



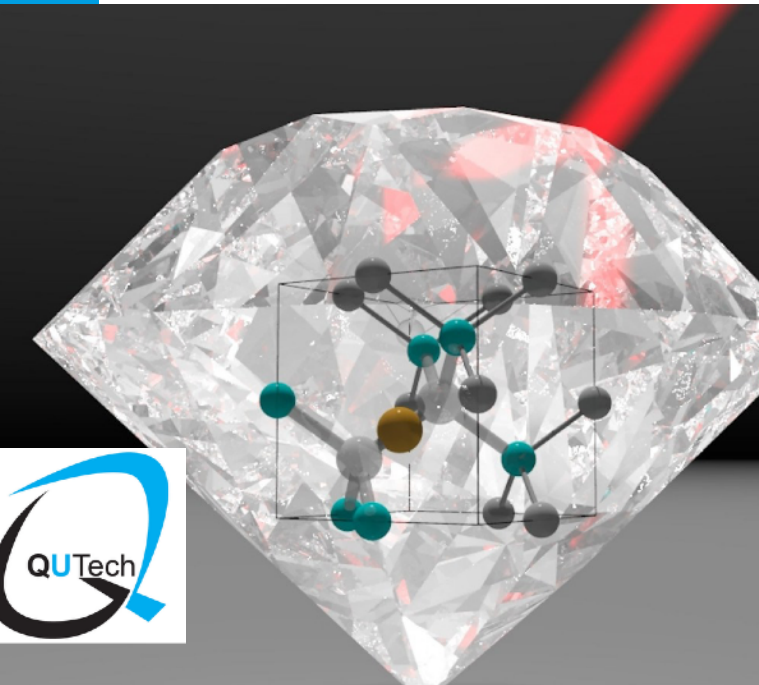
Quantum Integration Technology

Introduction of research topics

Ryoichi Ishihara

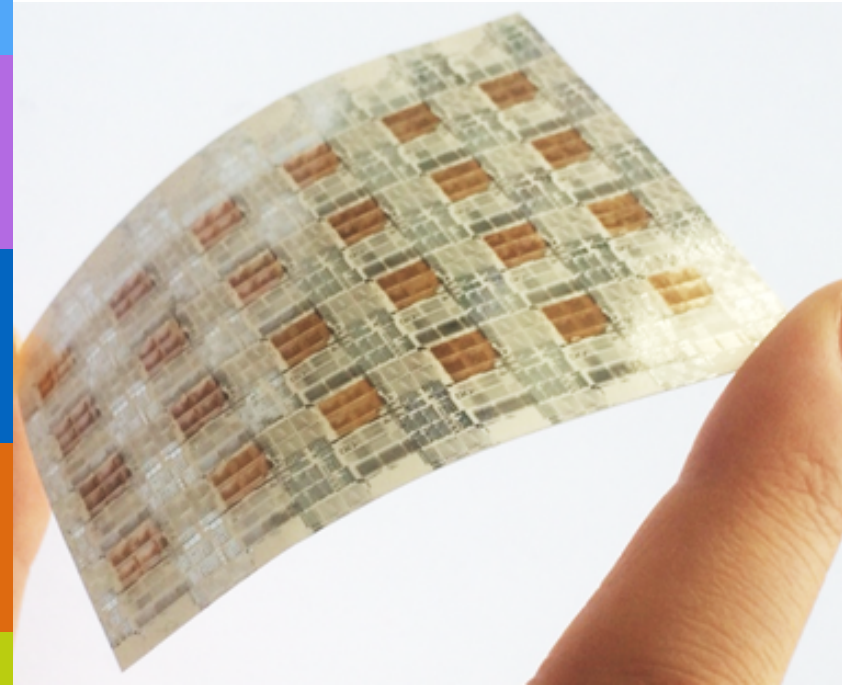
29/04/19

Quantum Technology

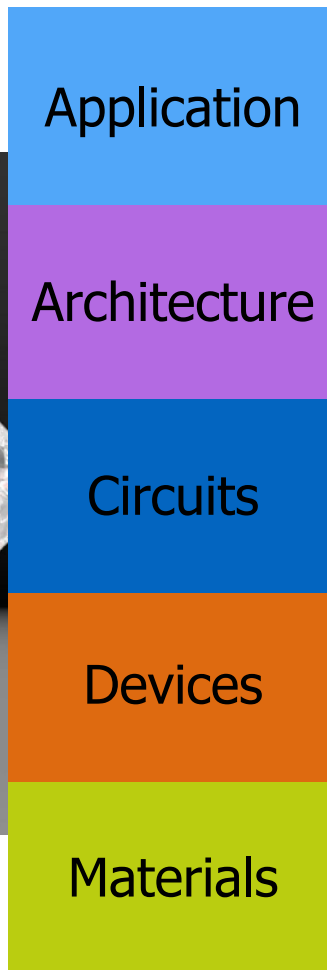


Diamond Color Center

Printed Electronics

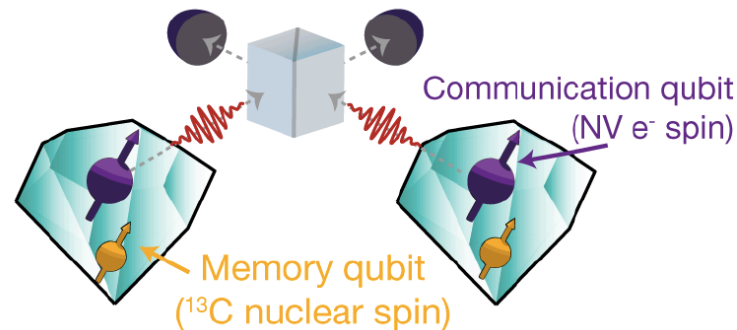
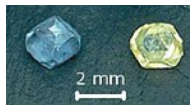
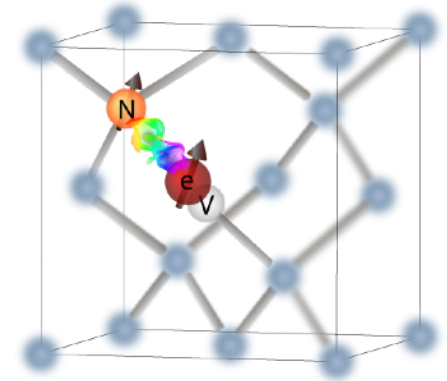


Liquid Silicon



Color center in diamond

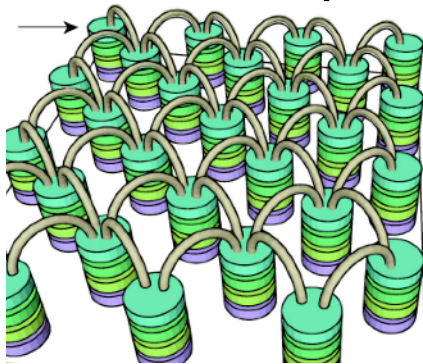
- Impurity doped in diamond
- Optically addressable/read-out qubit
- Spin-dependant fluorescence even at RT
- Magnetic, temperature and strain sensitive
- Biocompatible, chemically stable, thermally conductive and mechanically hard



B. Hensen, et al., Nature 526, 682-686 (2015)

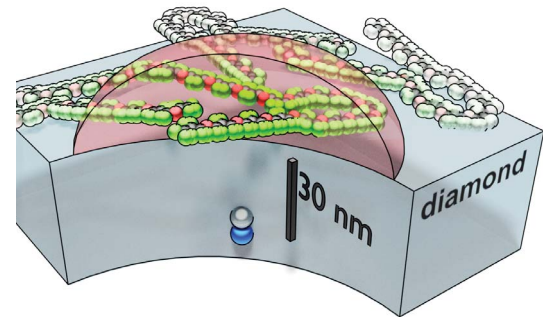
Application of diamond color-center

Quantum computer



N. H. Nickerson, et al.,

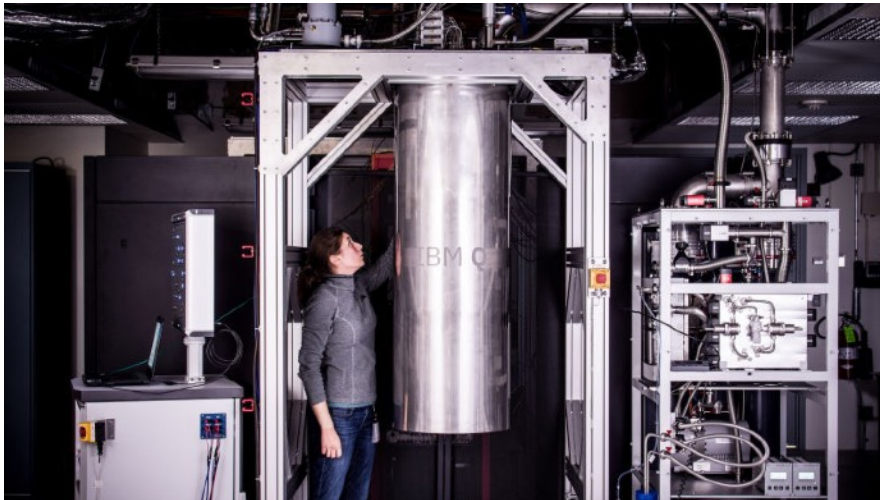
Quantum enhanced sensor



Nabeel Aslam, et al., Science 357, 67–71 (2017)

The impact of operating temperature

$T=100\text{mK}$



- Max. cooling power $\sim 100\mu\text{W}$
- Price $\sim 600\text{KEuro}$

$T=4\text{K}$



- Max. cooling power $\sim 0.1\text{W}$
- Price: $\sim 100\text{KEuro}$

Engineering challenges in diamond color-center

Circuits

- Integration with photonic and CMOS circuits

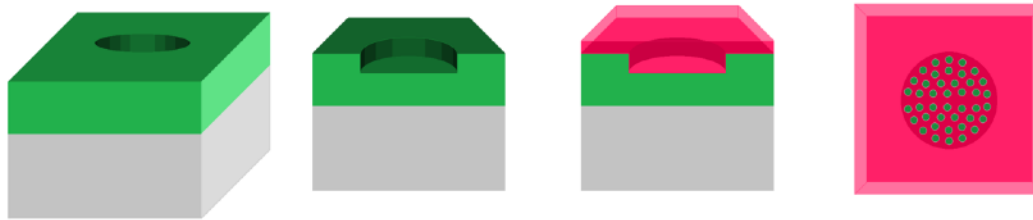
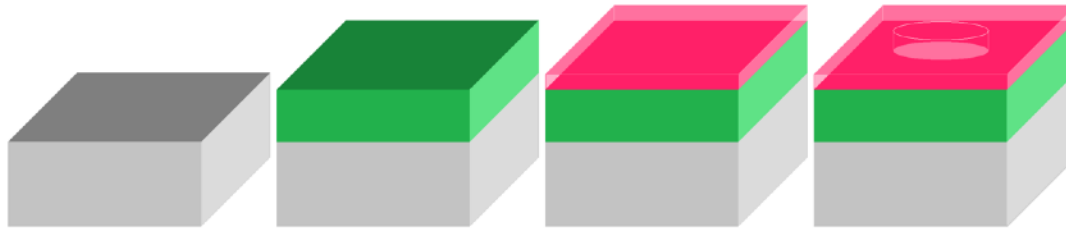
Devices

- Efficient spin-photon interfaces
- Predetermined positioning of color centers

Materials

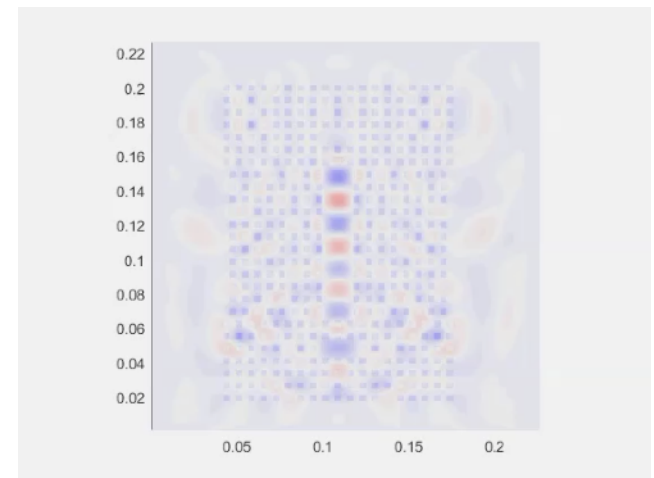
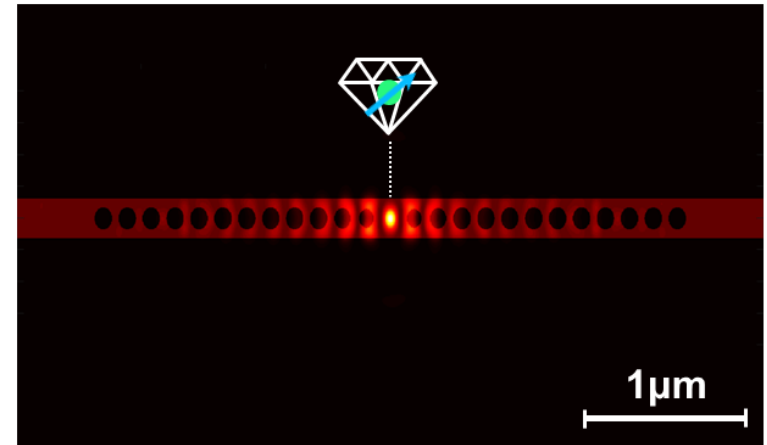
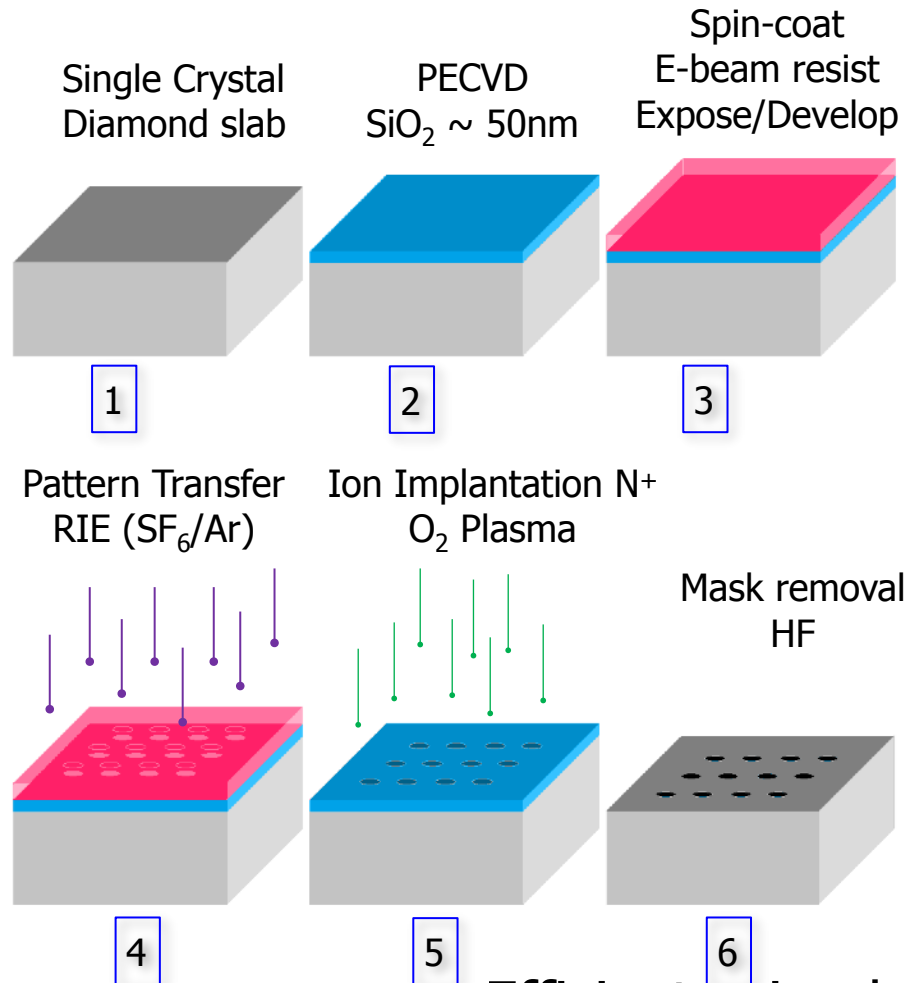
- Wafer-scale diamond growth and process

Large scale epitaxial growth of diamond



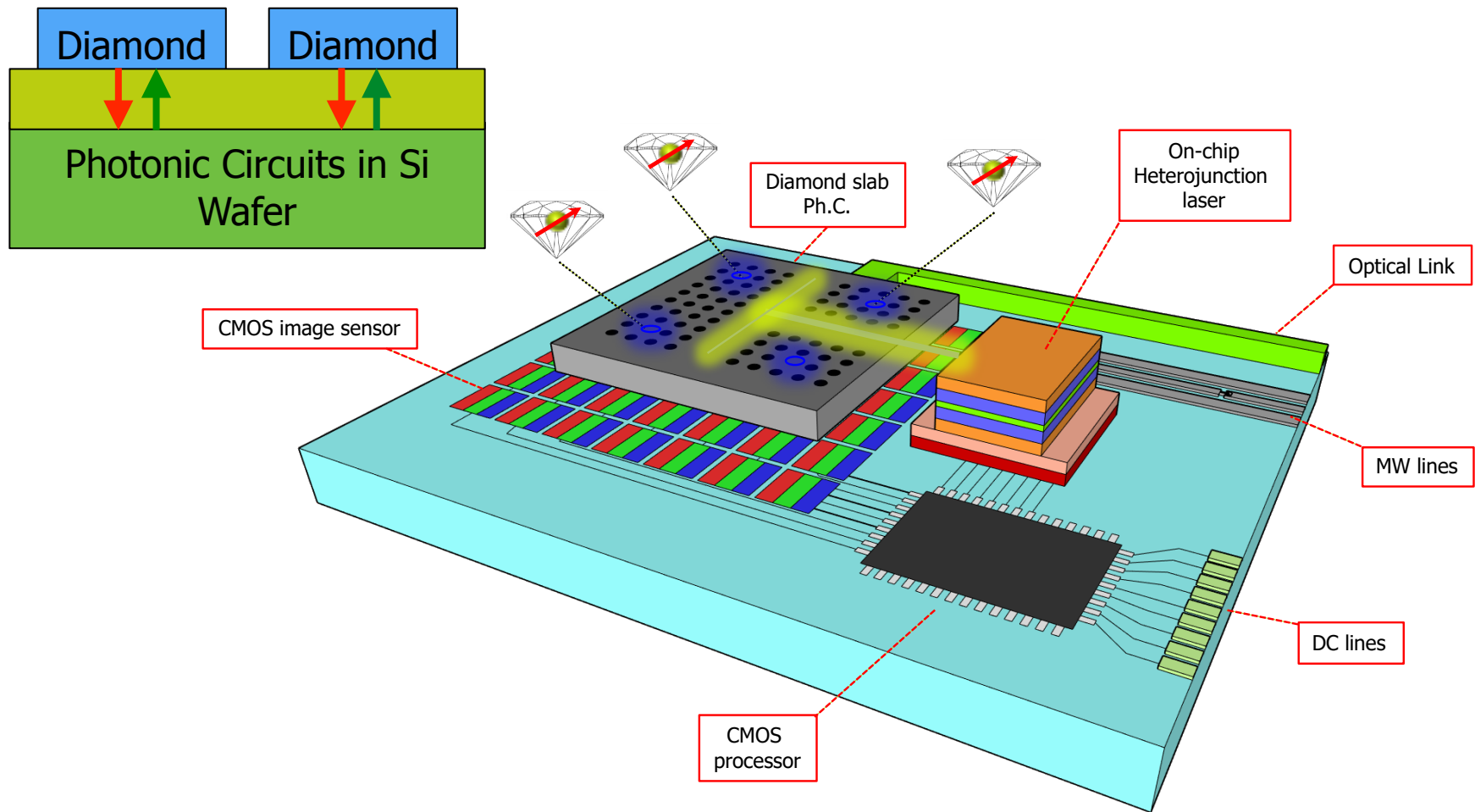
2D array of micro-diamonds grown on silicon wafer

Photonic crystal cavity in diamond



Efficient spin-photon interface

Diamond integration with silicon



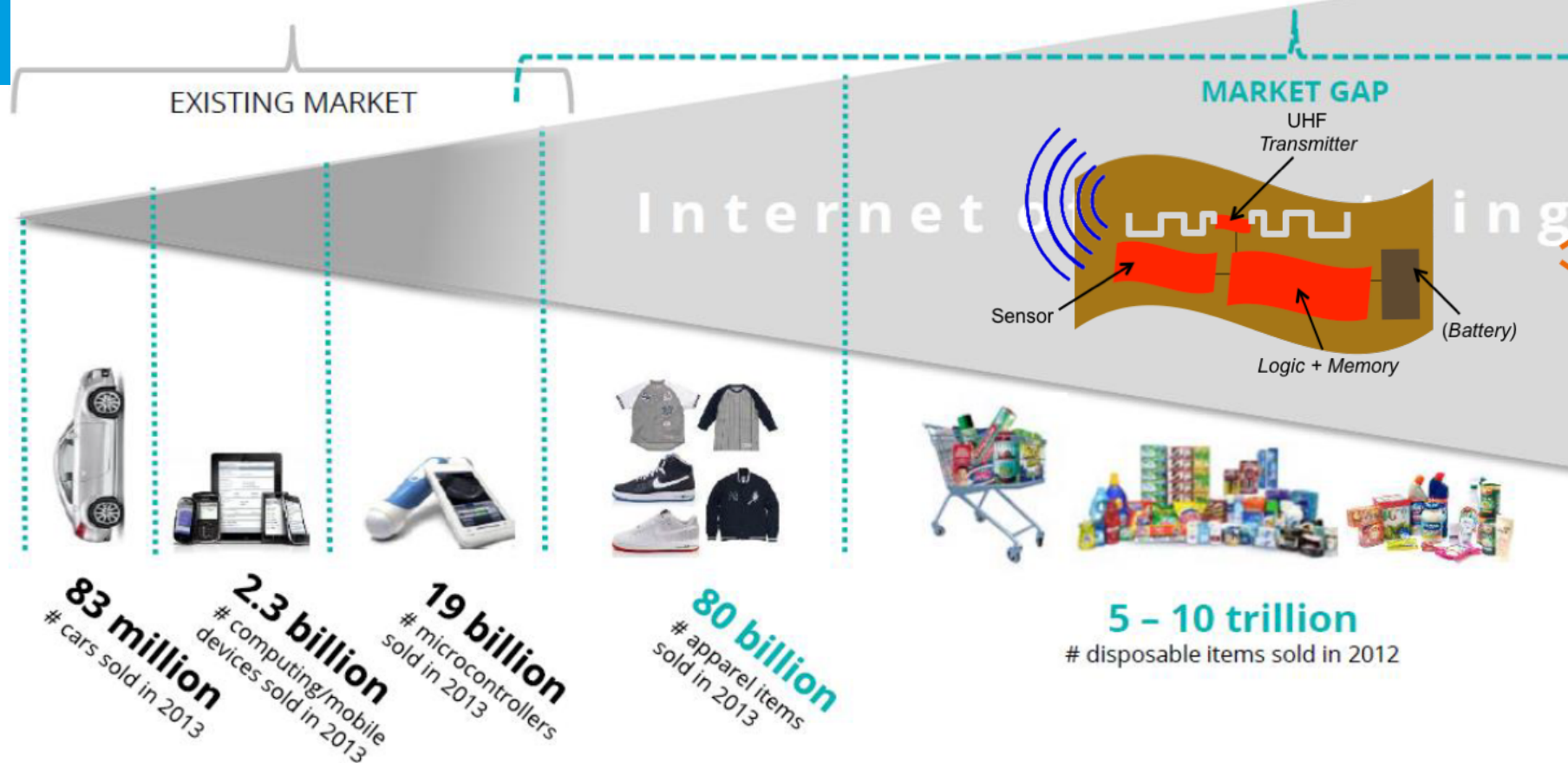
IoE

\$315 billion¹

(~23% of retail value)

\$100 billion

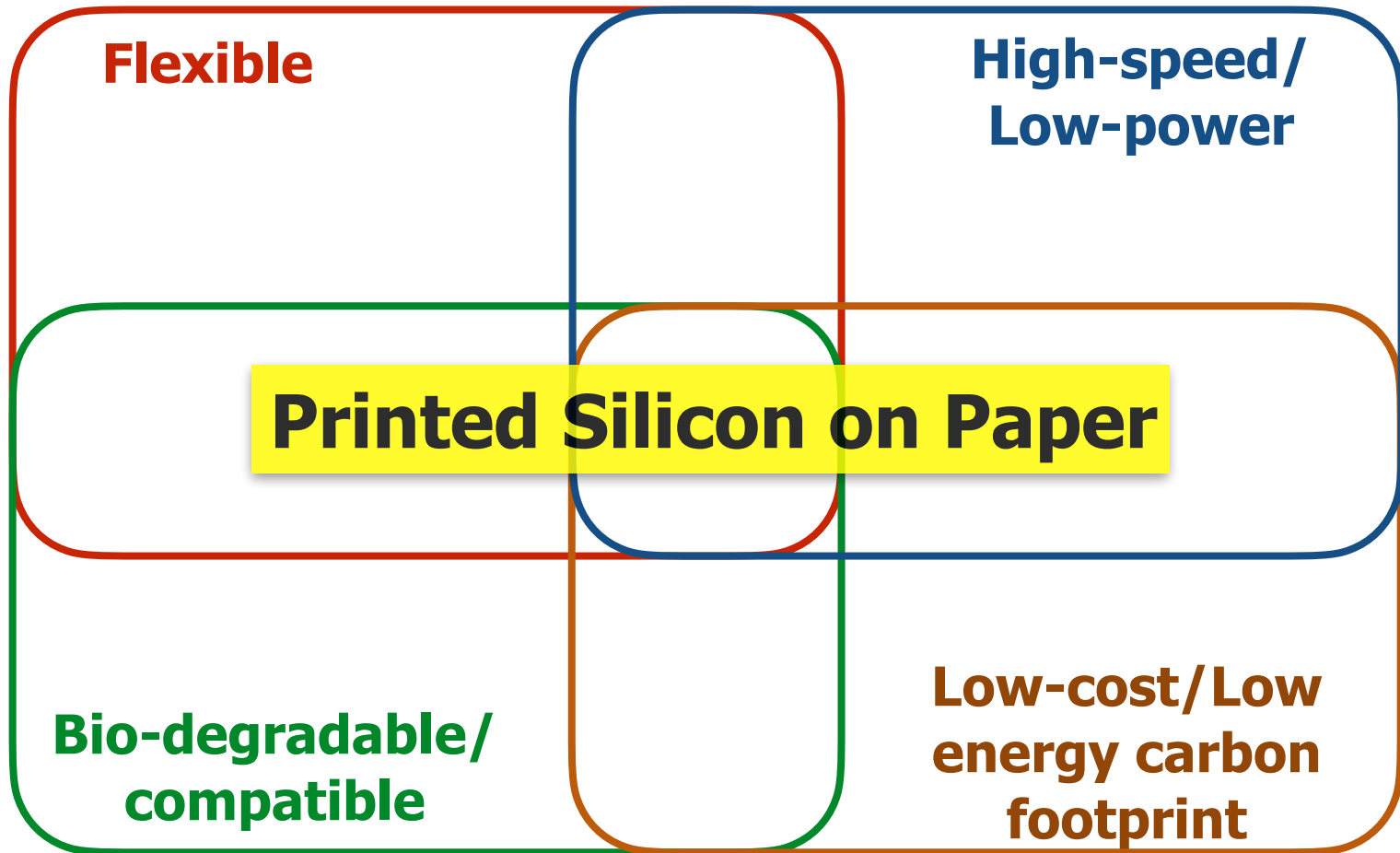
(1% of retail value)



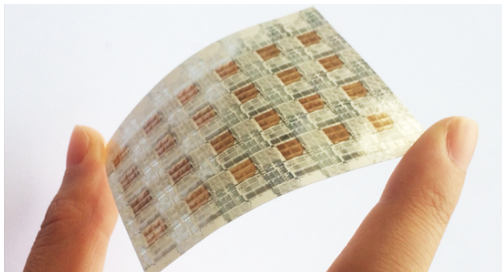
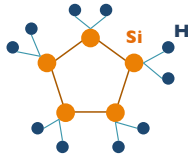
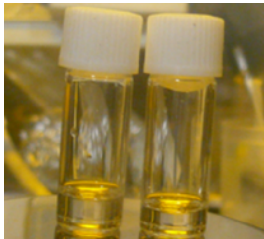
¹ Global semiconductor market (2013)

Source: IDC; Gartner; World Bank; IMF; HIS; The Semiconductor Industry Association; OICA; IC Insights; MarketLine; Apparel Market; Planet Forward

Future electronics challenge



Printed Silicon with liquid silicon



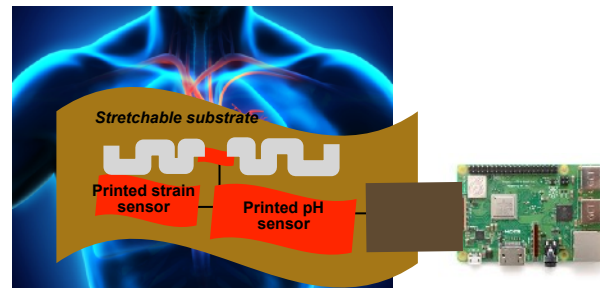
M. Trifunovic, et al., npj Flexible Electronics (1), 12 (2017)

Flexible
Bio-degradable/compatible
High-speed
Low-cost

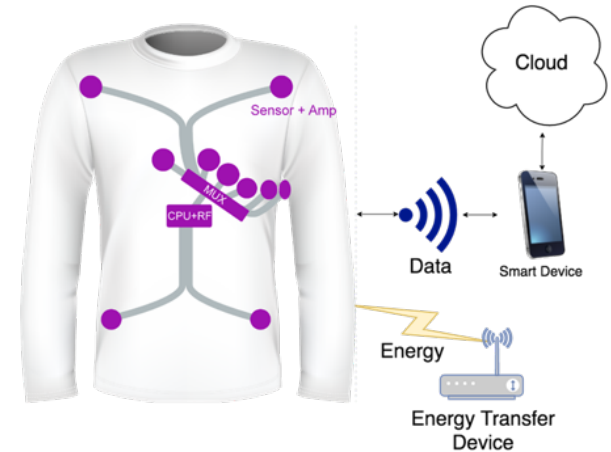
Agrifood



Medical



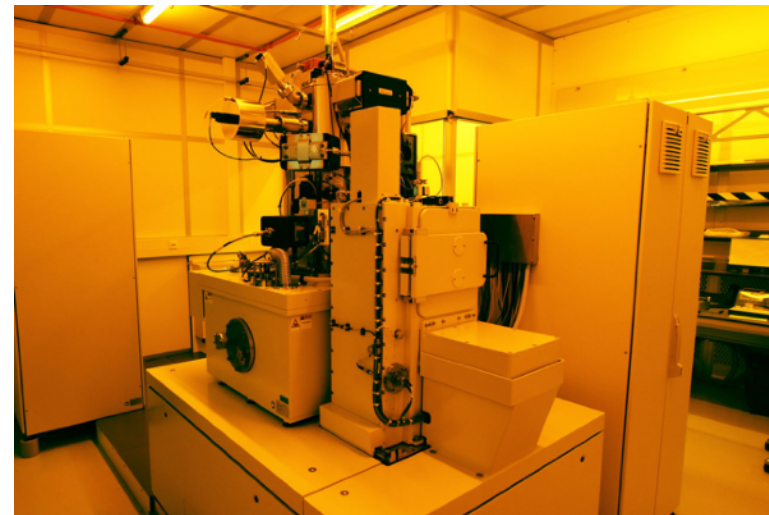
Wearable



Fabrication in cleanrooms



Kavli Nanolab Delft
Enabling nanodevice fabrication



- Printing silicon
- Photonic structure

- Diamond growth
- Diamond nano structure

QIT Partners



RECSiLICON



Panasonic



UNIVERSITÄT
LEIPZIG



ASML



FUJITSU

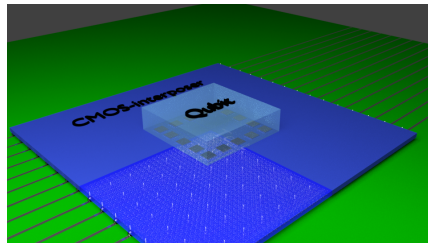
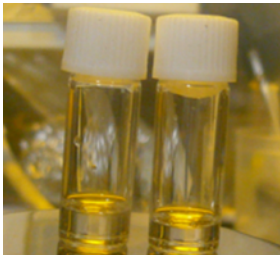


Tokyo Tech



QIT is for you, if you...

- want to use you hands for making emerging electronics
- are keen to interact with semiconductor device/material/equipment manufacturing companies
- like Japanese food (and others)



More to read

- "Cheap and environmental friendly silicon chips printed on paper"
- "High-mobility poly-Si TFTs directly printed on paper"
- "Diamond color centers for quantum internet and sensor", Issue 22.3, MAXWELL, April 2019

