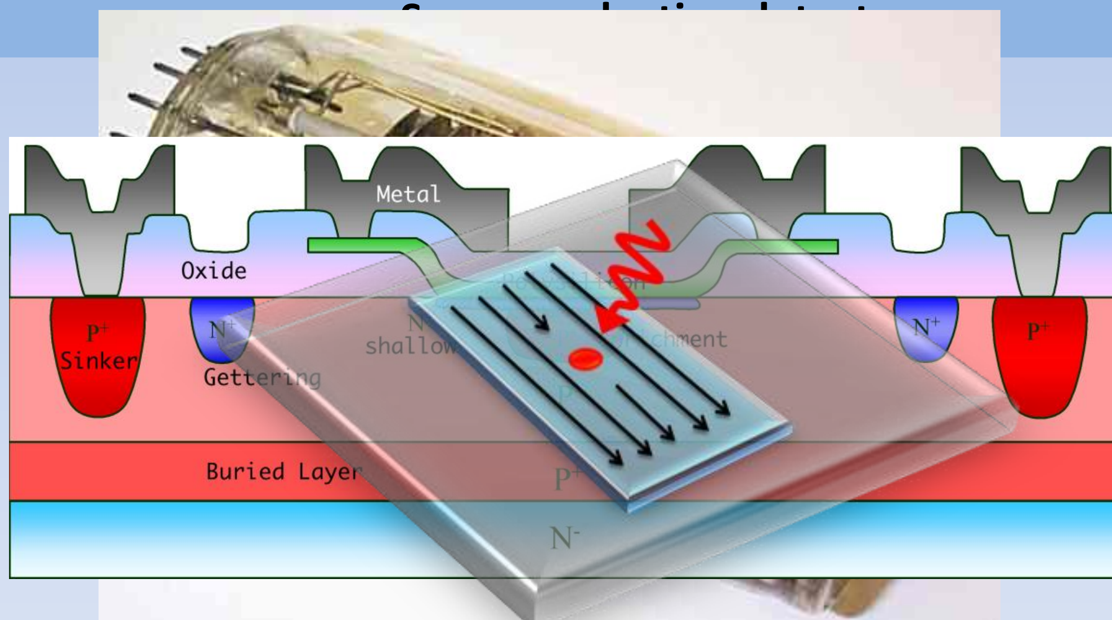
Wavelength



Detectors

Photomultipliers | **IR PMTs**

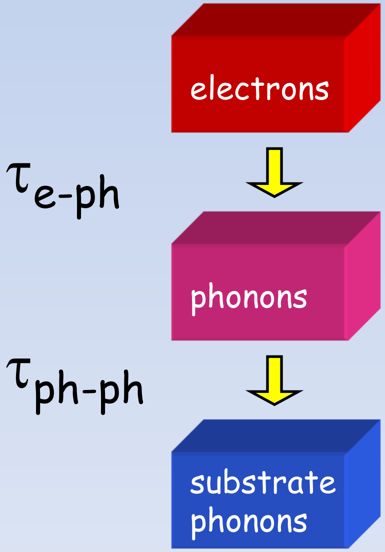
Si SPADs | **InGaAs SPADs**



Photon detection in superconductors

Typically superconducting energy gap Δ ~meV.
=> Superconductors make extremely sensitive detectors from X-ray to Terahertz wavelengths.

One optical photon creates ~100–1000 excited electrons (superconducting gap ~2_meV for NbN). cf semiconductor – one optical photon creates one electron-hole pair, typical band gap 1-2 eV).



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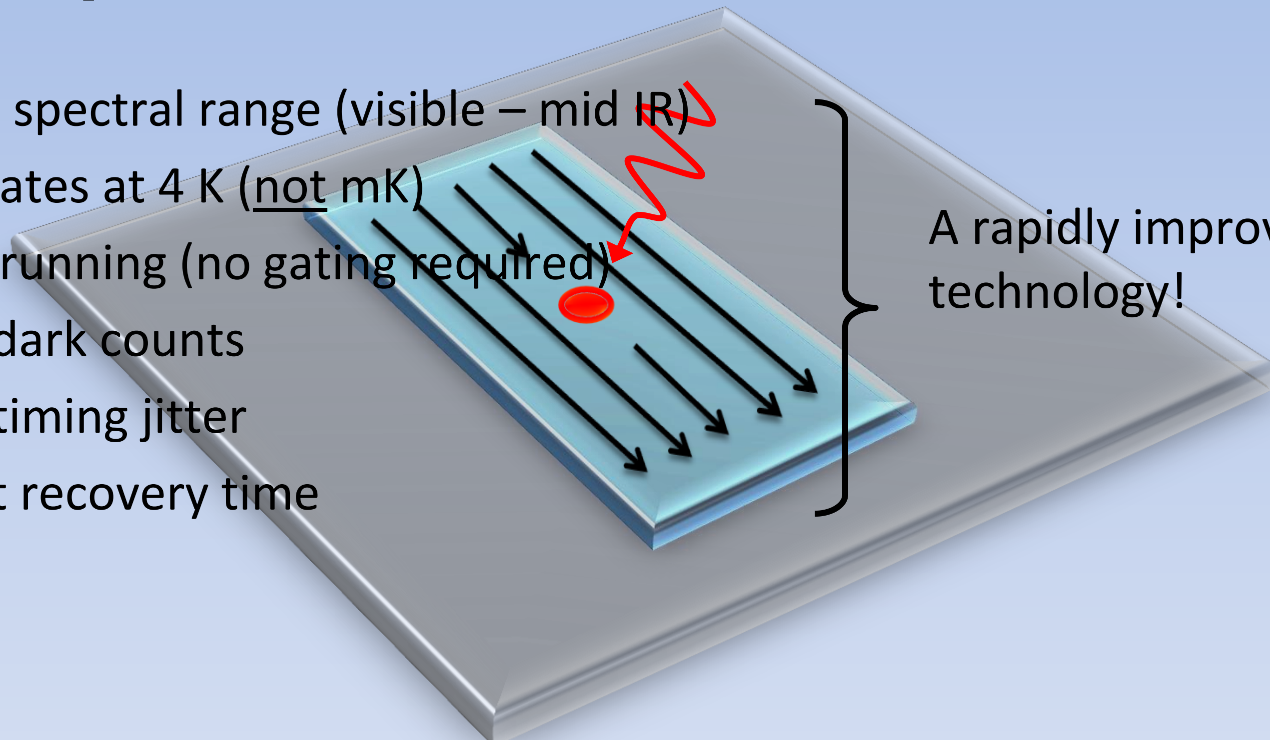
Superconducting nanowire single photon detector

Key Properties



- Wide spectral range (visible – mid IR)
- Operates at 4 K (<u>not</u> mK)
- Free running (no gating required)
- Low dark counts
- Low timing jitter
- Short recovery time

A rapidly improving technology!

Original Concept: Gol'tsman *et al* Applied Physics Letters **79** 705 (2001)

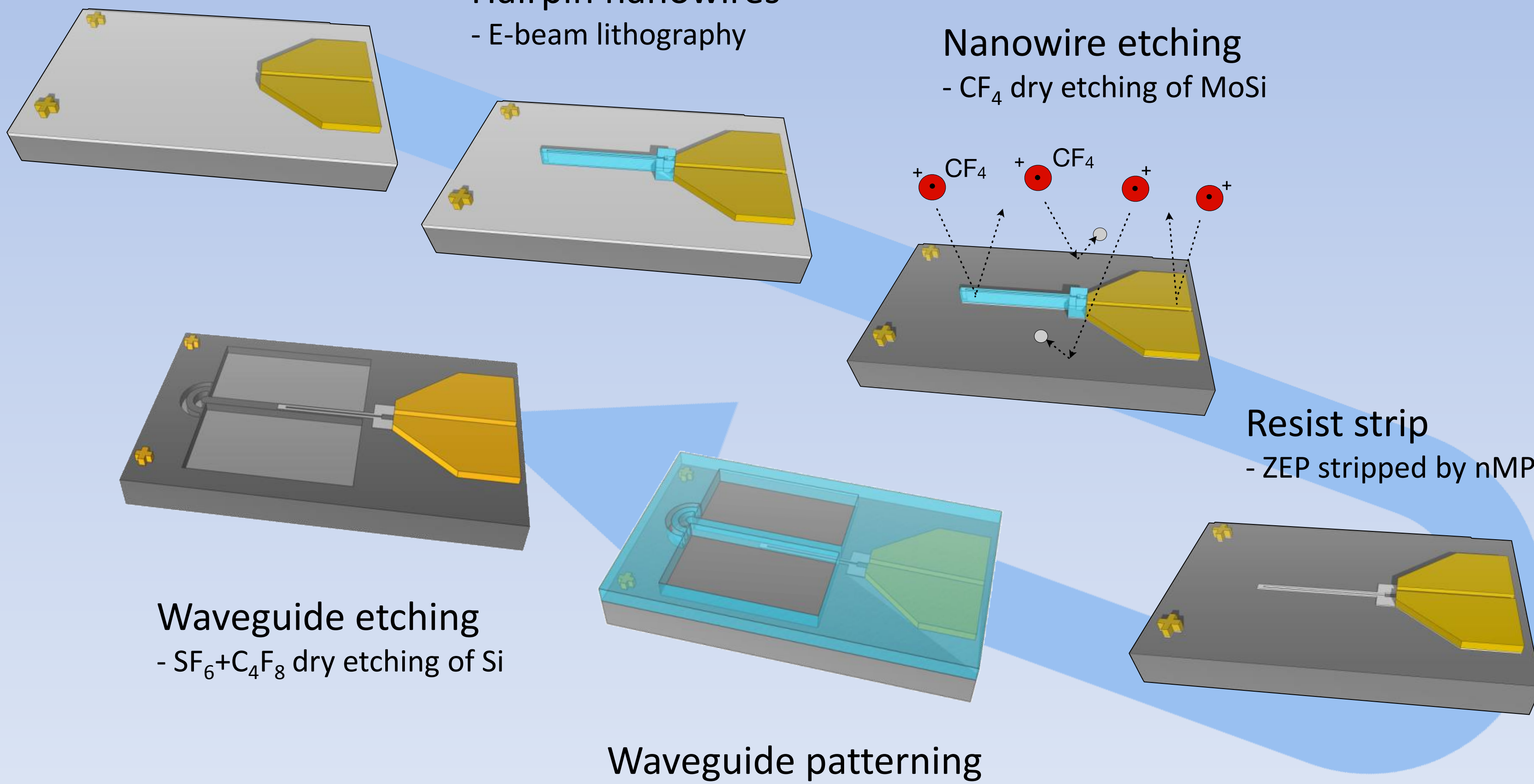
Topical Review: Natarajan *et al* Superconductor Science & Technology **25** 063001 (2012) **Open Access**

Waveguide Integrated SNSPDs

Gold contacts and alignment marks
- E-beam lithography
- Metal evap & lift-off

Hairpin nanowires
- E-beam lithography

Nanowire etching
- CF_4 dry etching of MoSi

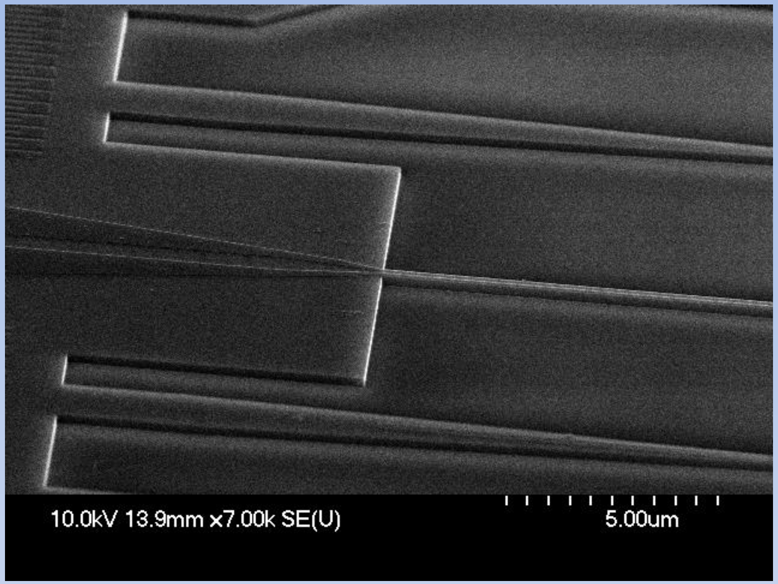


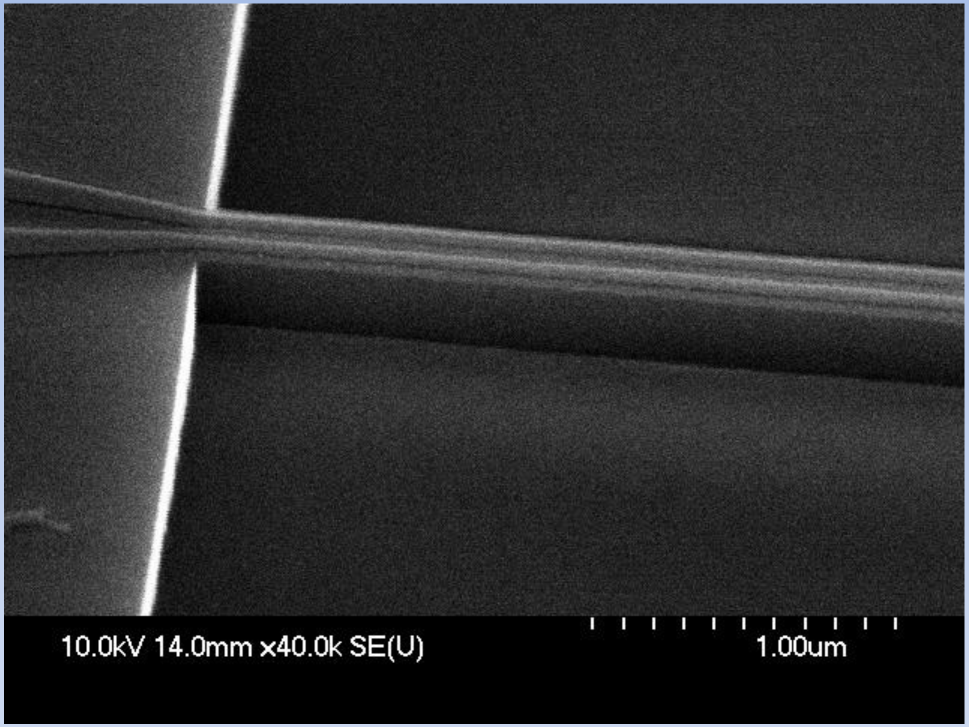
Resist strip
- ZEP stripped by nMP

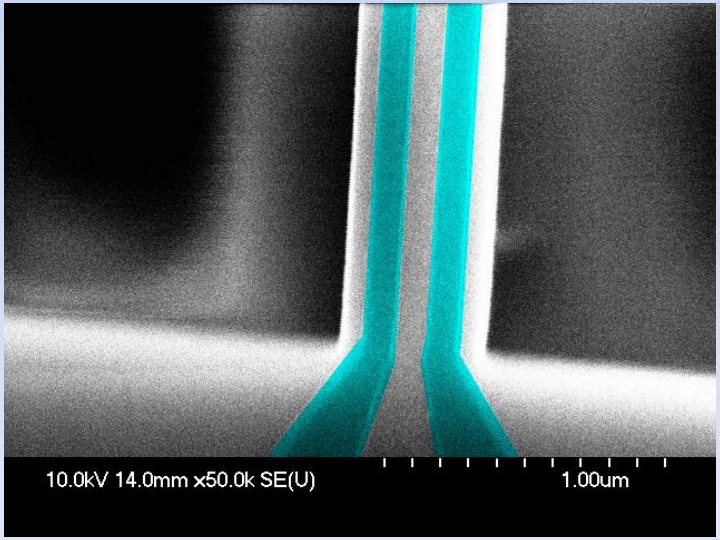
Waveguide patterning
- E-beam lithography

Waveguide etching
- SF_6+C_4F_8 dry etching of Si

Waveguide Integrated SNSPDs

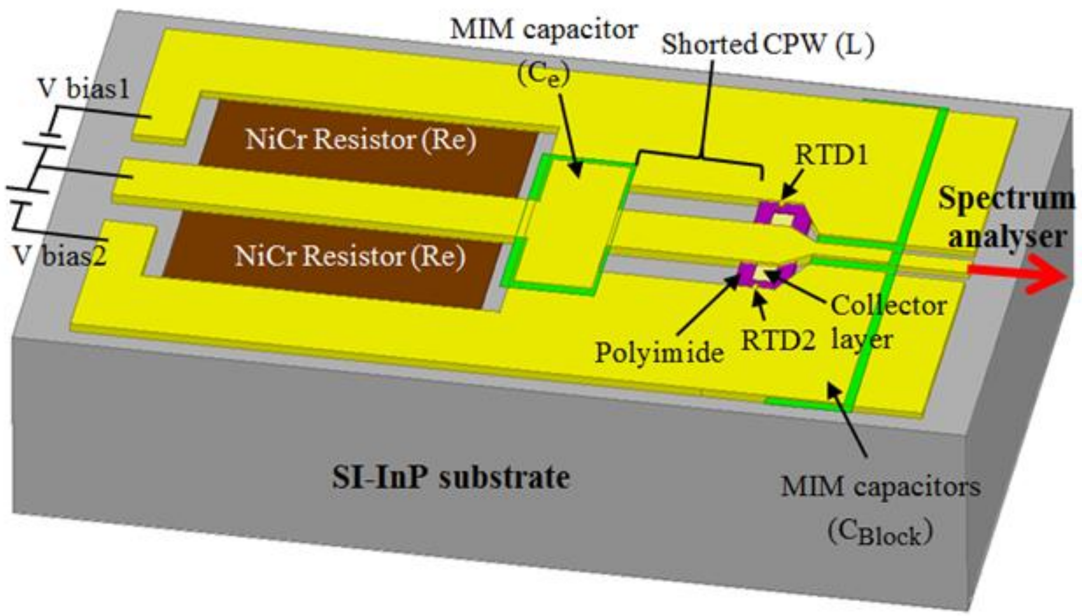


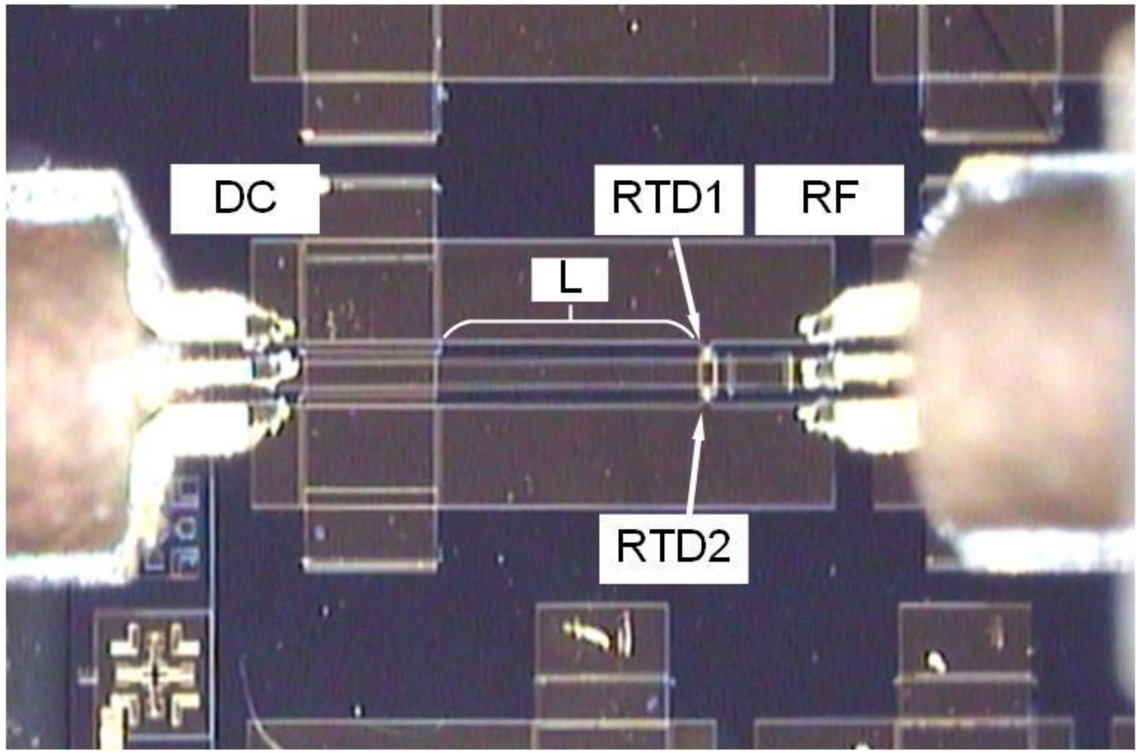




Layer to layer alignment across 3 stages of e-beam lithography ± 20nm

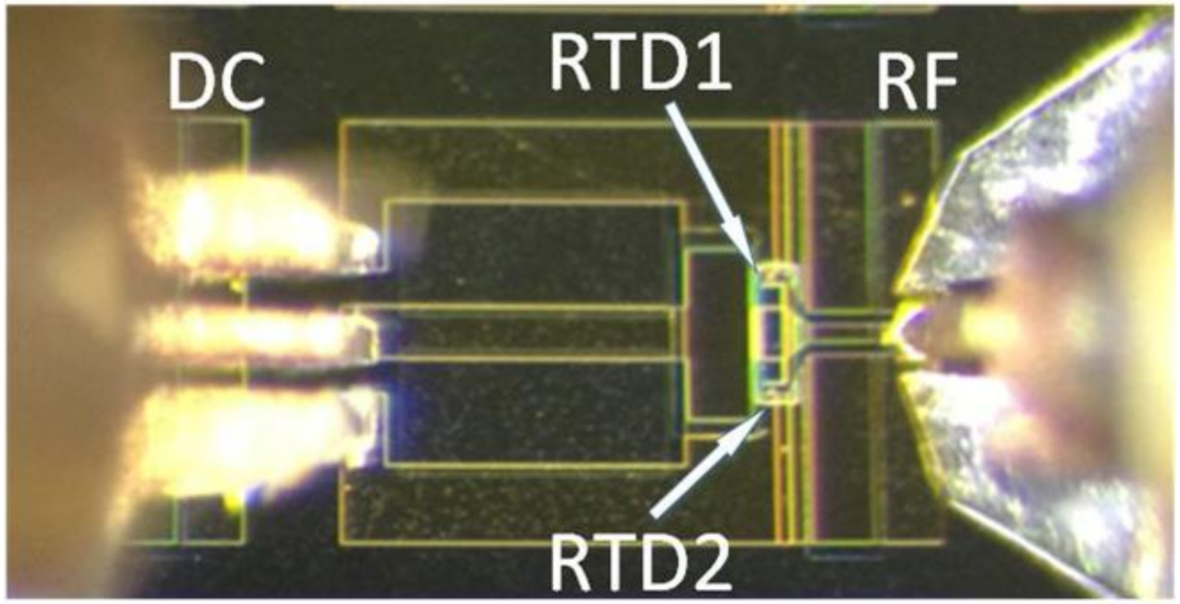
RTD THz Oscillators from JWNC





165 GHz Oscillator

- Polyimide process
- BCB Process
- CPW & Microstrip technologies
- NiCr resistors & SiNx MIM caps



300 GHz Oscillator

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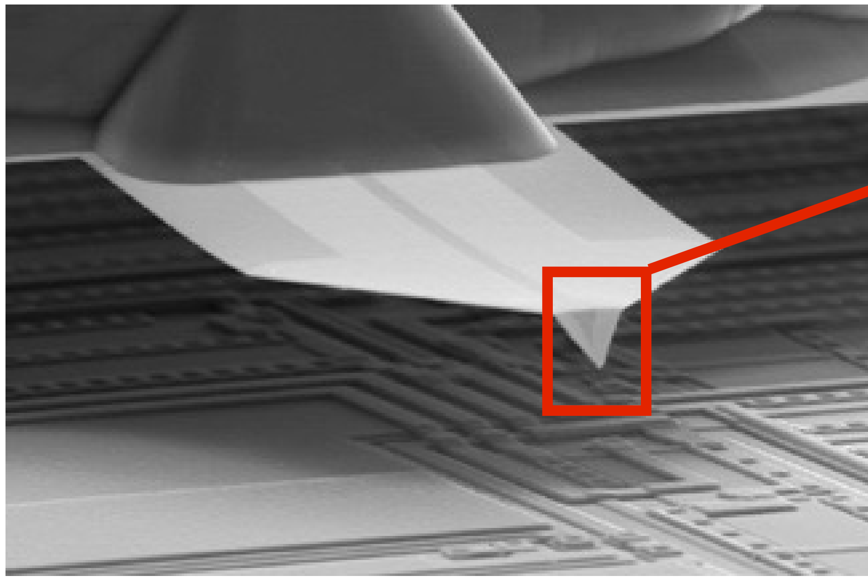
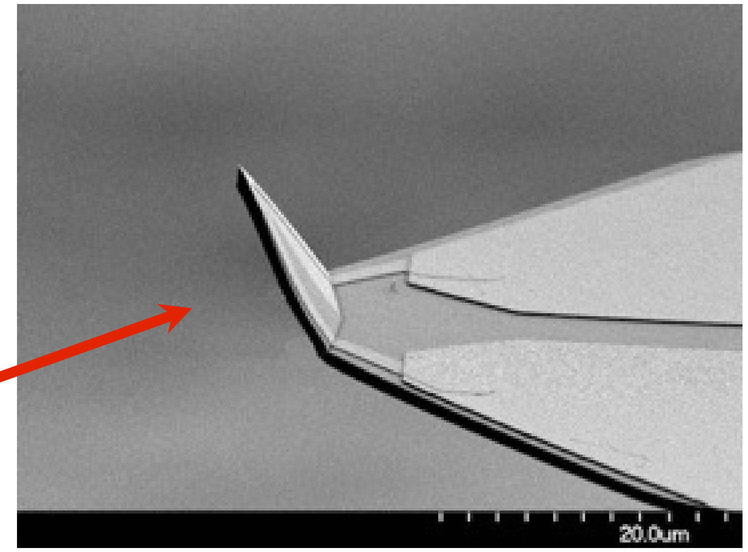
Research to Small Scale Manufacture

Thermocouples on Si pyramids

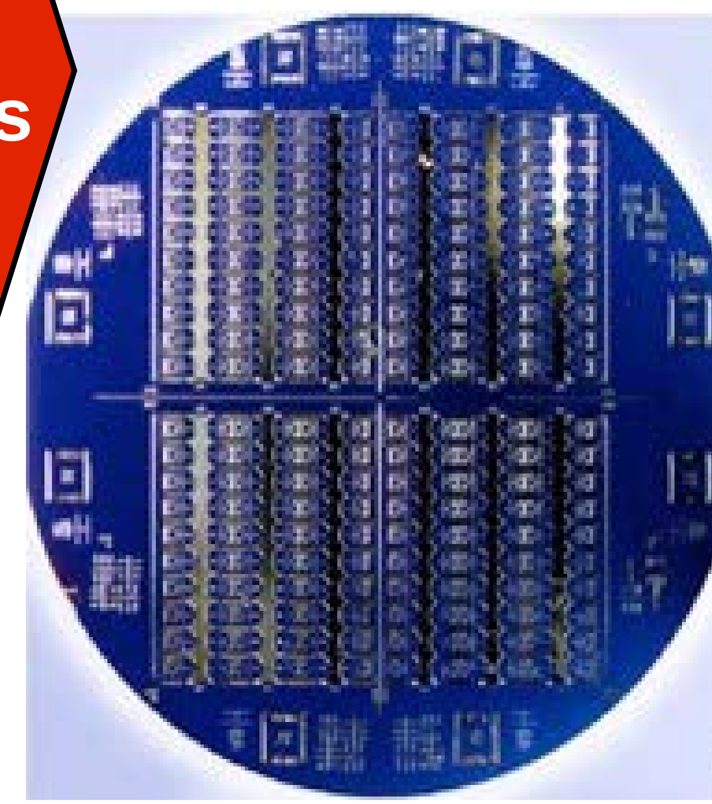




KELVIN NANOTECHNOLOGY

Scale up: from single devices to wafers

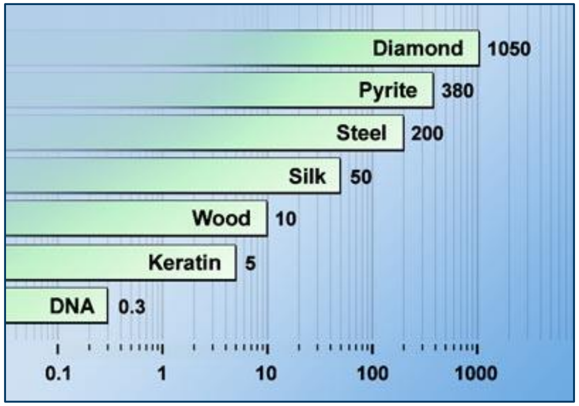
75 mm wafer manufacture



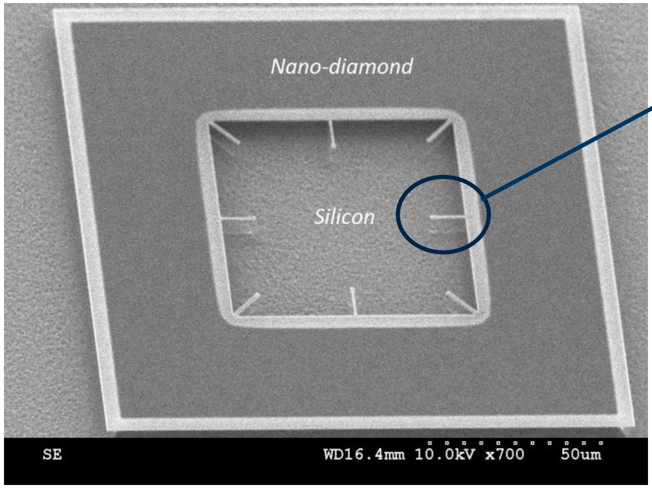
100% of thermal AFM probes manufactured in Glasgow JWNC

Project 2 - Diamond Cantilvers and MEMS

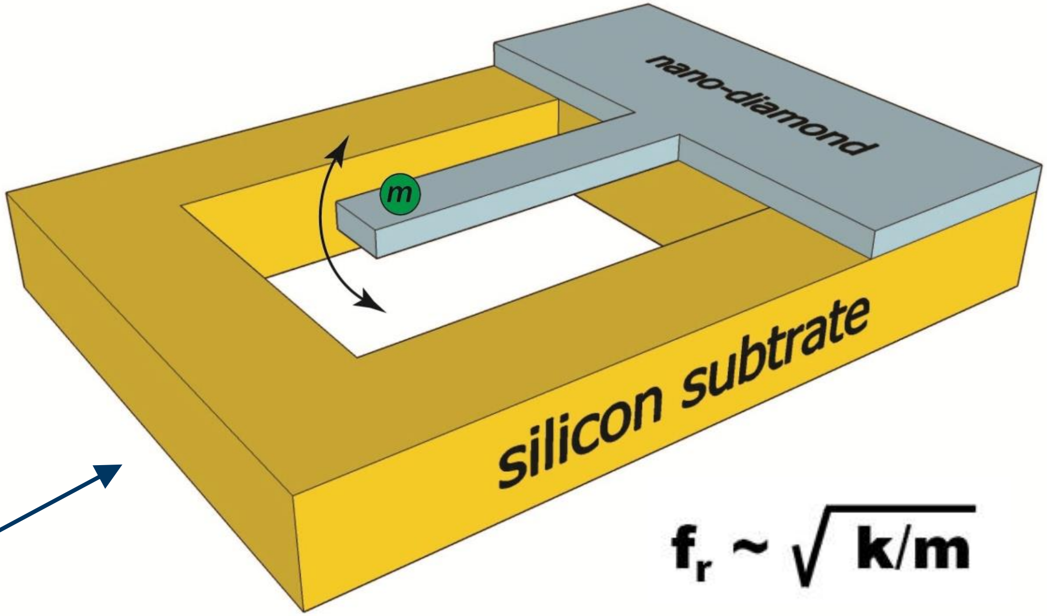
Andy McGlone (Phil Dobson, Manlio Tassieri & Julien Reboud)



Young's Modulus (GPa)
from metamodern.com



Diamond cantilevers

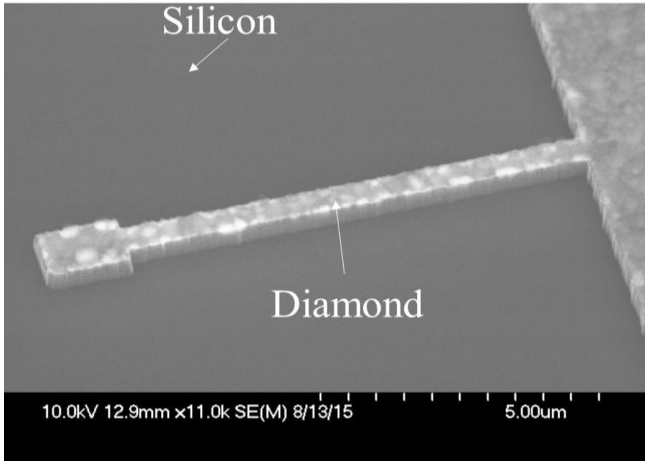


$$f_r \sim \sqrt{k/m}$$

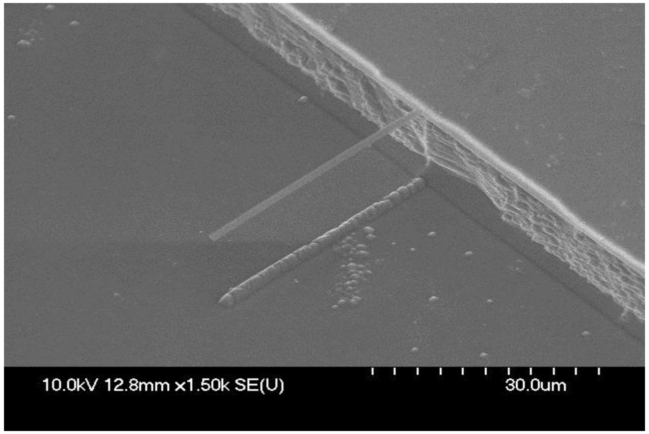
High spring constant, *k* (High Young's modulus)
+
Low effective mass, *m* (Nano-fabricated structure)

Dry etching of diamond cantilevers

- **Diamond Etch**
  - Oxford Instruments System 100 RIE
  - Ar/O2 gas mixture
  - Etch rate ~ 22 nm/m



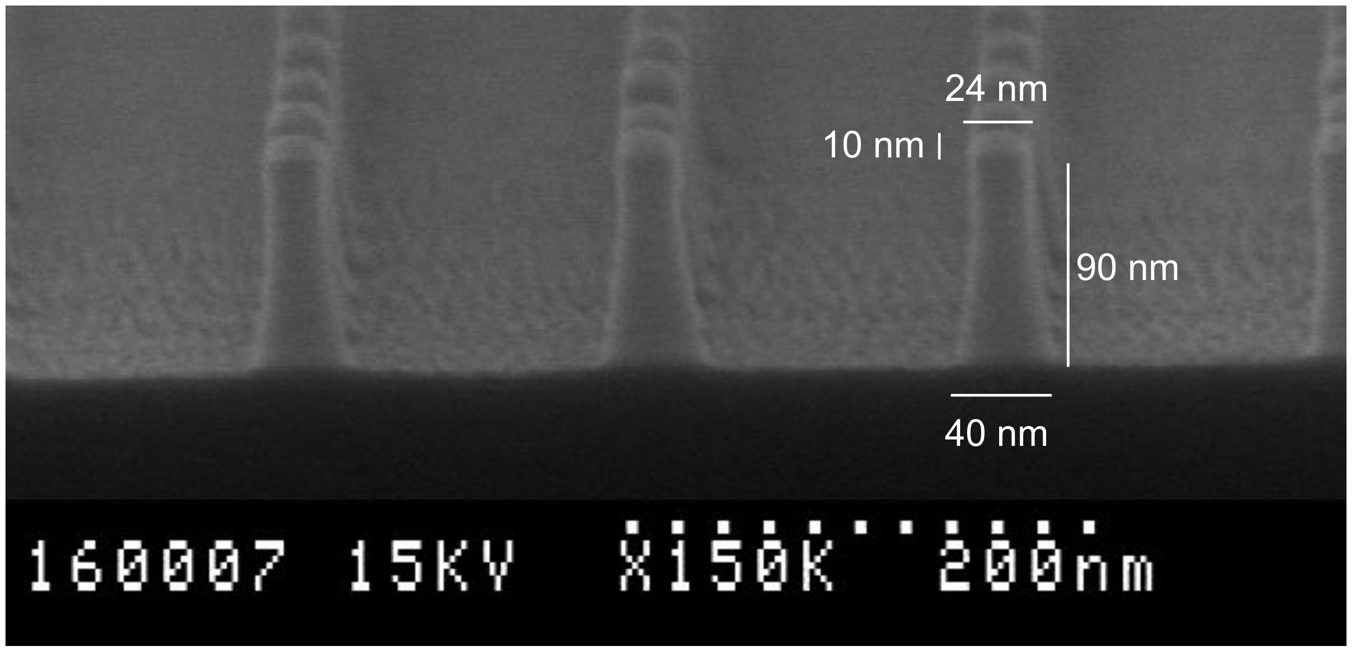
- **Silicon Etch**
  - STS ICP
  - C4F8 Mixed process
  - KOH wet etch
  - Minimal undercut

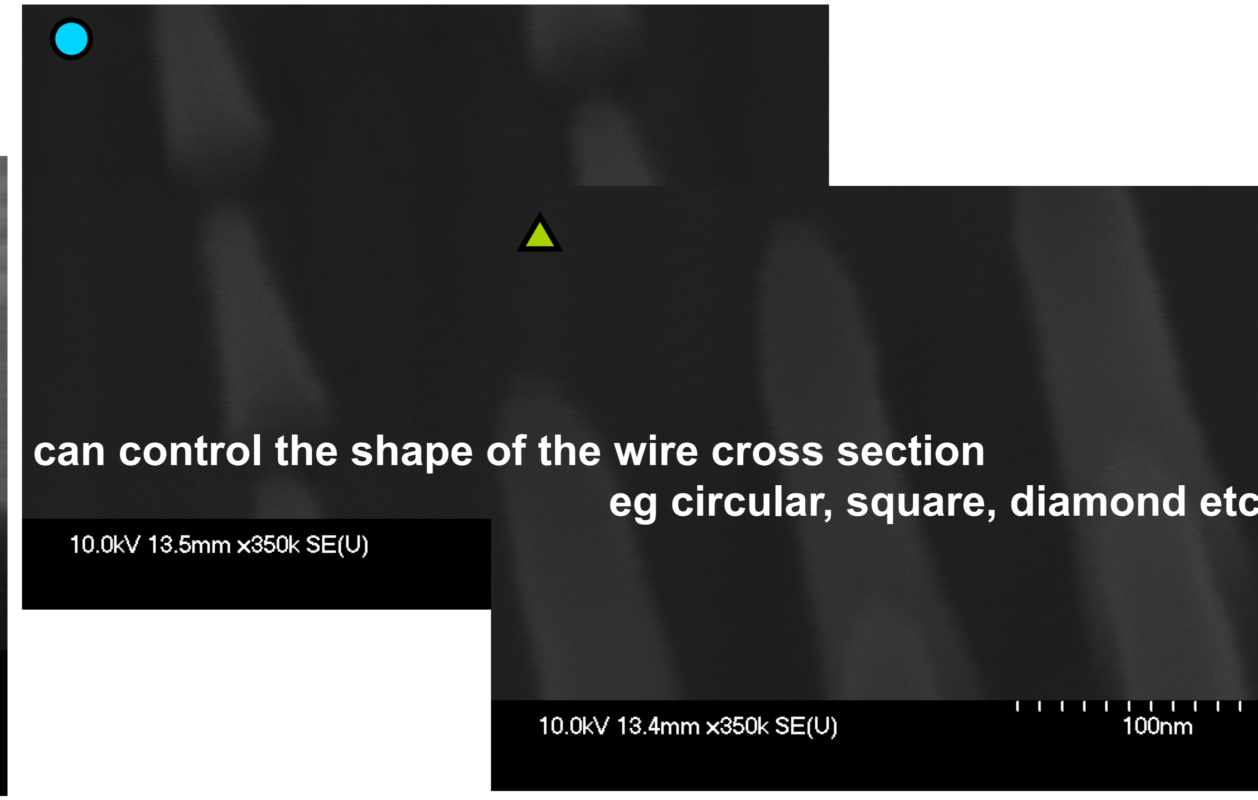


Critical features down to ~ 300nm

WP2

2.1 nanowire formation by ebl and etching

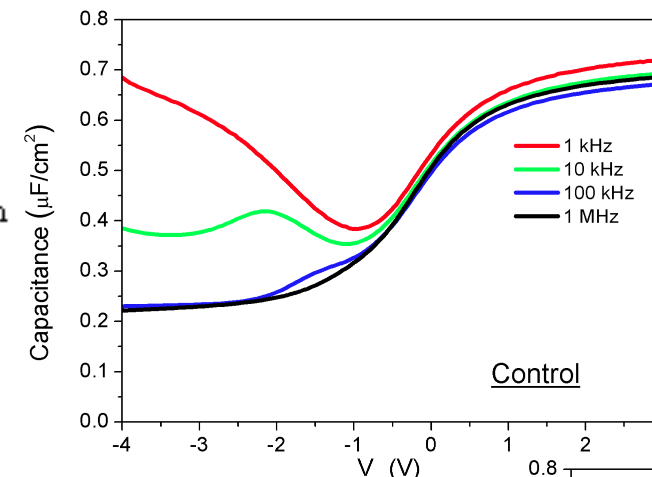




Towards vertical sidewalls in III-V FinFETs: dry etch processing and its associated damage on the electrical and physical properties of (100)-oriented InGaAs

Olesya Ignatova[1], Uthayasankaran Peralagu[1], Xu Li[1], Matthew Steer[1], Muhammad Mirza[1], Jun Lin[2], Ian Povey[2], Patrick Carolan[2], Karim Cherkaoui[2], Paul Hurley[2] and Iain Thayne[1]

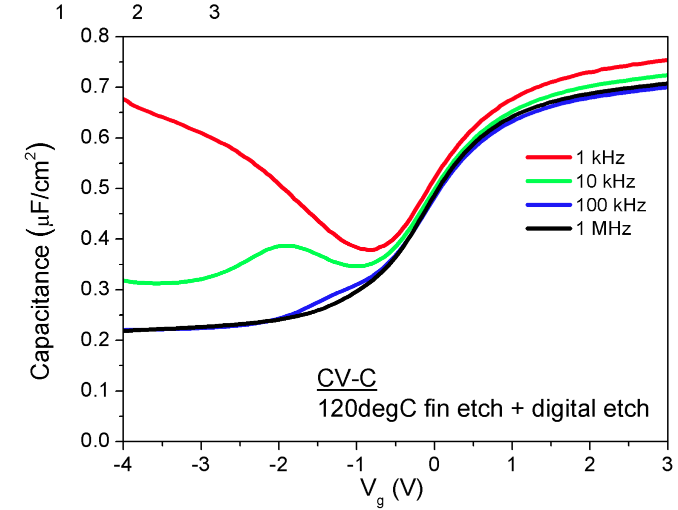
[1]*School of Engineering, University of Glasgow, Scotland, UK*
[2]*Tyndall National Institute, Cork, Ireland*



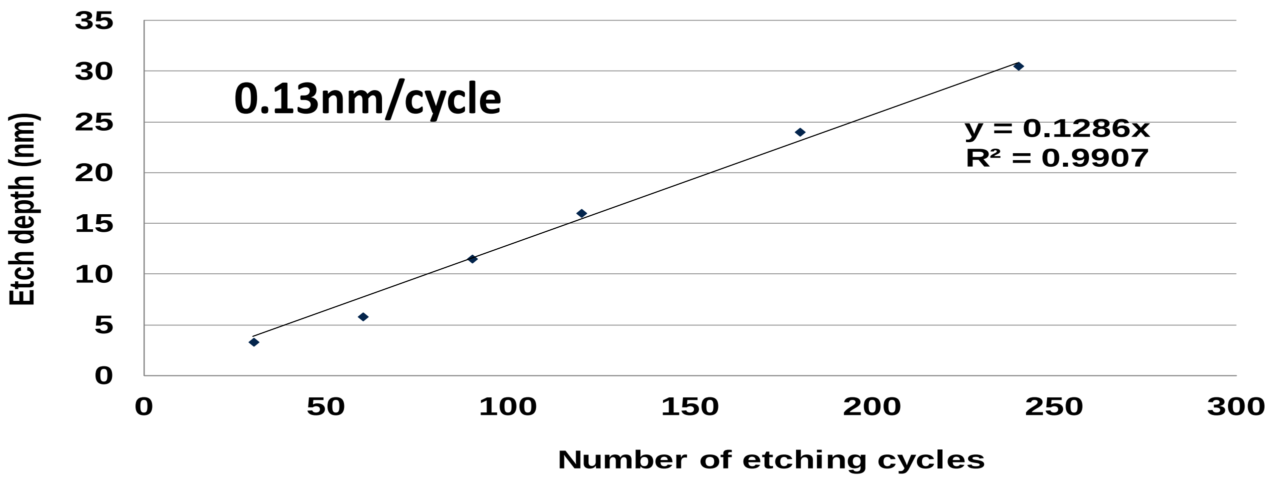
Demonstration of III-V fins with vertical sidewalls using $Cl_2/CH_4/H_2/O_2$ dry etch chemistry in conjunction with digital etching for recovery of etch damage

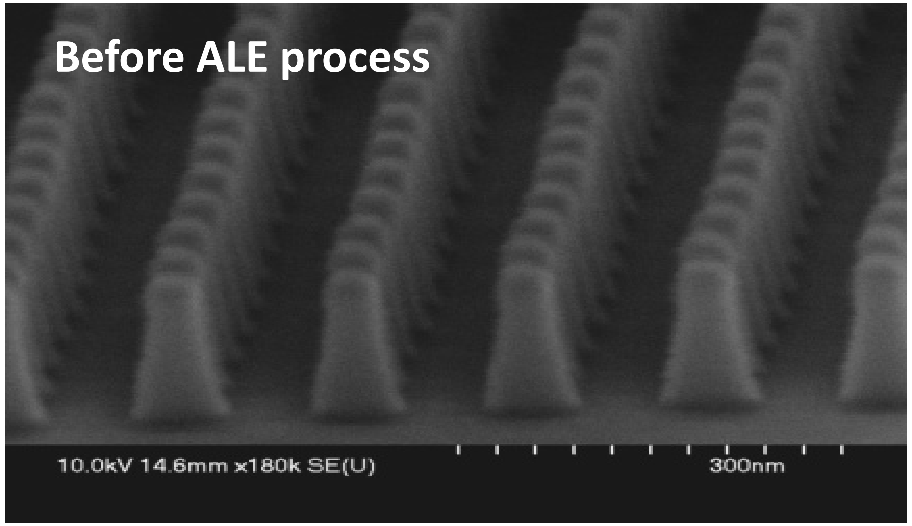
Uthayasankaran Peralagu[1], Xu Li[1], Olesya Ignatova[1], Matthew Steer[1], Ian Povey[2], Paul Hurley[2] and Iain Thayne[1]

[1]*School of Engineering, University of Glasgow, Glasgow, G12 8LT, United Kingdom*
[2]*Tyndall National Institute, University College Cork, Lee Maltings, Prospect Row, Cork, Ireland*

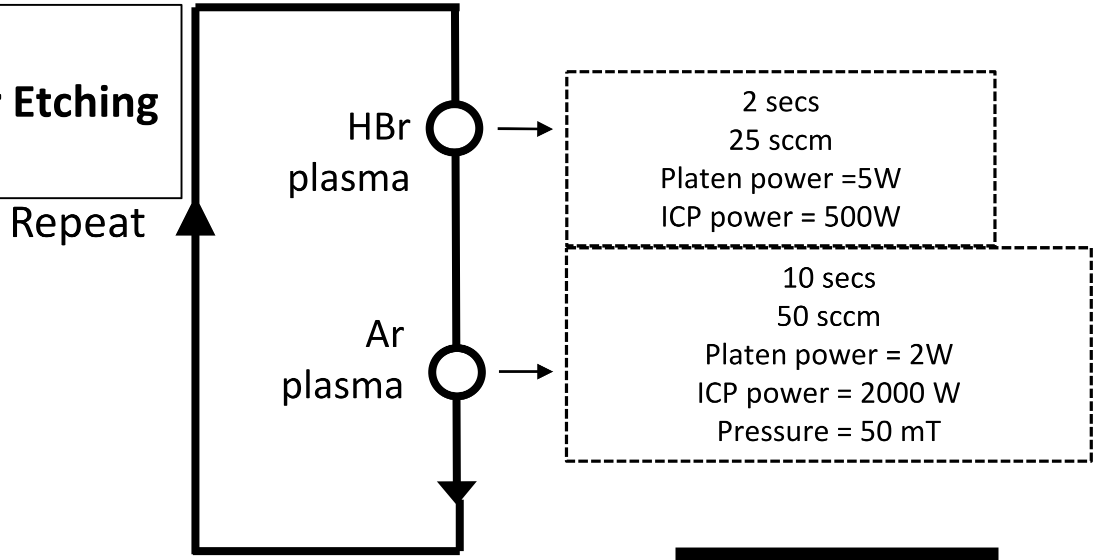


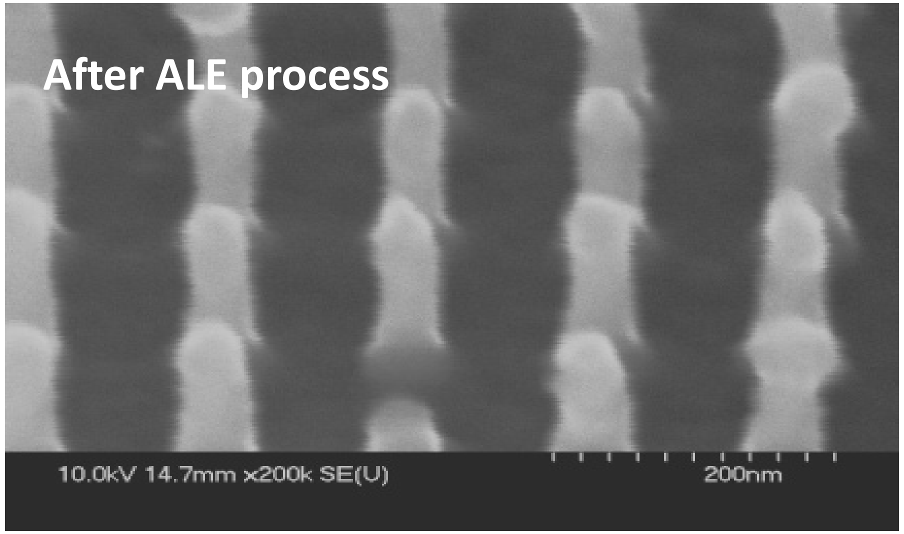
ST1.1.3 – Vertically etched nanowires - ALE





HBr/Ar
Atomic layer Etching details





Lateral ALE of InGaAs - I

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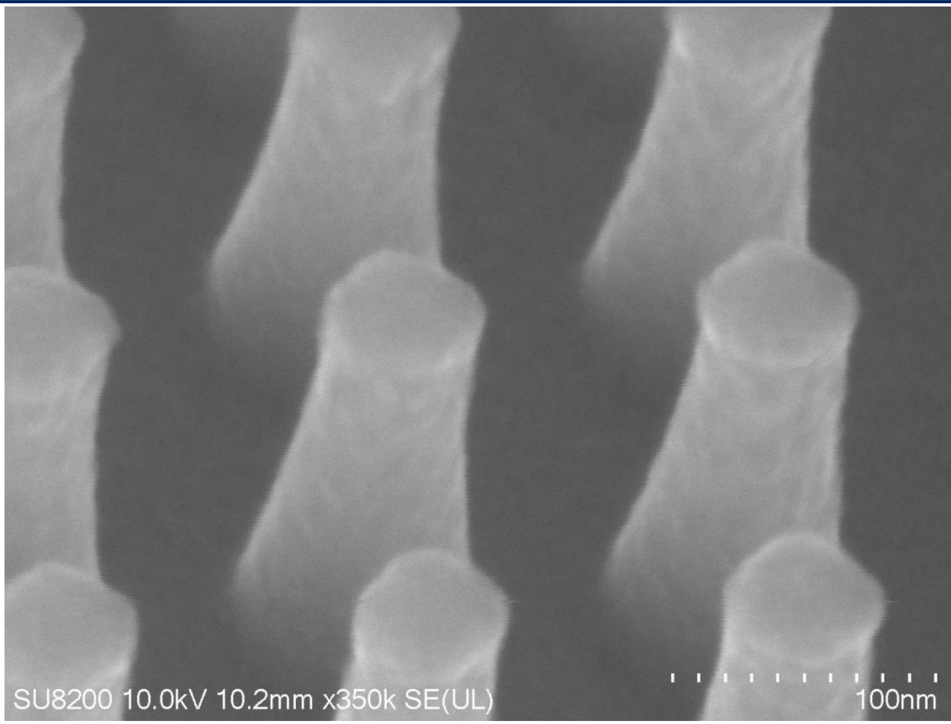
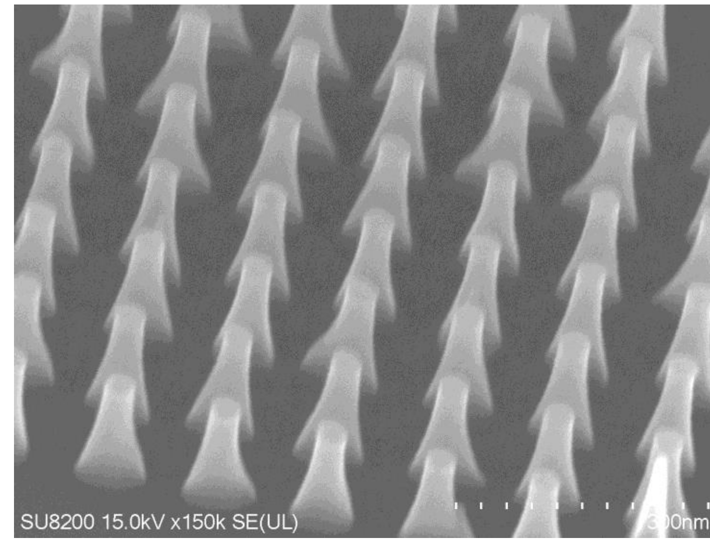


Iga160823b: HBr-Ar ALE for lateral etch at **20°C**
the original wire as shown in right hand side
Surface midification step:
HBr/Ar=25sccm/25sccm-ICP/Platen=500w/5w/4s/bias ~0v
Modified layer removal step:
Ar=50sccm-ICP/Platen=2000w/5w/10s/bias 55v
30cycles



Iga160819a:
wire etched in $Cl_2/CH_4/H_2/O_2$ chemistry with ICP etcher at 120°C for 1m55s

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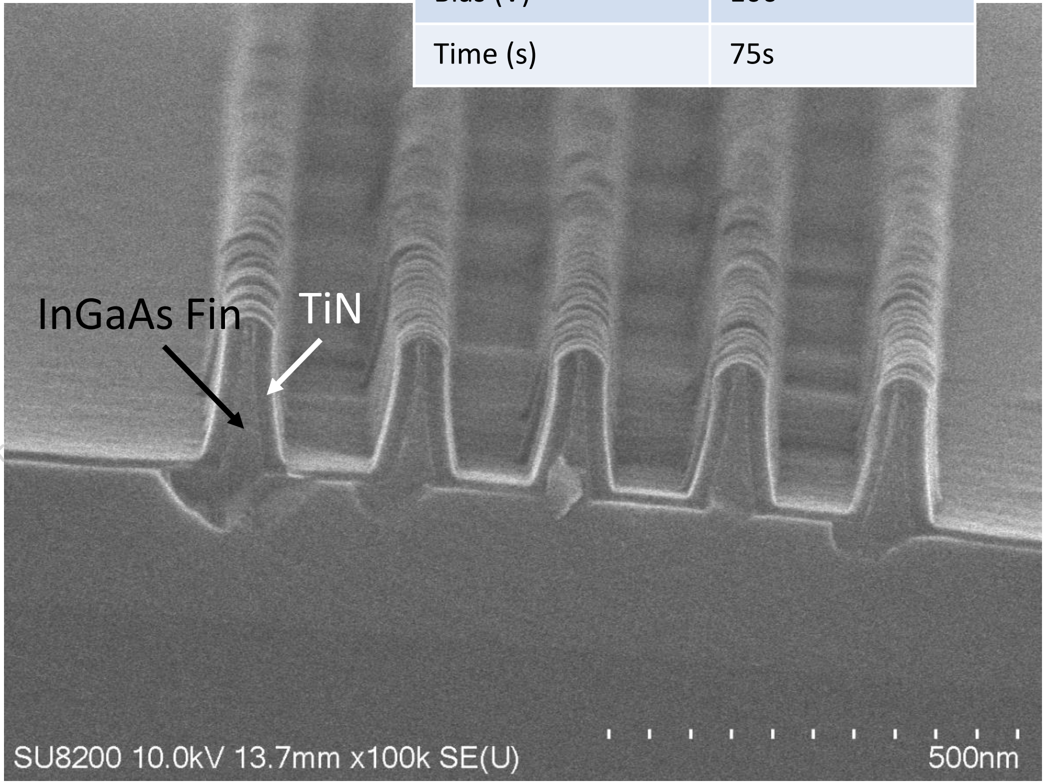
Process Module Development – Recent Progress (**New Data**)

- Alignment Markers
- HSQ patterning
- Nanowire Etch
- ALD High-k gate dielectric deposition
- ALD TiN gate metal deposition
- Anisotropic gate etch for sidewall metal only
- ALD dielectric deposition
- BCB spacer patterning
- BCB spacer etch back
- Isotropic etch of dielectric to expose TiN gate
- Patterning and etch back of BCB spacer, high-k
- Mesa isolation
- Substrate contact patterning
- SU8 spacer patterning
- Gate metal bondpad patterning

Chemistry	SF_6/N_2
Flow rates (sccm)	25/25
Power (W)	25
Pressure (mT)	10
Bias (V)	100
Time (s)	75s



Process Module Development – Recent Progress (**New Data**)

- Alignment Markers
- HSQ patterning
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- ALD High-k gate dielectric deposition
- ALD TiN gate metal deposition
- Anisotropic gate etch for sidewall metal only
- ALD dielectric deposition

Chemistry	SF_6/N_2
Flow rates (sccm)	25/25
Power (W)	100
Pressure (mT)	10
Bias (V)	300
Time (s)	40s