Energy Harvesting & Energy Efficient Micro / Nanoelectronics @ Glasgow

Prof Douglas J. Paul

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School of Engineering, University of Glasgow

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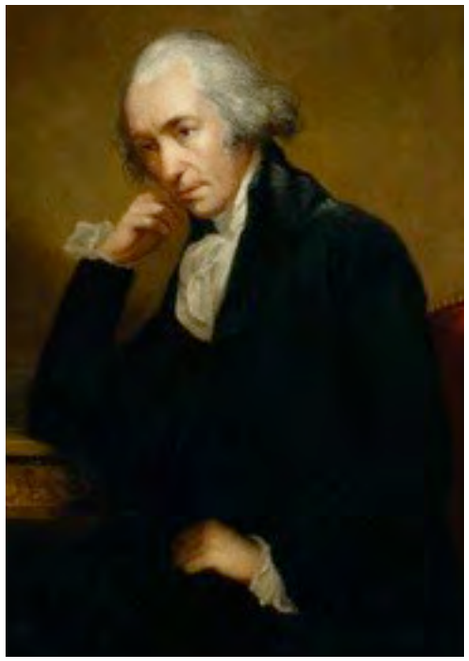
The University of Glasgow

- Established in 1451
- 7 Nobel Laureates
- 16,500 undergraduates, 5,000 graduates and 5,000 adult students
- £186M research income pa

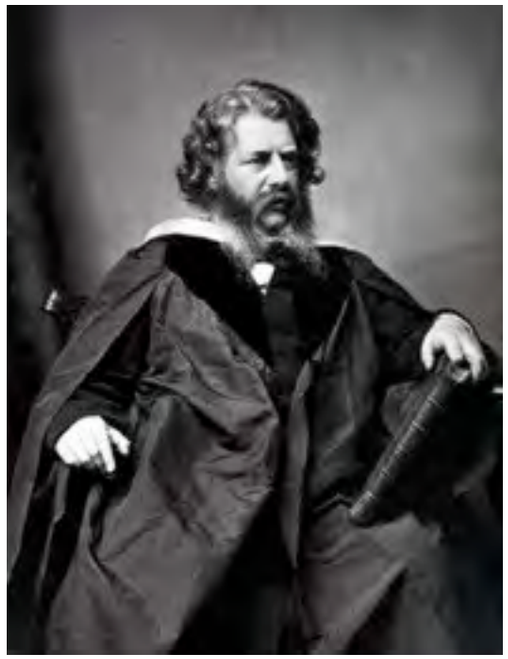
- 400 years in High Street
- Moved to Gilmorehill in 1870
- Neo-gothic buildings by Gilbert Scott

Famous Glasgow Scholars

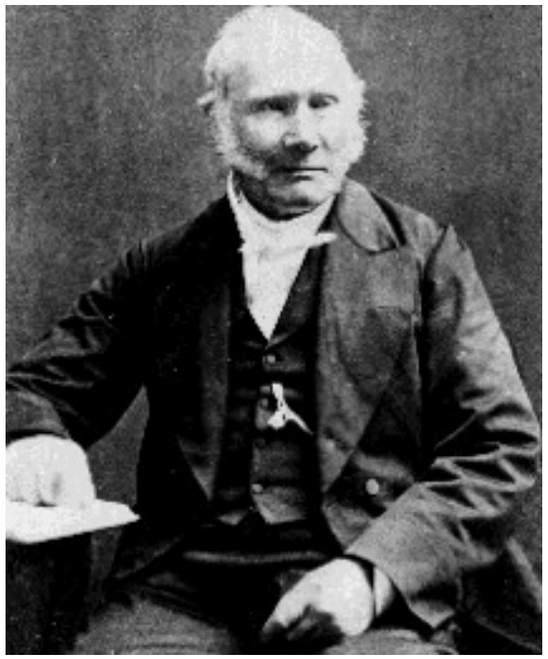
William Thomson
(Lord Kelvin)



James Watt



William John
Macquorn Rankine



Rev Robert Stirling

Rev John Kerr

Joseph Black

John Logie Baird

Adam Smith

University of Glasgow

James Watt Nanofabrication Centre @Glasgow

Vistec VB6

E-beam lithography

Süss MA6 optical lith

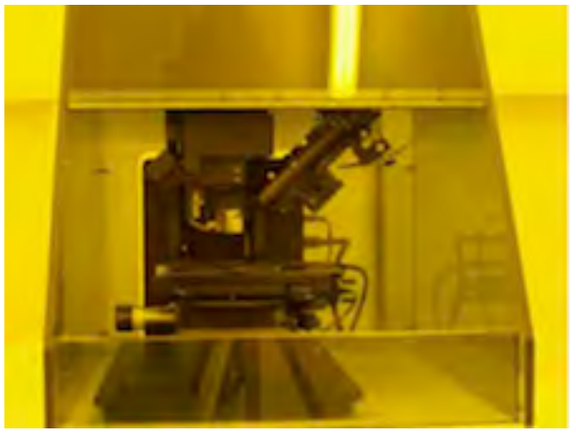
- 750m² (+150 m²) cleanroom - pseudo-industrial operation
- 15 technicians + 4 PhD research technologists
- Processes include: MMICs, III-V, Si/SiGe/Ge, integrated photonics, metamaterials, MEMS (microfluidics)
- Part of EPSRC III-V National Facility & STFC Kelvin-Rutherford Facility
- Commercial access through Kelvin NanoTechnology
- http://www.jwnc.gla.ac.uk/

14 RIE / PECVD / ALD

6 Metal dep tools

4 SEMs: Hitachi S4700

Veeco: AFMs



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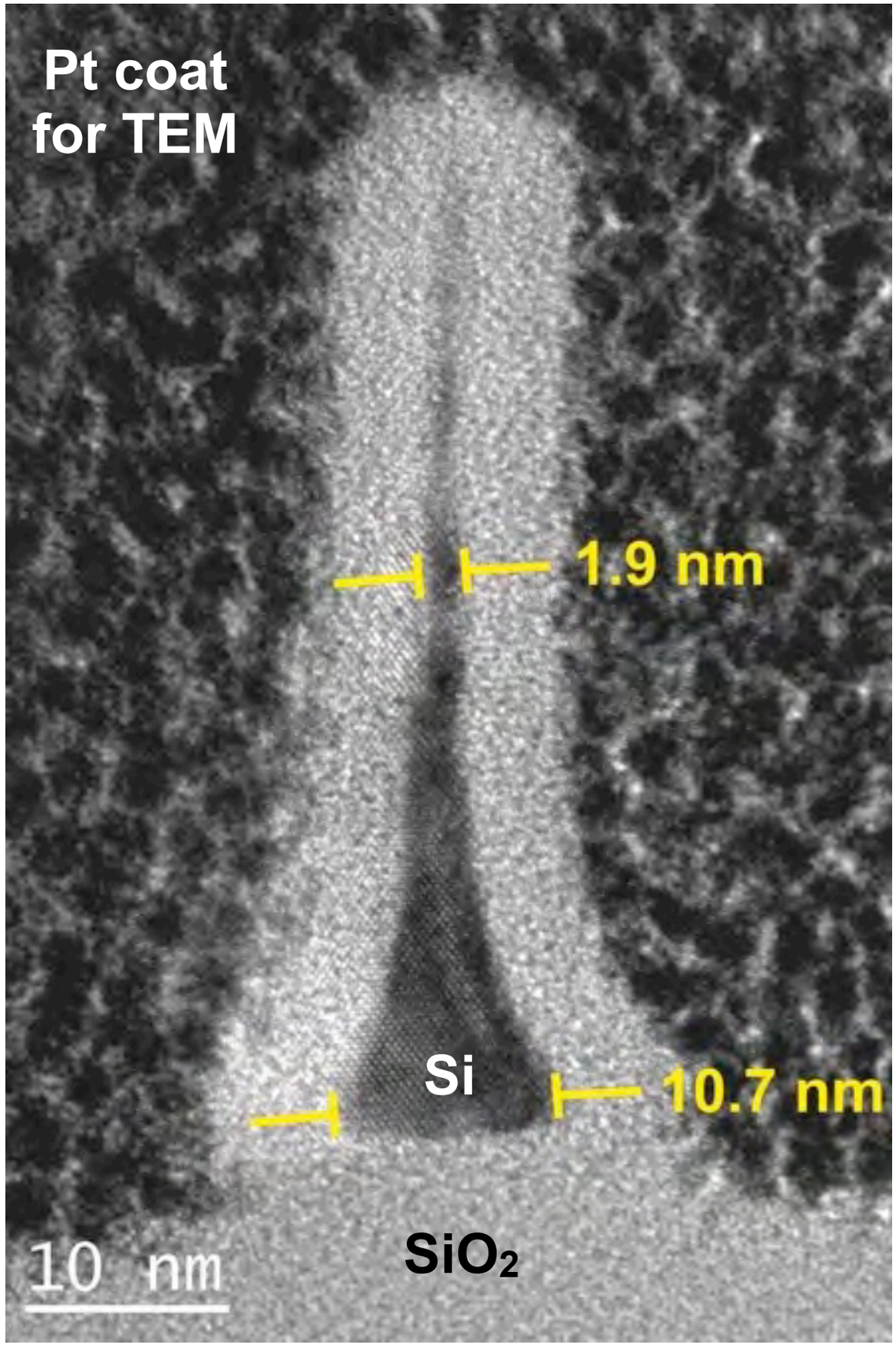
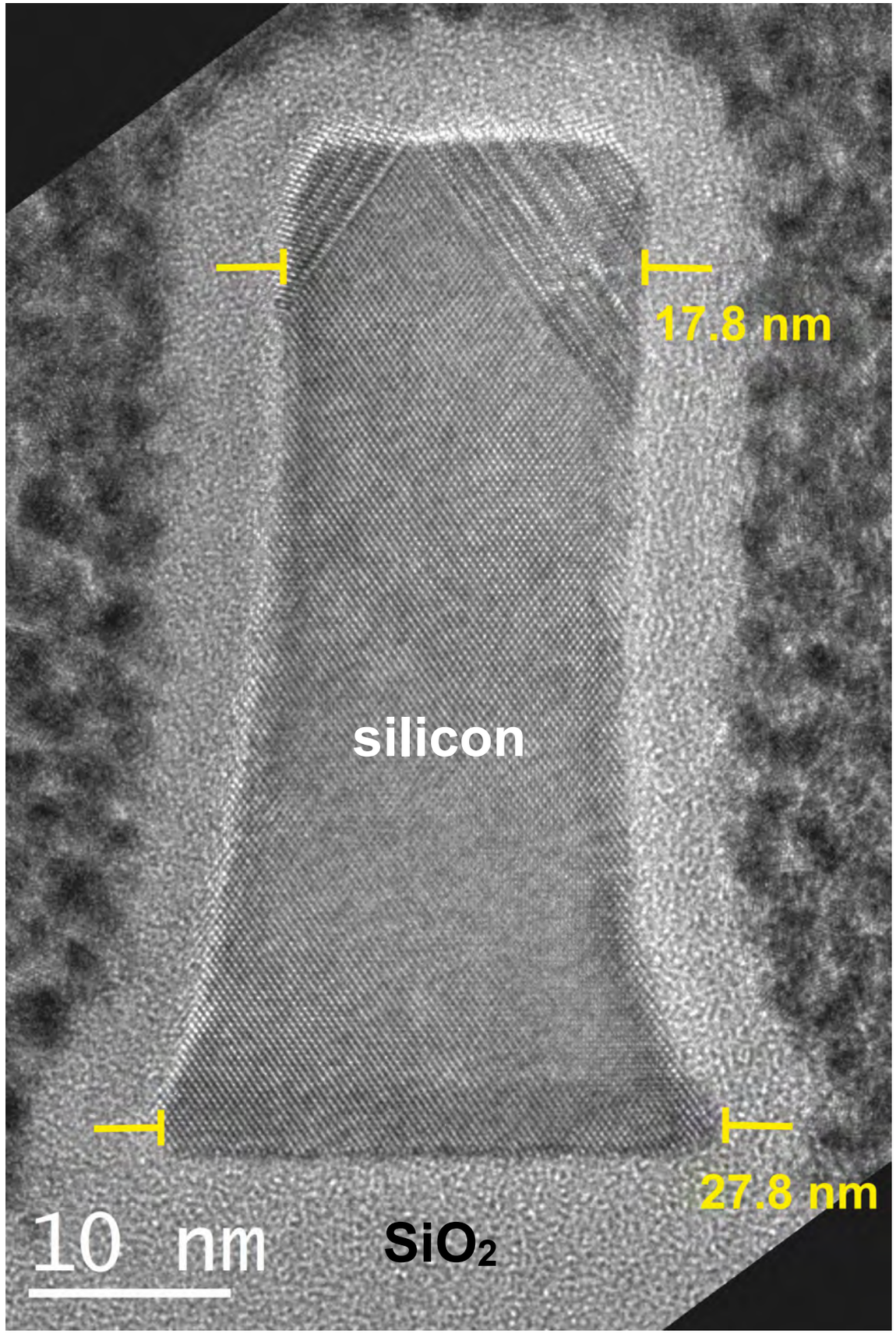
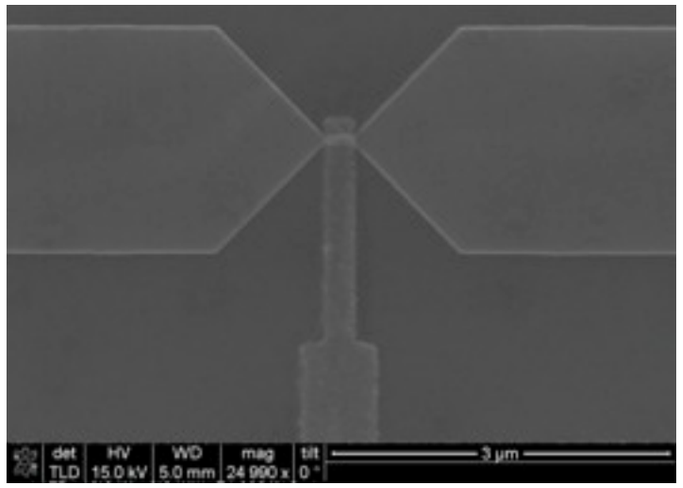
Si Nanowires: How many atoms wide?

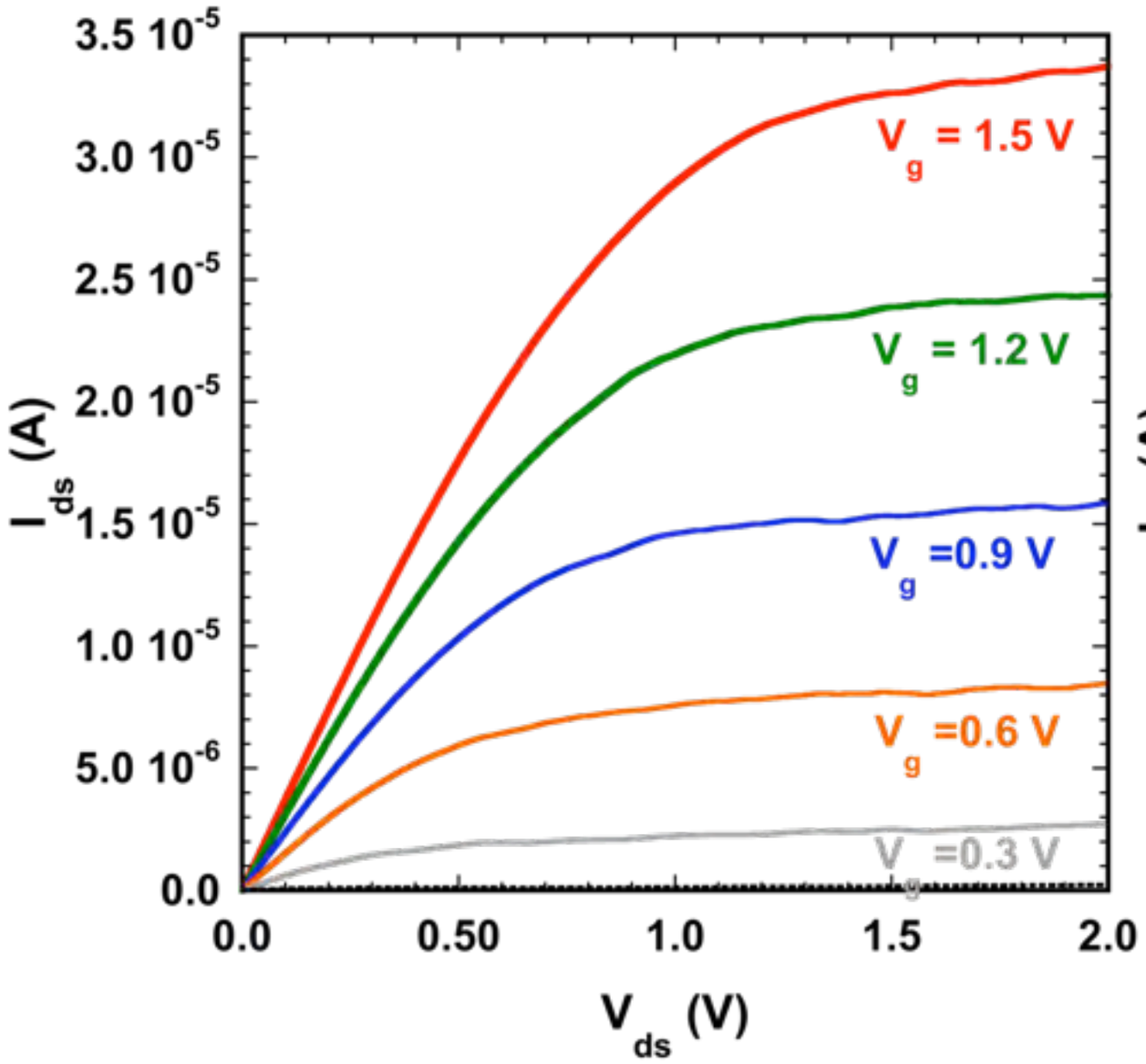


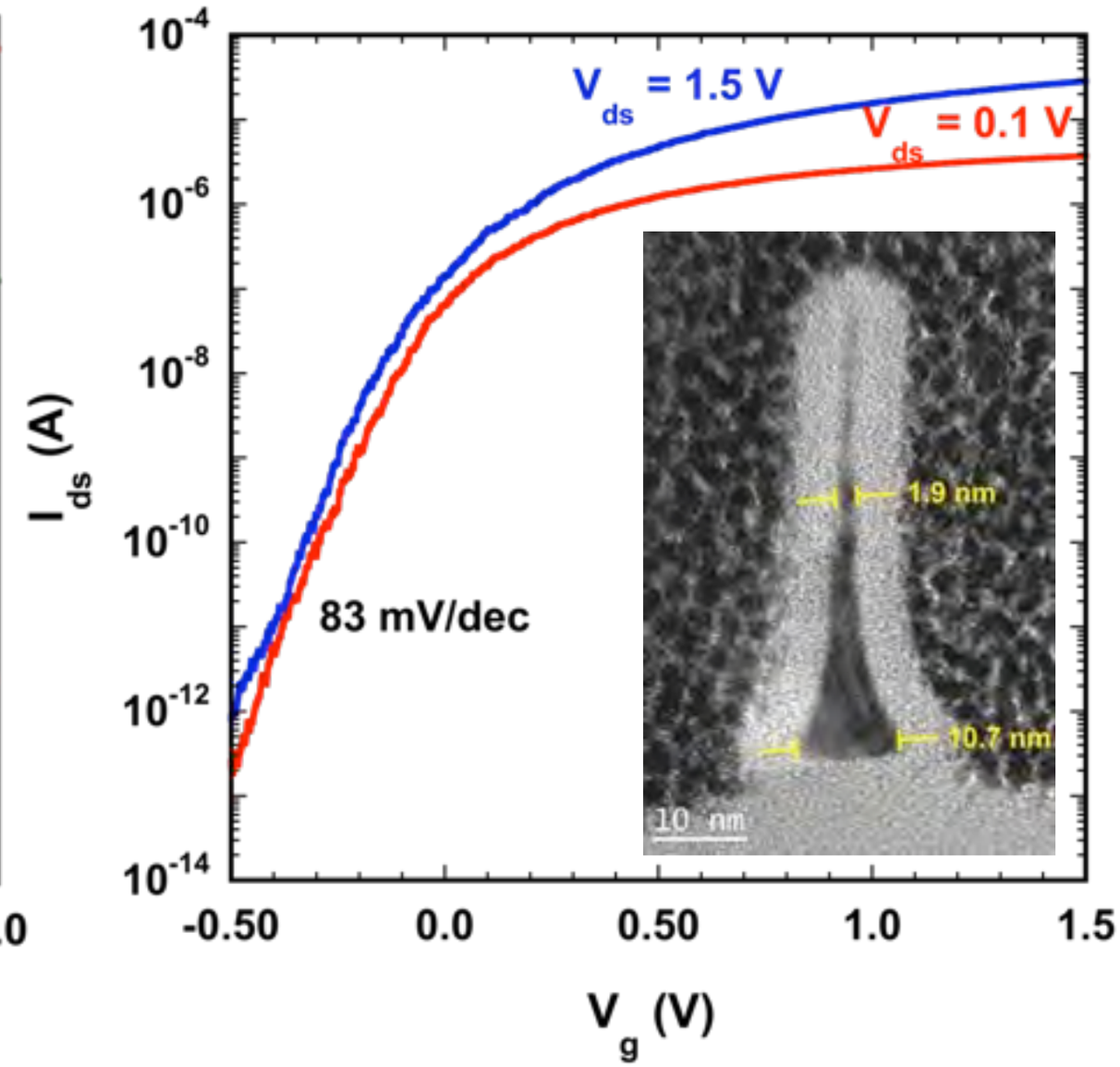


10 nm Width Si Nanowire FET

200 nm gate length
10 nm wide, 50 nm tall nanowire







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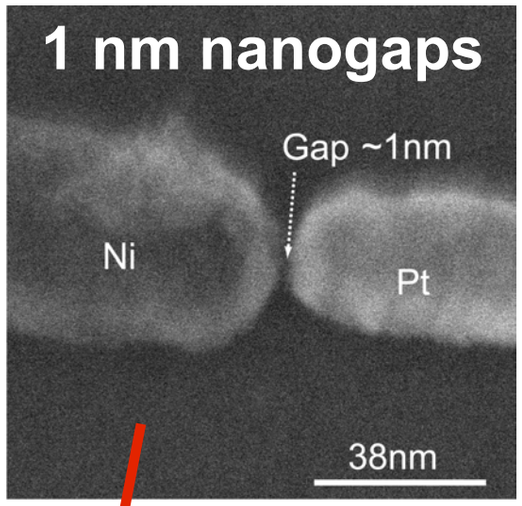
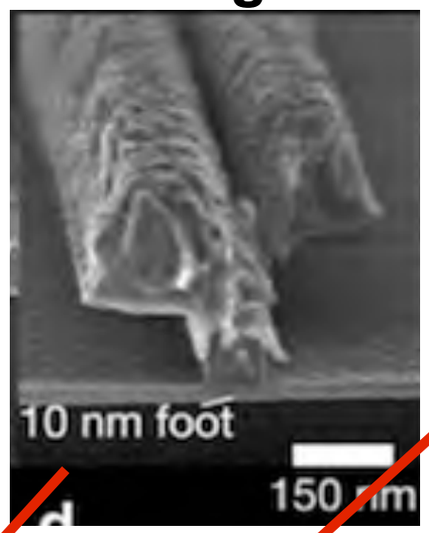
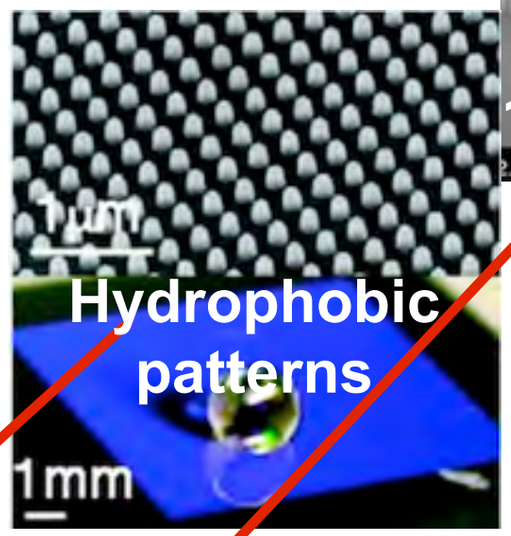
Micro and Nanotechnology from Glasgow



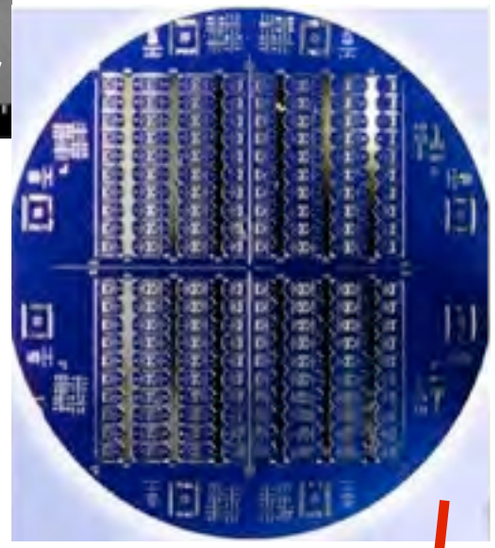
Nanoelectronics: 10 nm T-gate HEMT





Healthcare: STEM cell interrogation

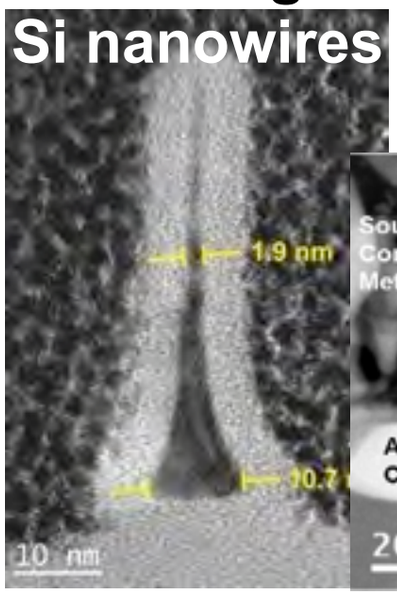
Manufacture: AFM probes



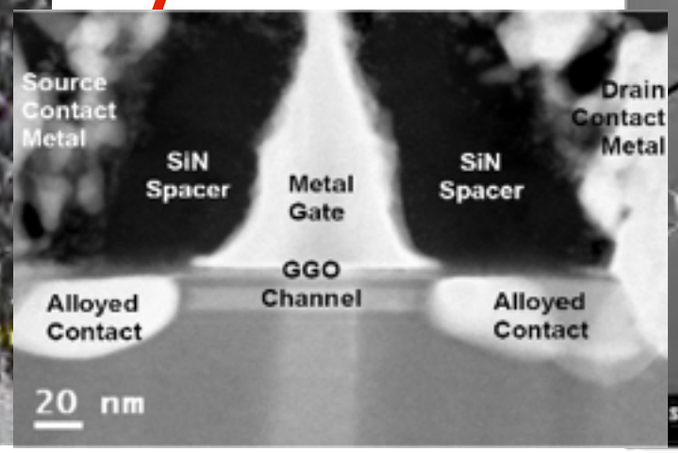
metres

10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1}

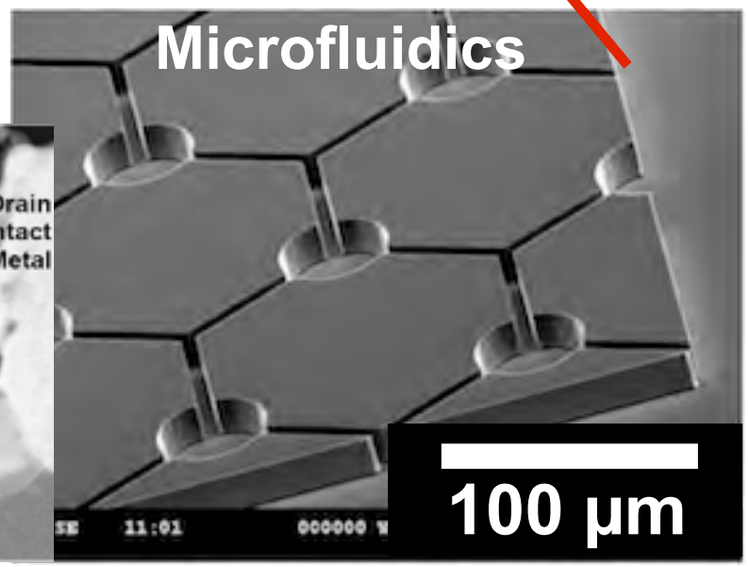
Sensing: Si nanowires



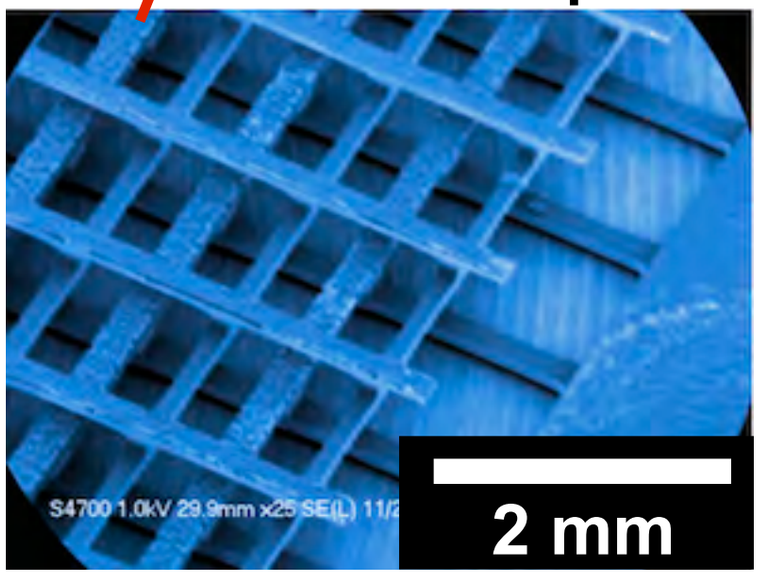
III-V CMOS



Environment: Microfluidics



MEMS: THz optics



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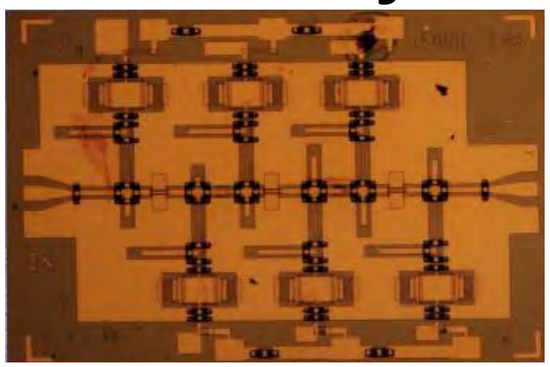
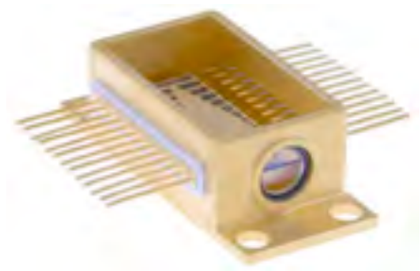
Applications for Micro & NanoTechnology

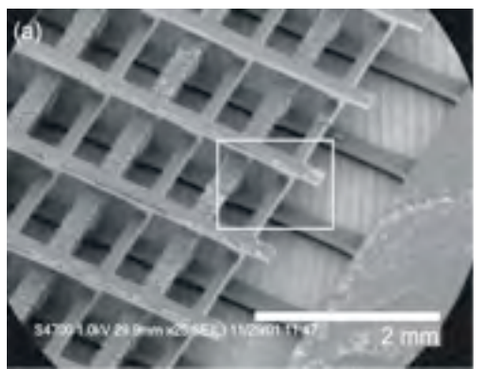
Defence & Security



MMICs: 183 GHz LNA

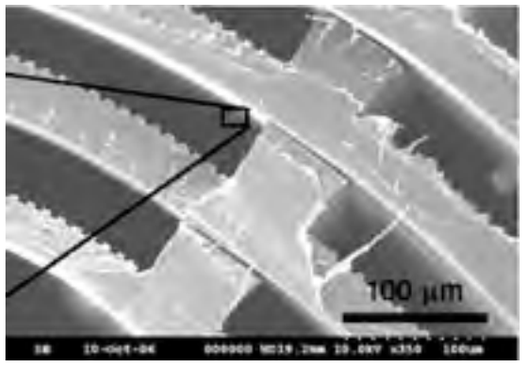


MIR QC laser counter measures

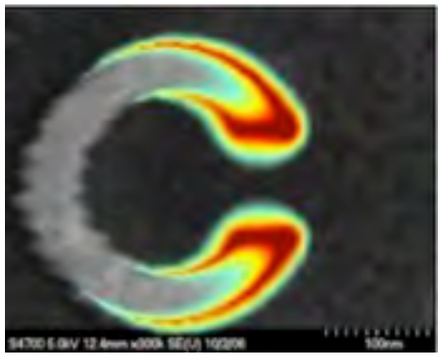


THz / mm-wave optics

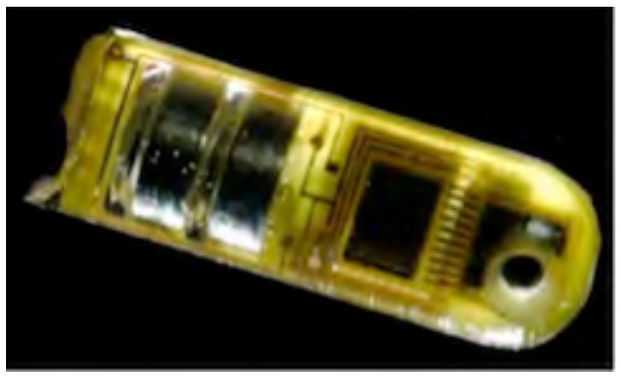
Healthcare



Medical scaffolds



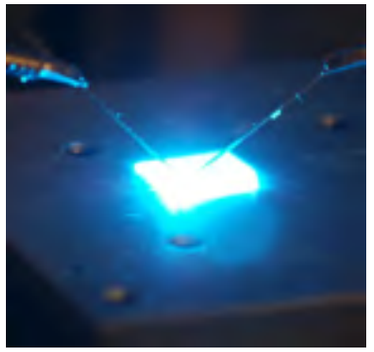
Plasmon sensors for cancer detection



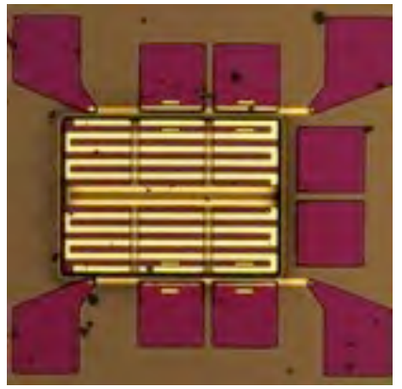
Lab-on-a-pill

Energy

PV cells

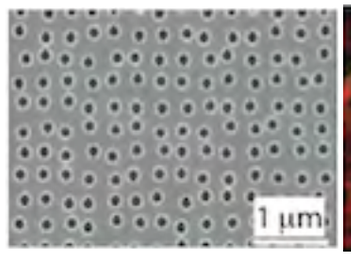


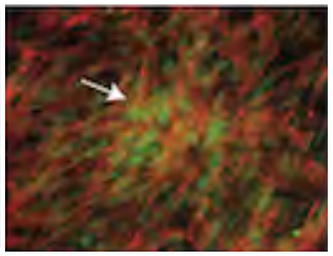
GaN white light LEDs



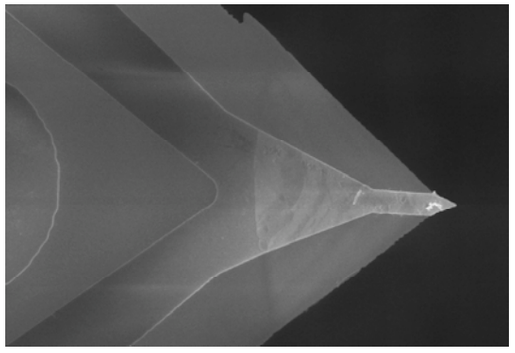
Thermoelectric energy harvesting

Micro & Nanoscience

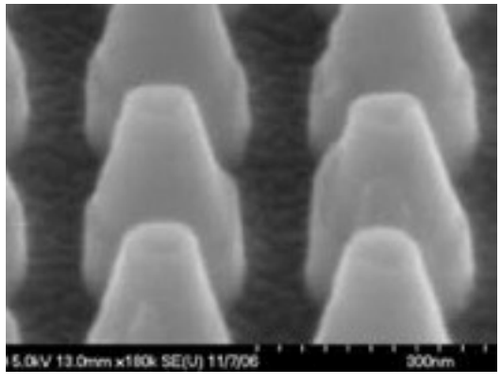




Directed STEM cell growth



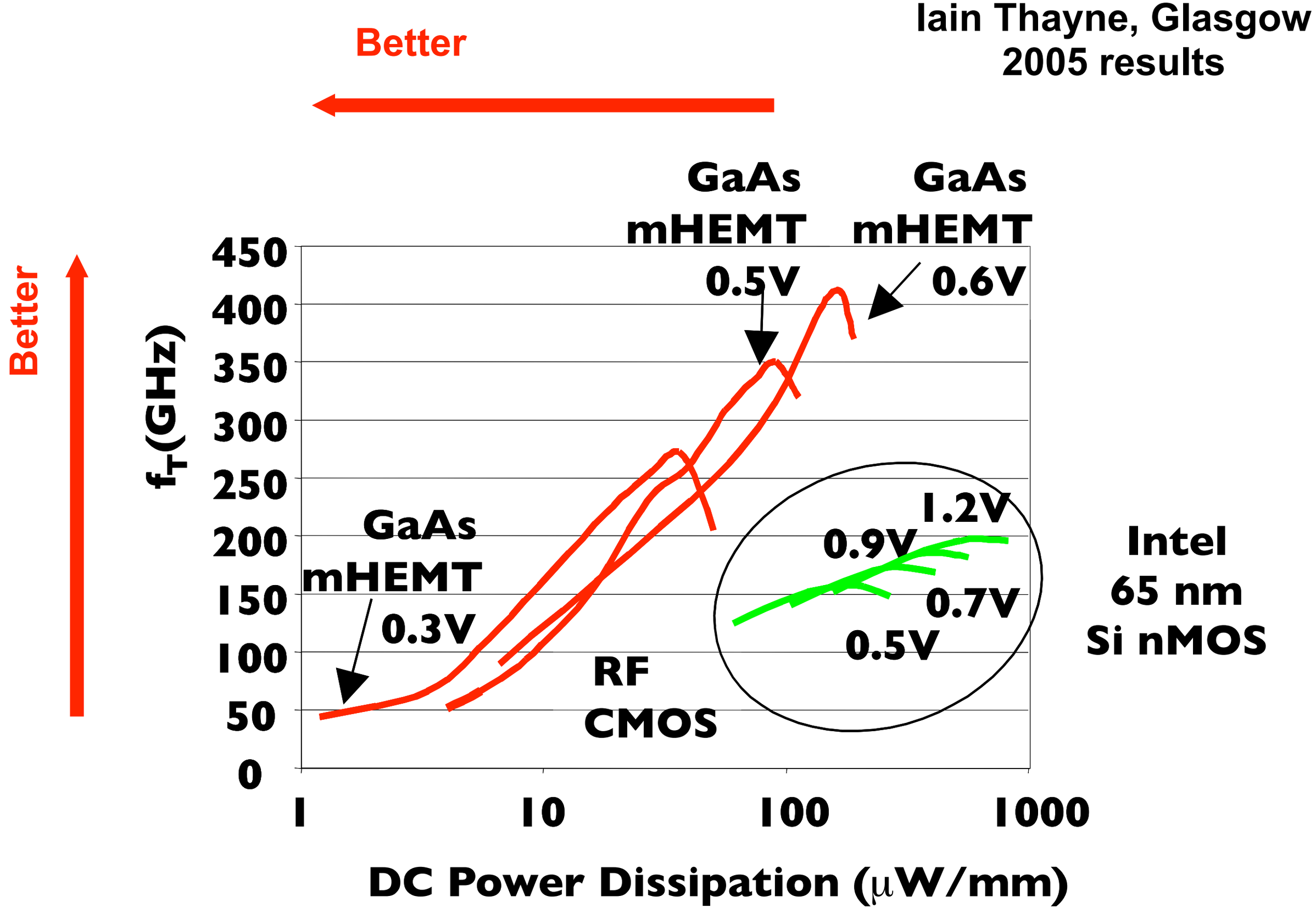
Electrochemical AFM



Magnetic rock sensors

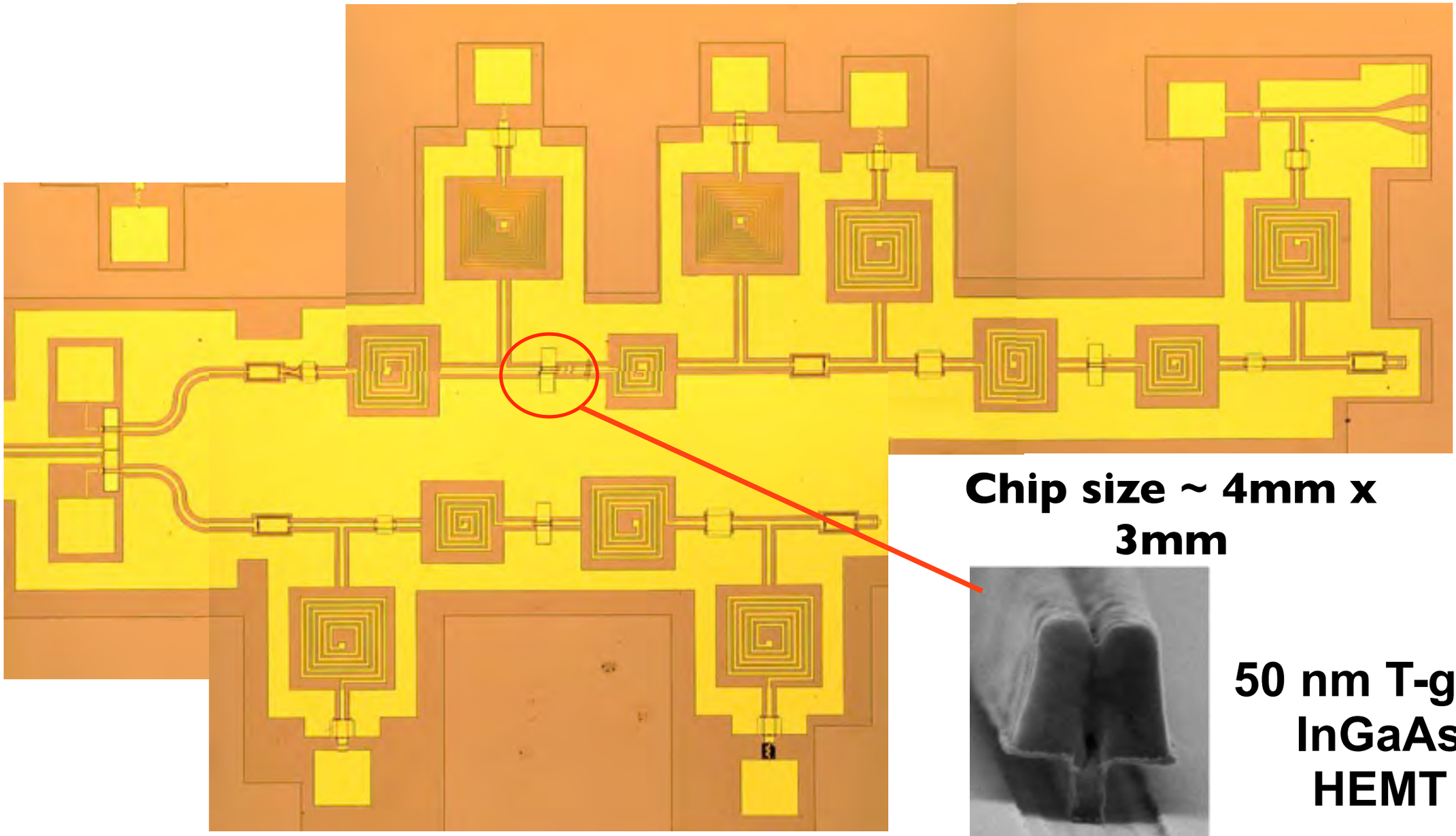
High mobility => improved efficiency

Iain Thayne, Glasgow
2005 results



Fully integrated radio

~ 200 process steps to produce…..



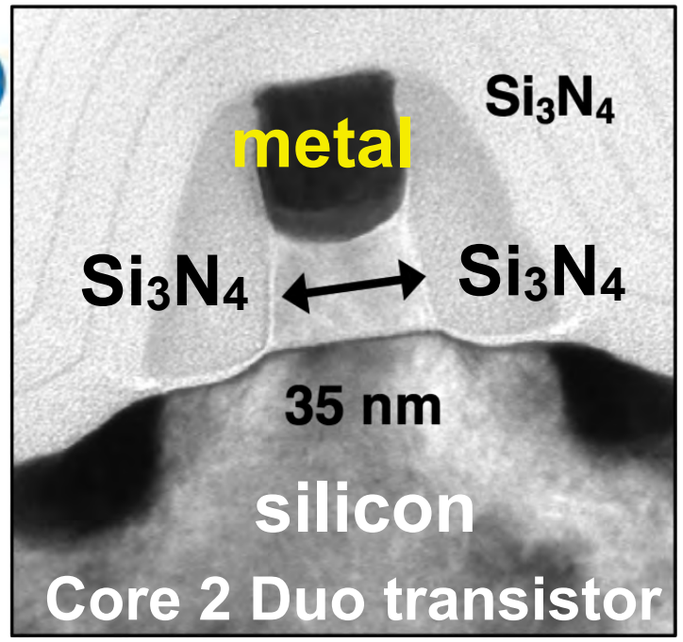
Chip size ~ 4mm x 3mm

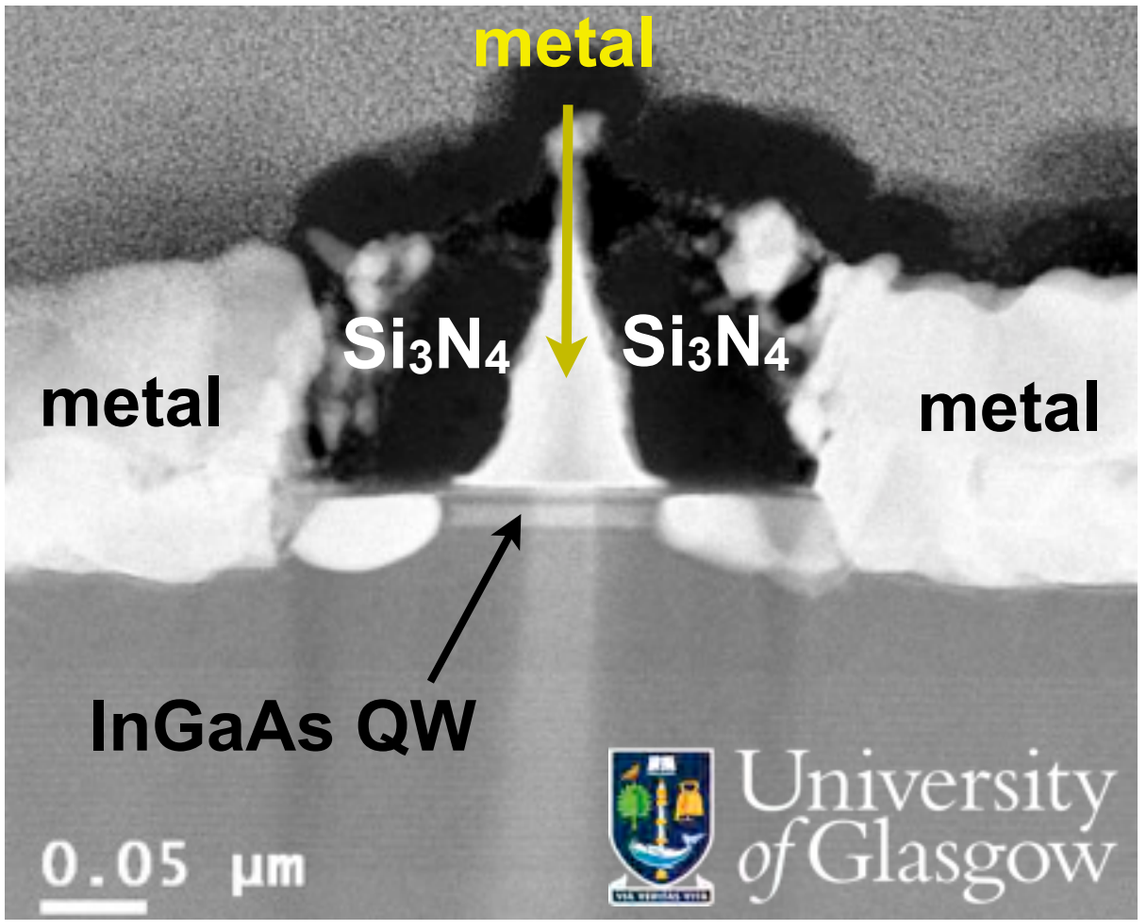
50 nm T-gate InGaAs HEMT

- **0.5 mW radio at 6 GHz transmission**

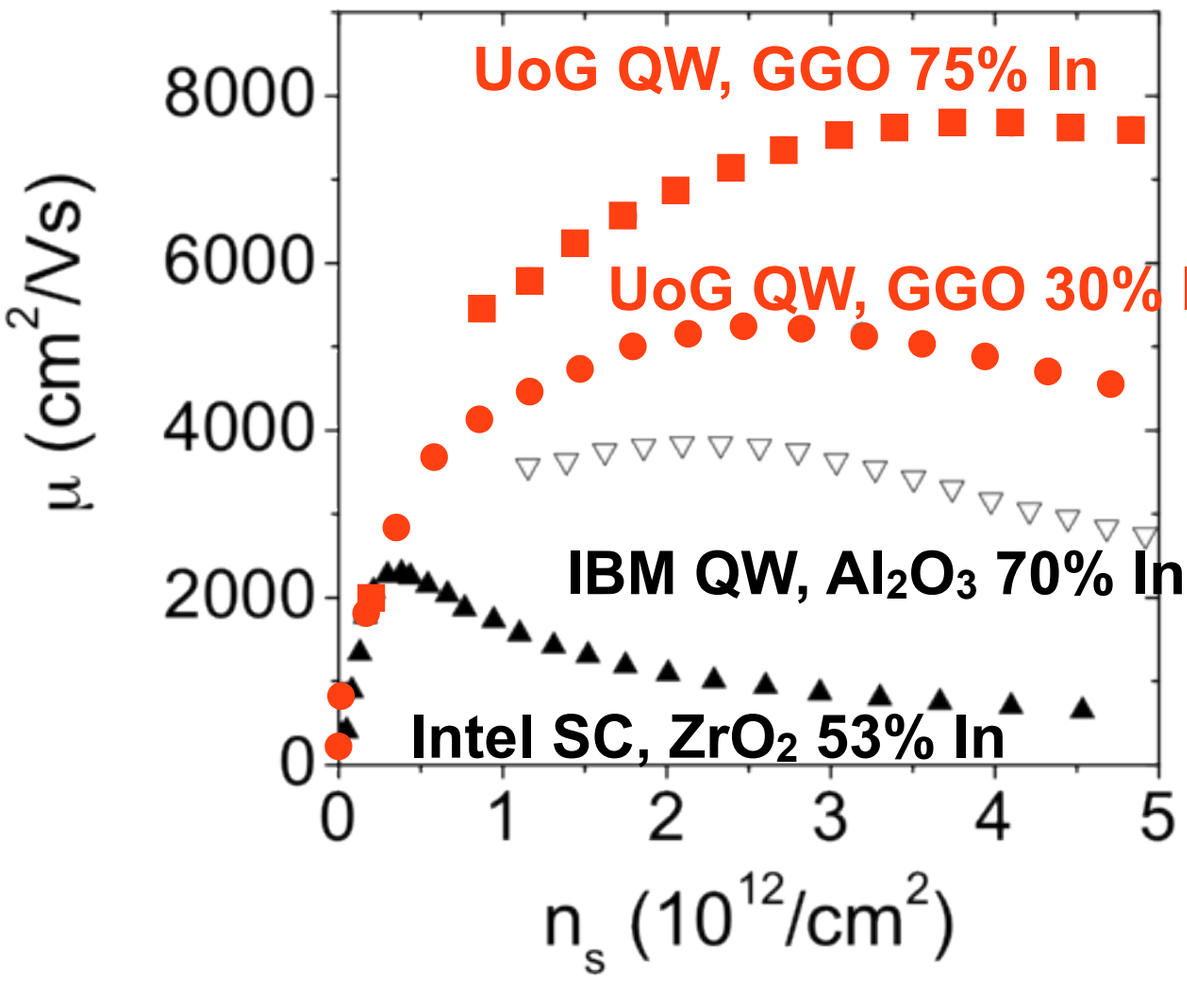
Iain Thayne, Glasgow 2005

Compound Semiconductor MOSFET Mobility



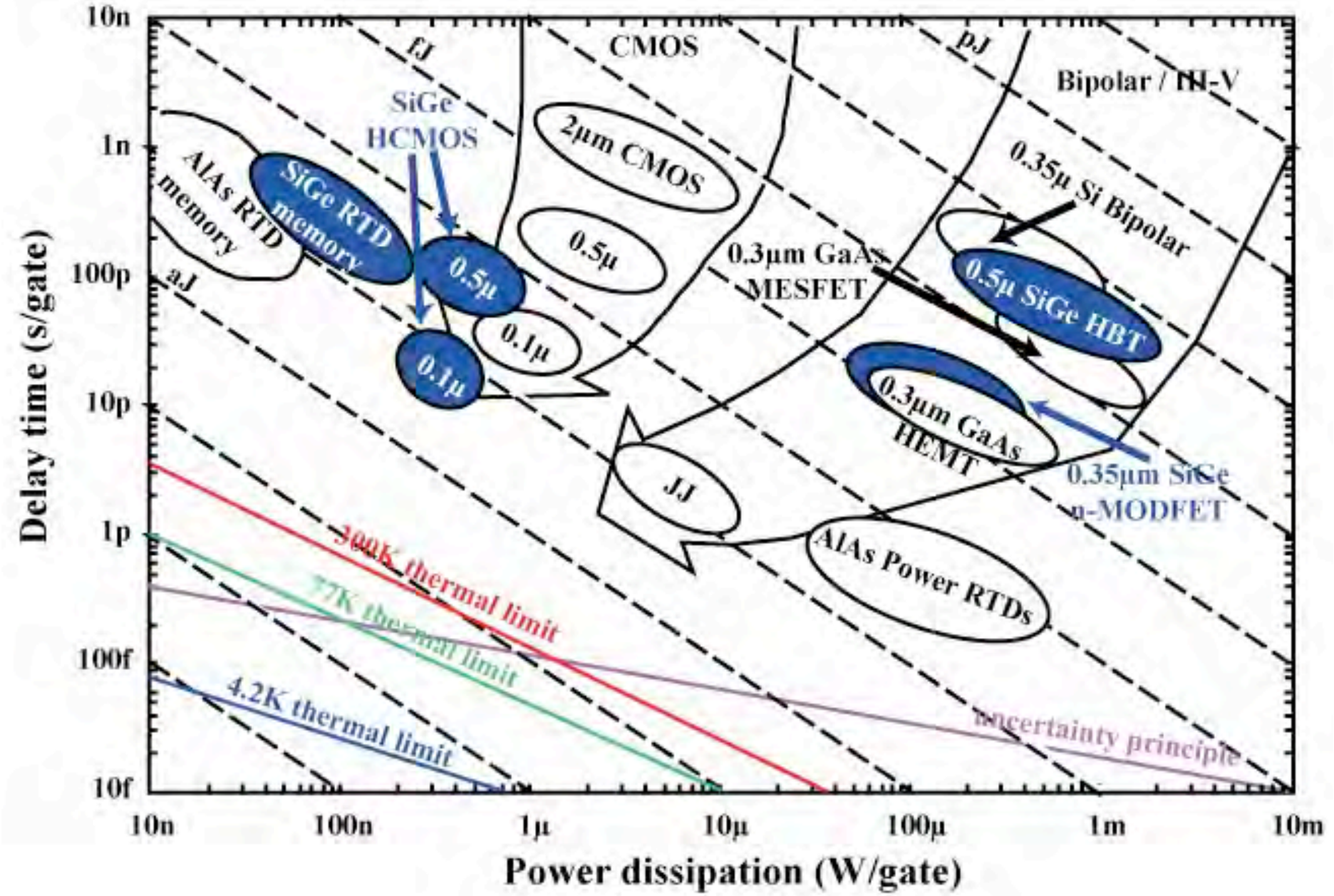


University of Glasgow results compared



- **10-20x mobility improvement over silicon**

Technology Roadmaps



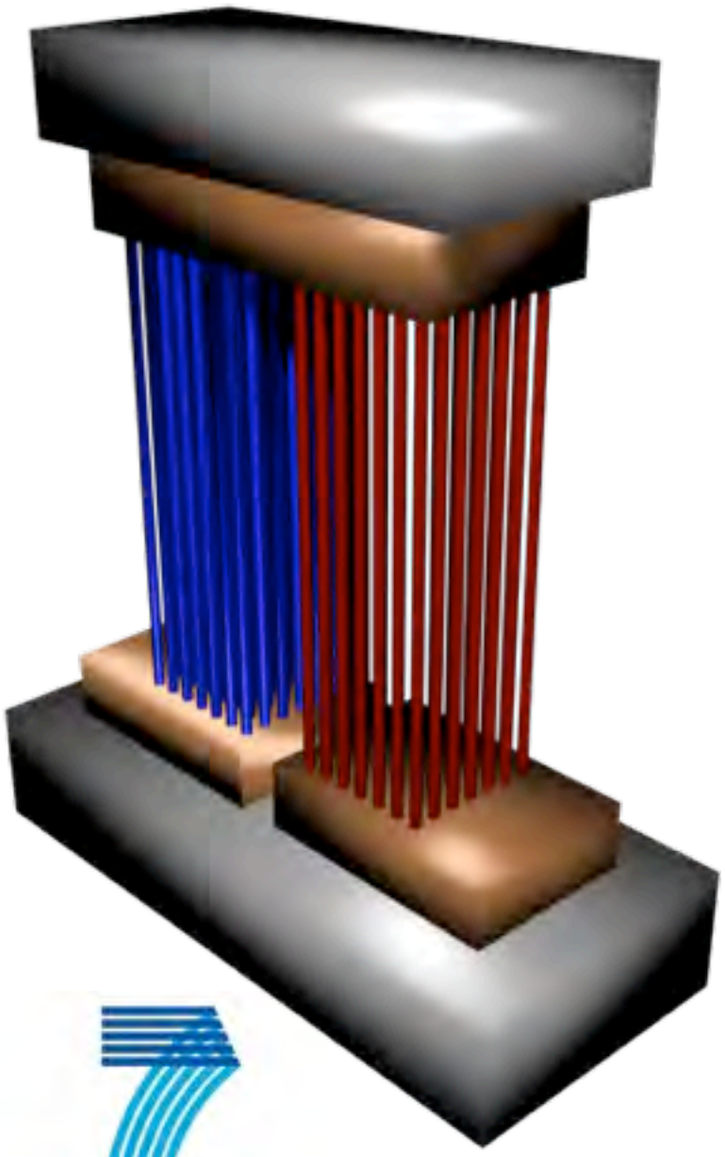
D.J. Paul, Advanced Materials 11, 191 (1998)

Co-editor, Technology Roadmap for European Nanoelectronics, 1999 & 2000

University of Glasgow

SiGe Microfabricated Thermoelectric Generators

Generate Renewable Energy Efficiently using Nanofabricated Silicon (GREEN Silicon)



D.J. Paul, A. Samarelli, L. Ferre Ilin, J. Watling, Y. Zhang, J.M.R. Weaver, P. Dobson & D. MacLaren

University of Glasgow, U.K.

S. Cecchi, J. Frigerio, F. Isa, G. Isella, D. Chrastina

L-NESS, Politecnico de Milano, Como, Italy

T. Etzelstorfer & J. Stangl

University of Linz, Austria

E. Müller Gubler

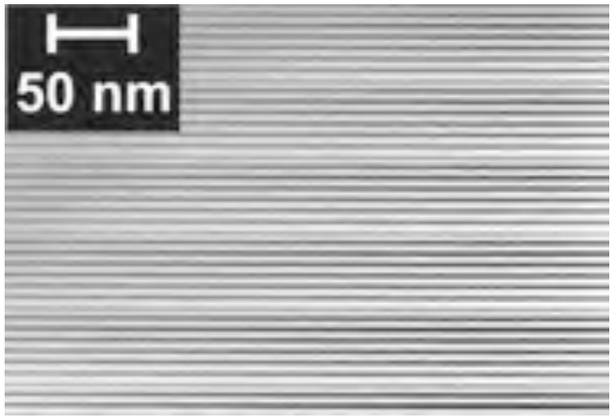
ETH Zürich, Switzerland

SEVENTH FRAMEWORK PROGRAMME

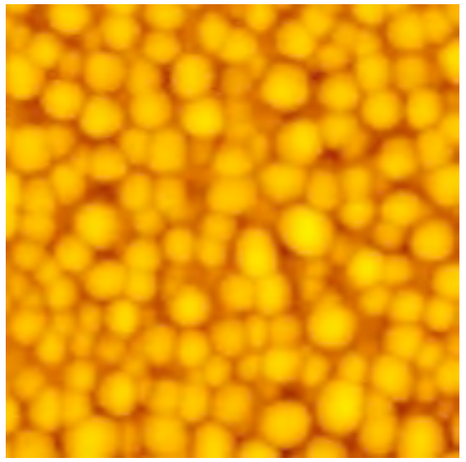
http://www.greensilicon.eu/GREENSilicon/index.html

GREEN Silicon Approach

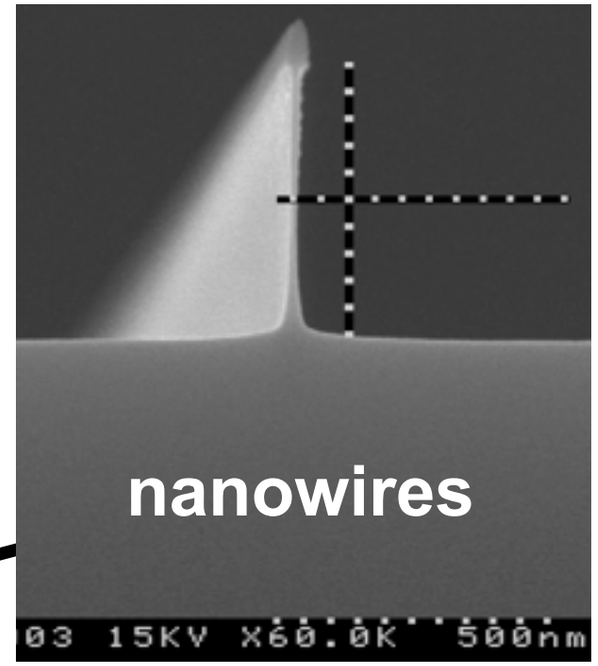
Low dimension technology



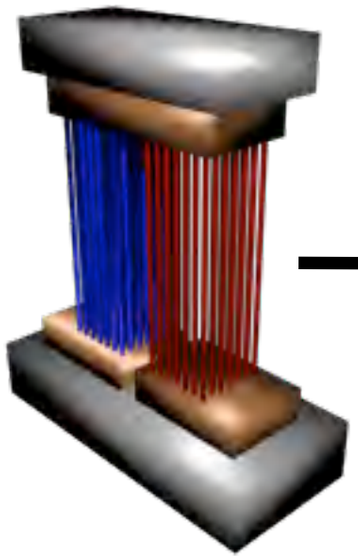
superlattices

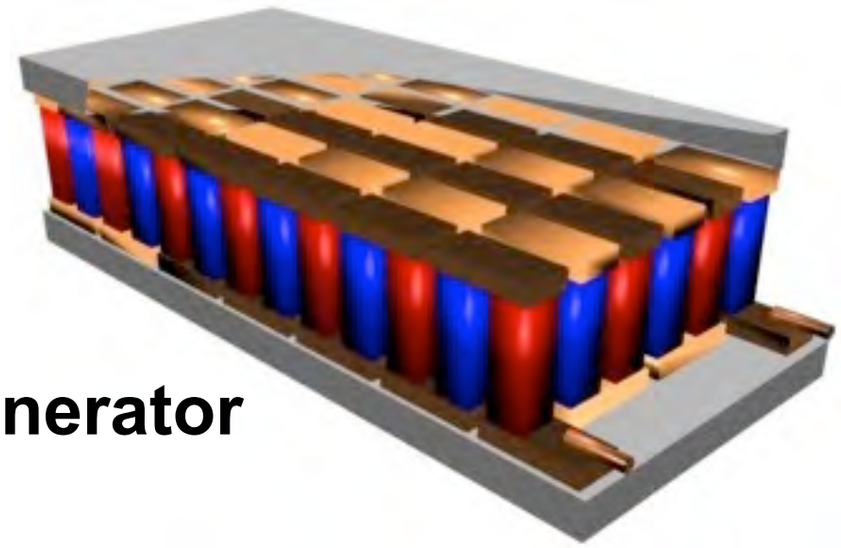


quantum dots



Module



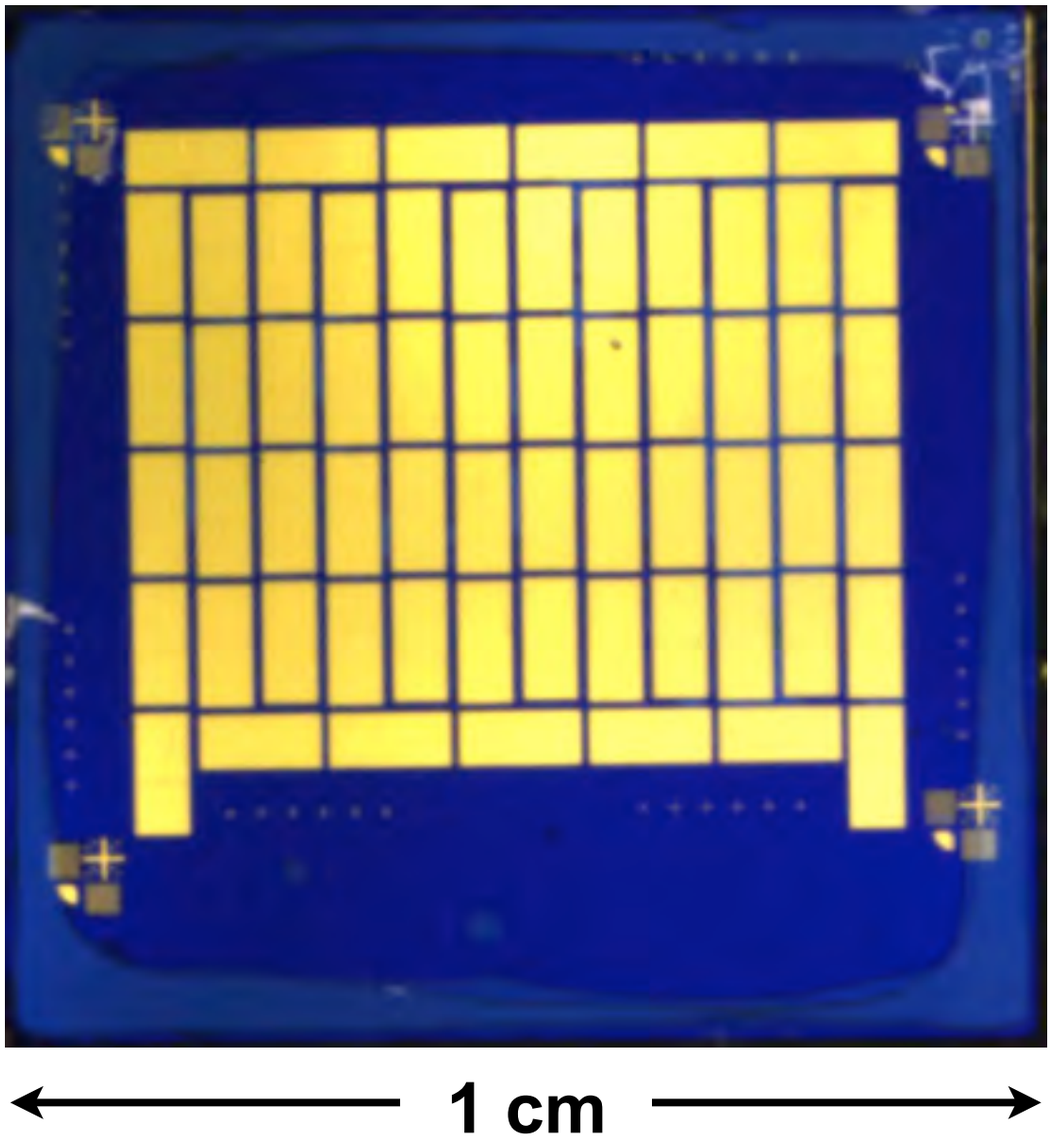


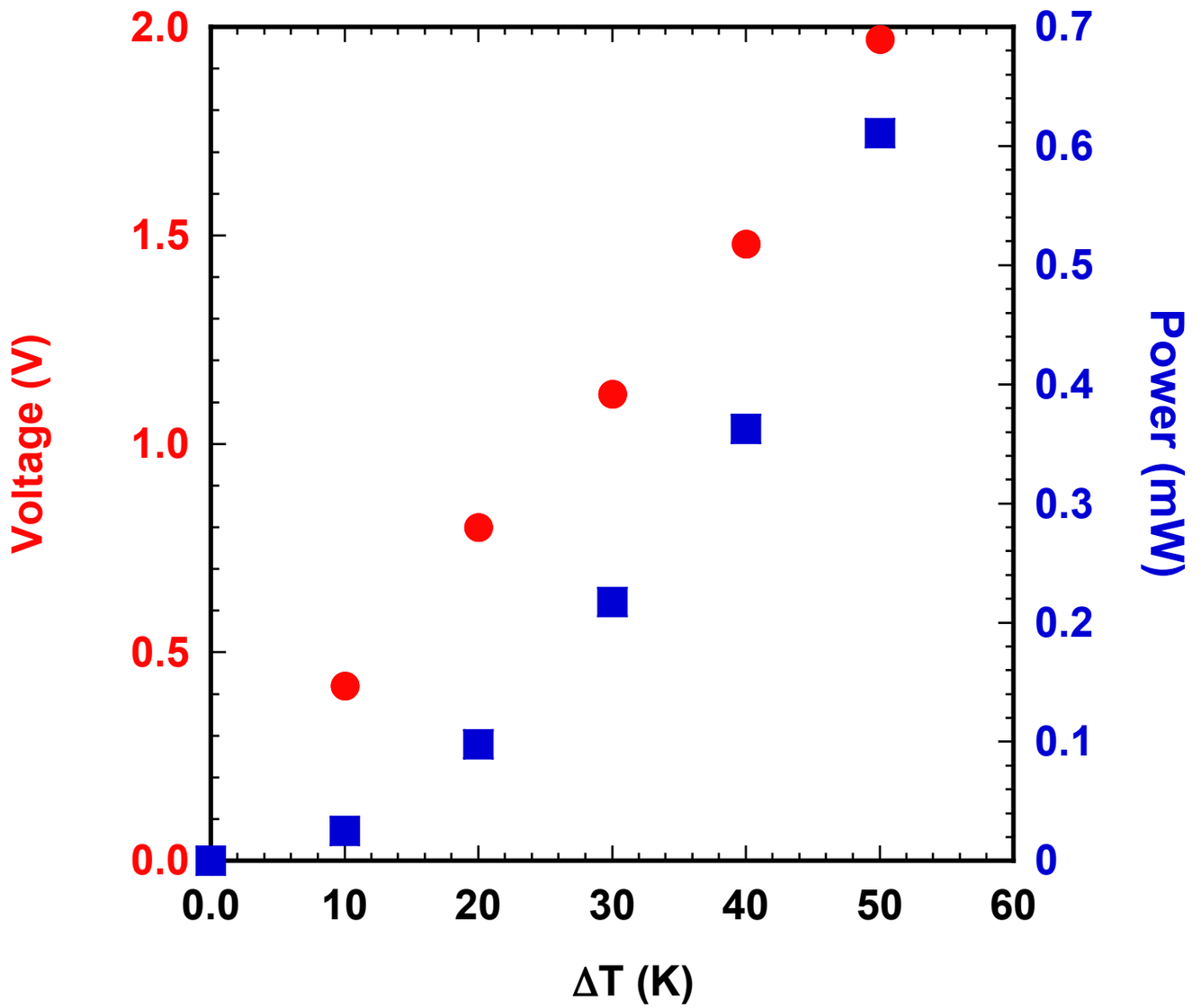
Generator

- **Si/SiGe technology –> cheap and back end of line compatible**

SiGe MEMS Generator: 122 Legs

n-type





- High power factor produces high voltage for small number of legs
- In bump bonding presently limits high temperature operation

Summary

- Commercial & research micro/nanoelectronics experience
- Thermoelectrics energy harvesting
- EC ICT FET MEL-ARI Nanoelectronics Roadmap
- EC Zeropower Strategic Research Agenda
- Looking forward to working with you all in EC ICT-Energy

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http://userweb.eng.gla.ac.uk/douglas.paul/index.html