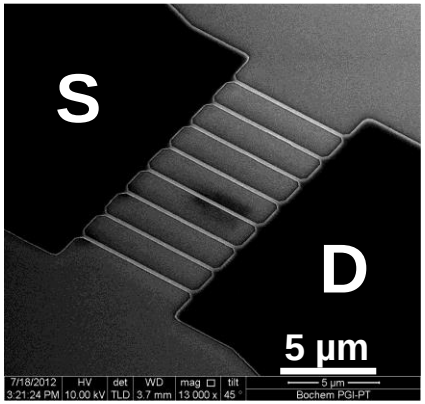
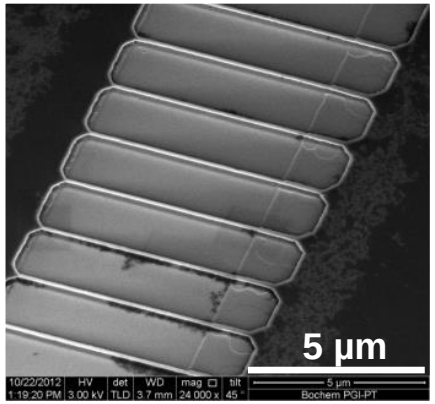
Photo-responsive Properties on Locally Confined Ultrathin Silicon Nanowires

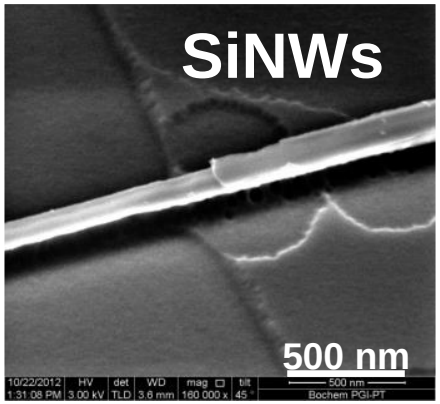
P.D. Tran, T.J. Macdonald, B. Wolfrum, R. Stockmann, A. Offenhausser, T. Nann and B. Thierry

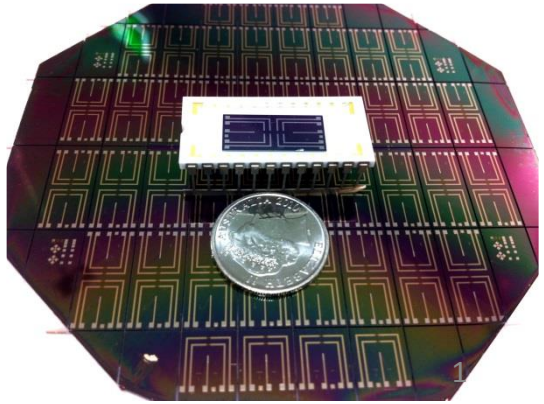
Ian Wark Research Institute, University of South Australia, Australia
Peter Grünberg Institute, Forschungszentrum Juelich GmbH, Juelich, Germany

http://bionanoengineering.com









Why Ultrathin Silicon Nanowire ?

- Silicon nanowires (SiNWs) are *promising functional building blocks* for novel optoelectronic devices[1,2]
- *Down-scaling to ultrathin SiNWs* open up opportunities to explore new fundamental properties of one-dimensional materials → high performance nanoscaled devices
- The performance of planar SiNWs optoelectronic devices is currently limited by the inherent low fill factor and light reflection
- CdTe quantum dots (QDs) are high-efficiency fluorescence materials with tuneable emission wavelength → "light harvesting antenna" for ultrathin SiNWs devices

Aim: To fabricate and improve the performance of novel, locally confined ultrathin SiNWs photo-resistors

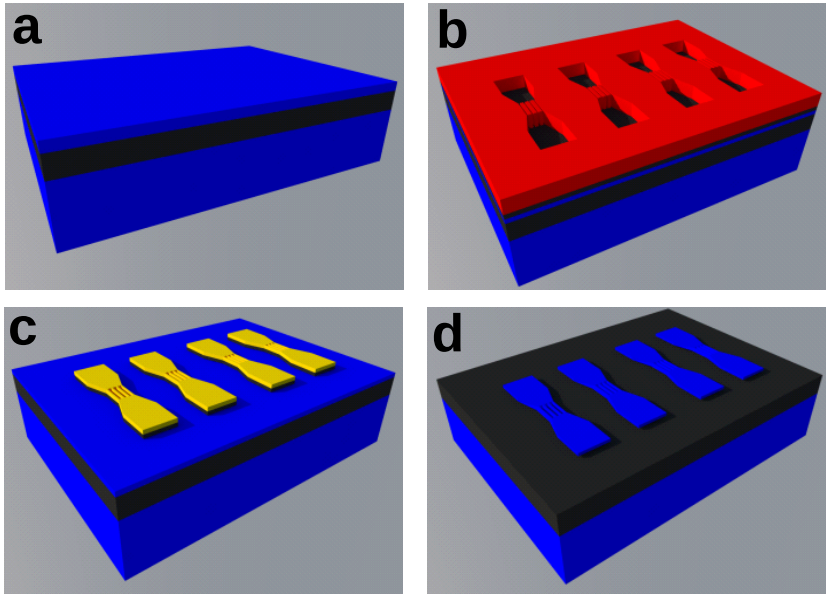
1. Zhang, A.; Kim, H.; Cheng, J.; Lo, Y.-H. *Nano Letters* **2010,** 10, (6), 2117-2120.
2. Garnett, E.; Yang, P. *Nano Letters* **2010,** 10, (3), 1082-1087.

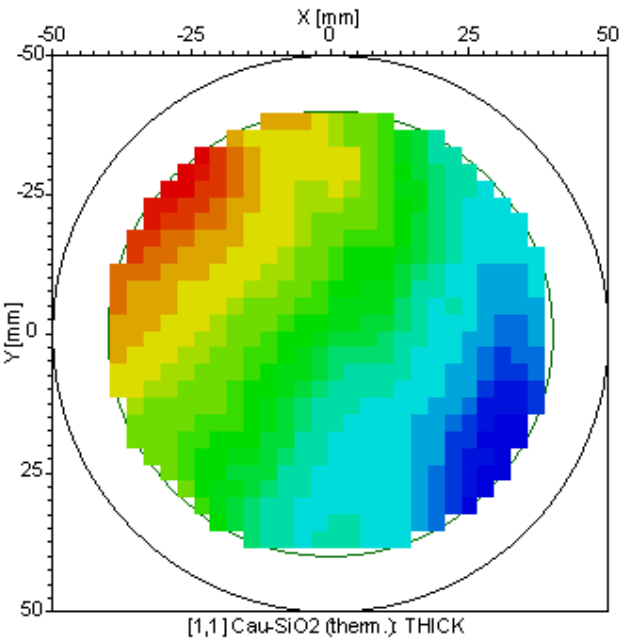
The Fabrication

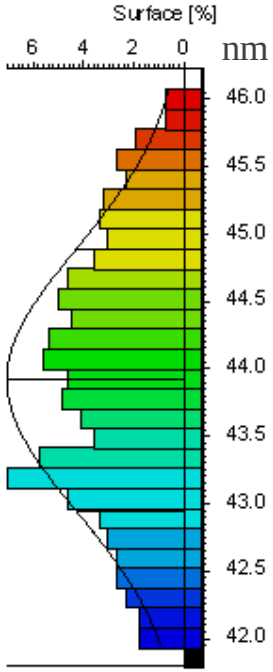
1. SiNWs Patterning

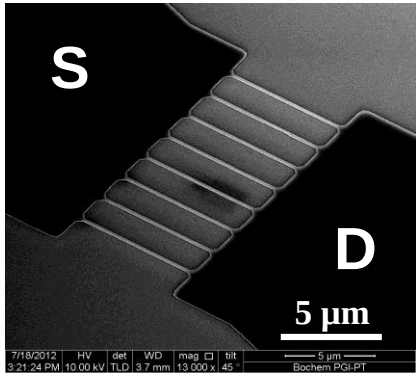
2. Localized Etching

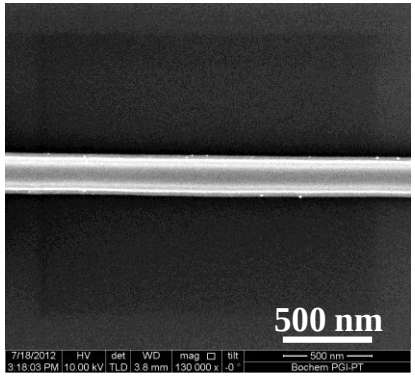
3. Packaging











SiNWs patterning by e-beam lithography and TMAH etching

✓ Wafer-scaled homogeneity of the Si device layer thickness (~ 40nm)

✓ Highly-ordered SiNWs (WxL: 200 nm x10 µm) with smooth trapezoidal shape

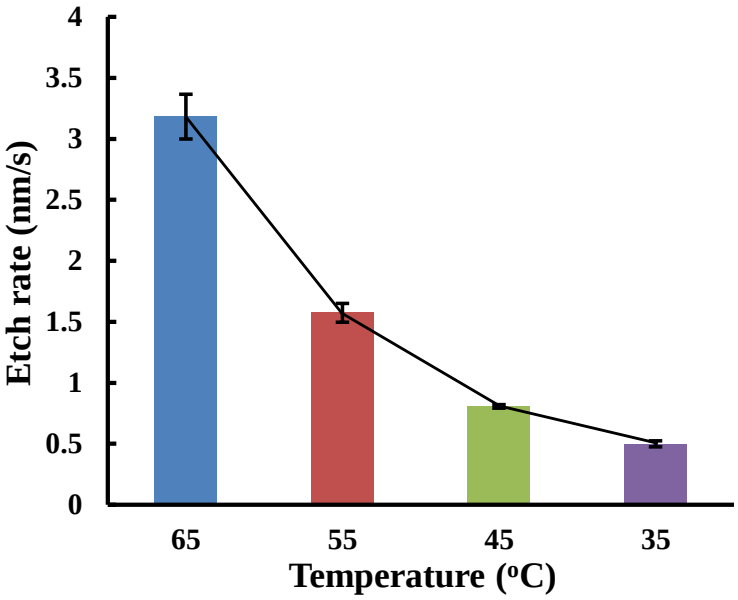
The Fabrication

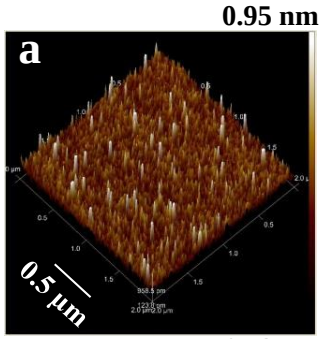
1. SiNWs Patterning

2. Localized Etching

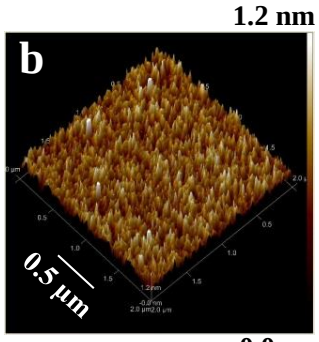
3. Packaging

Optimization of the TMAH wet etching using isopropanol additive for localized etching

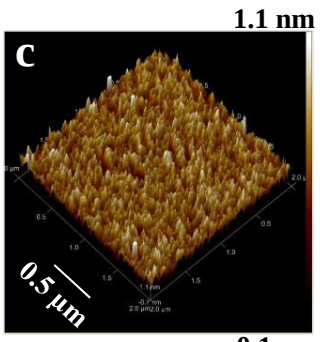




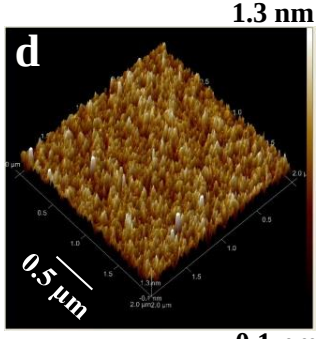
Pristine Si



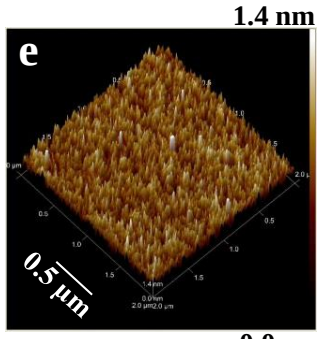
35°C



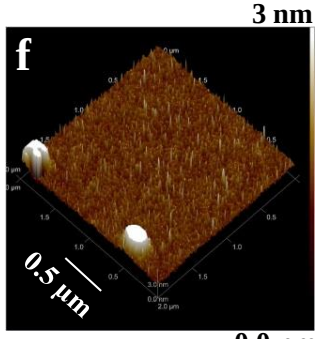
45°C



55°C



65°C



Oxidation + HF

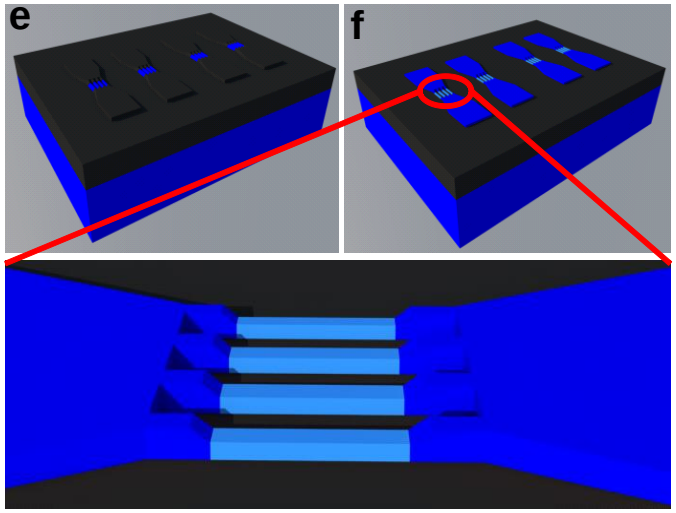
- ✓ A *very slow* (~0.5 nm/s) and *well-controlled TMAH etching rate* on Silicon (100) was obtained
- ✓ *Atomic smooth Si surface* is maintained after etching (rms roughness ~0.15 nm)

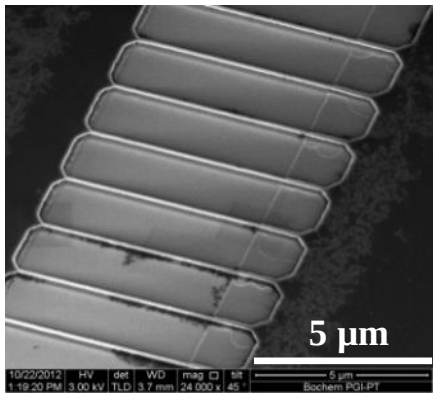
The Fabrication

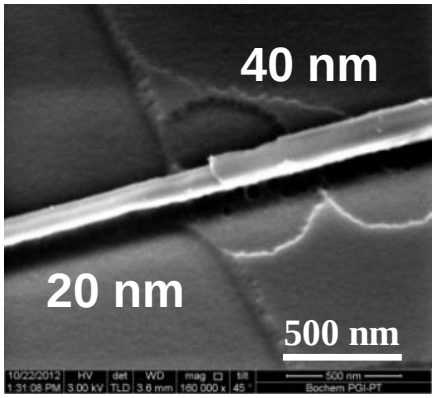
1. SiNWs Patterning

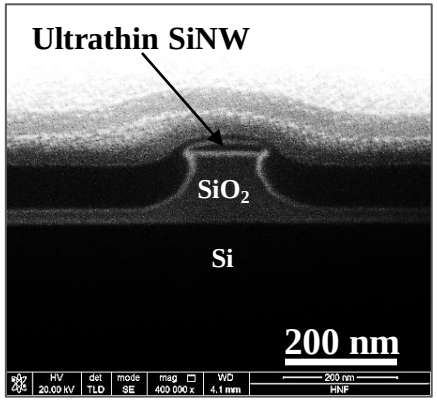
2. Localized Etching

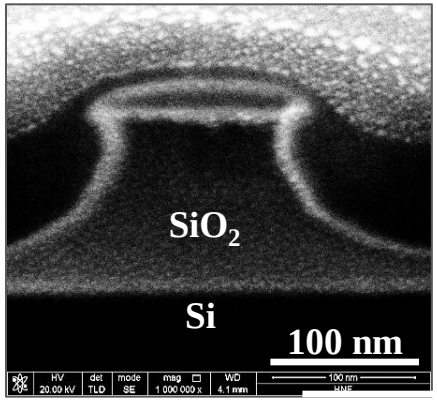
3. Packaging











Ultrathin SiNWs were fabricated with thickness down to ~20 nm by localized wet-etching with optimized TMAH

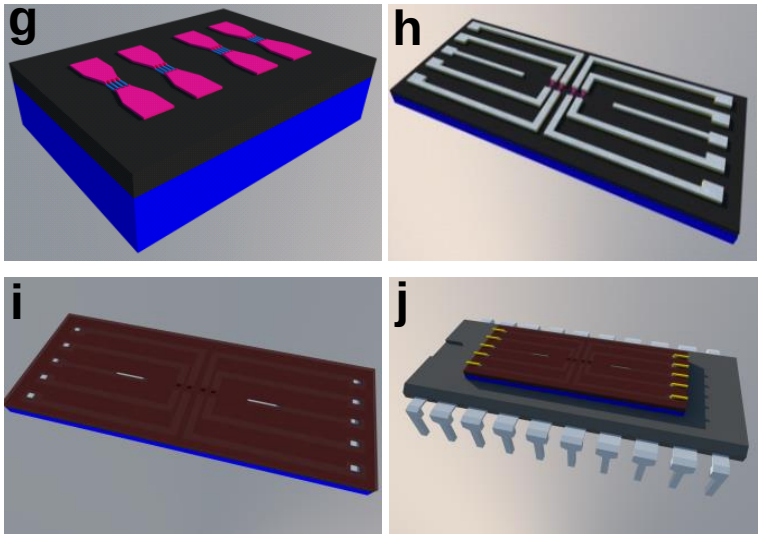
- ✓ Compatible with device integration techniques
- ✓ Thickness scalable to sub-20 nm
- ✓ Straight forward and easy to implement

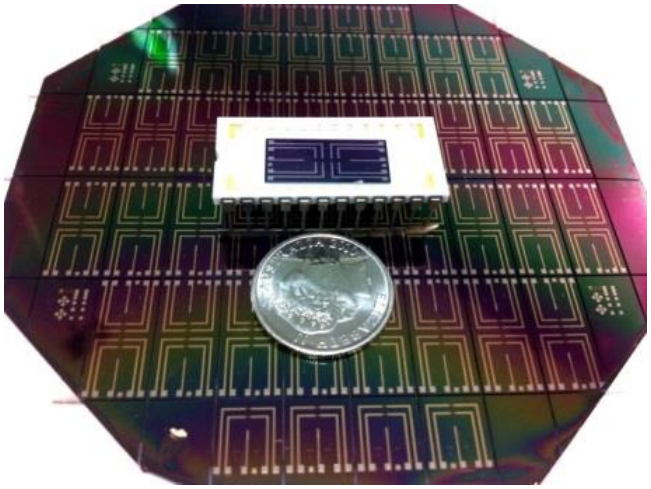
The Fabrication

1. SiNWs Patterning

2. Localized Etching

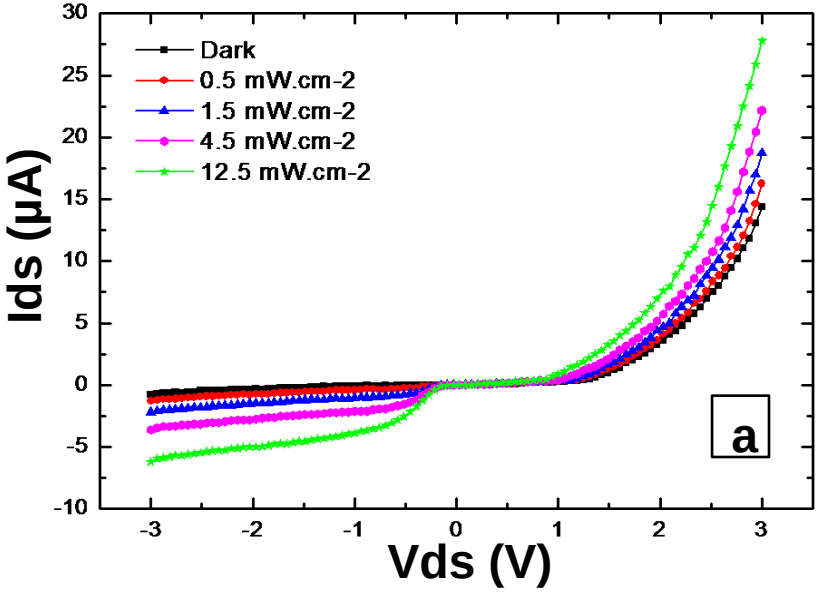
3. Packaging

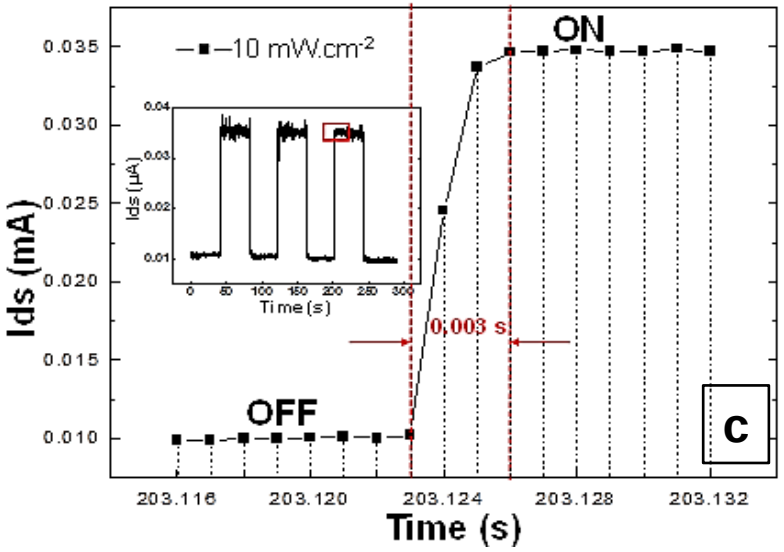


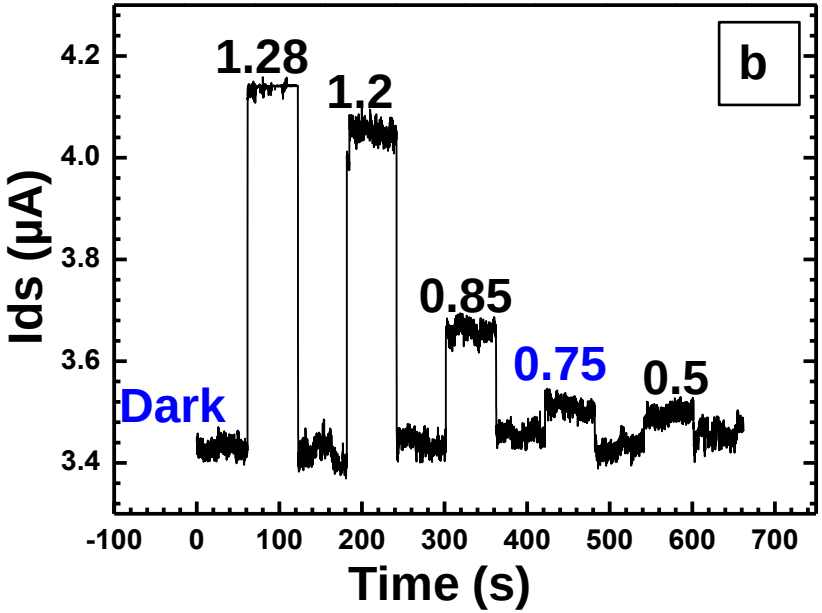


A novel wafer-scaled top-down process for the fabrication of locally thinned-down silicon nanowires based device has been developed

Ultrathin SiNWs Characterizations



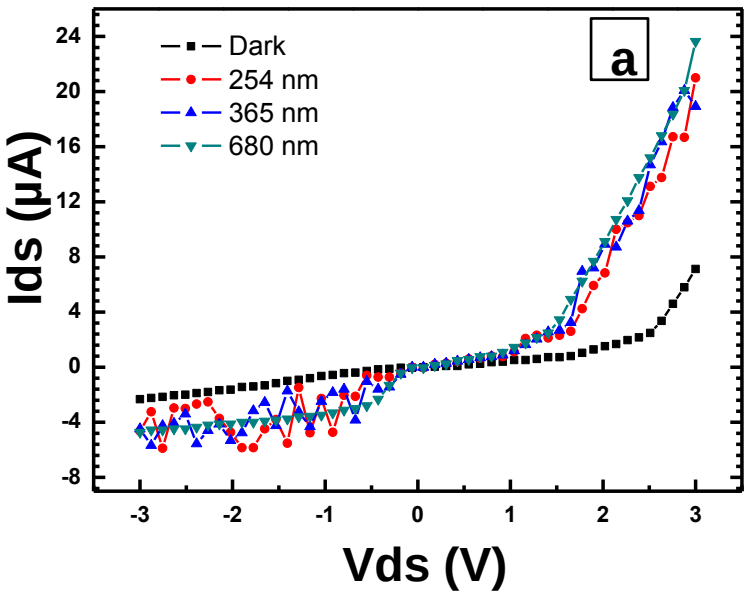


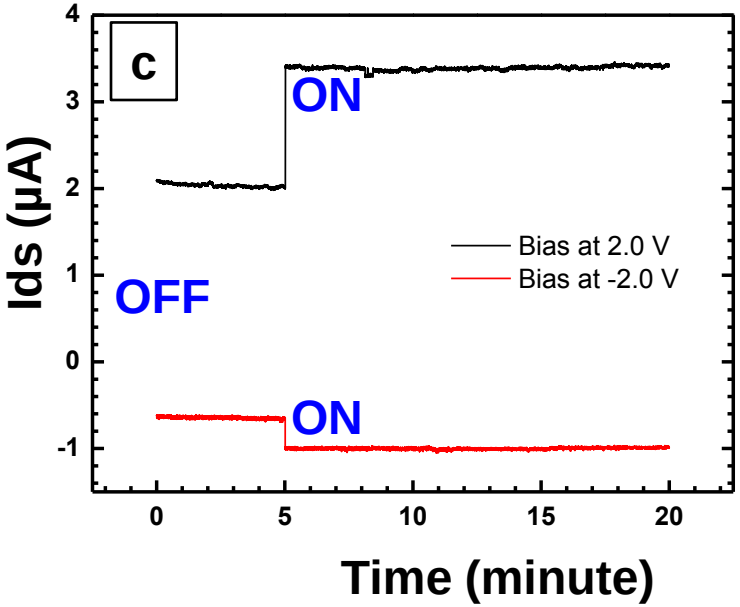


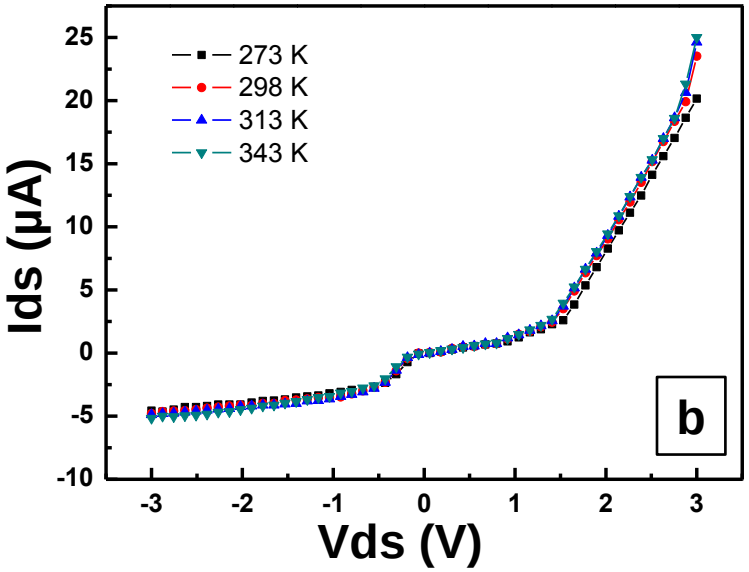
- ✓ High photosensitive, LOD: 0.75 $mW.cm^{-2}$
- ✓ High photoresponsivity, R ~ 10^4 A/W >> 0.7A/W (commercial silicon PIN photodiode)
- ✓ Good time response: t = 0.003s

→ High mobility photocarriers are generated in high quality ultrathin SiNWs

Ultrathin SiNWs Characterization



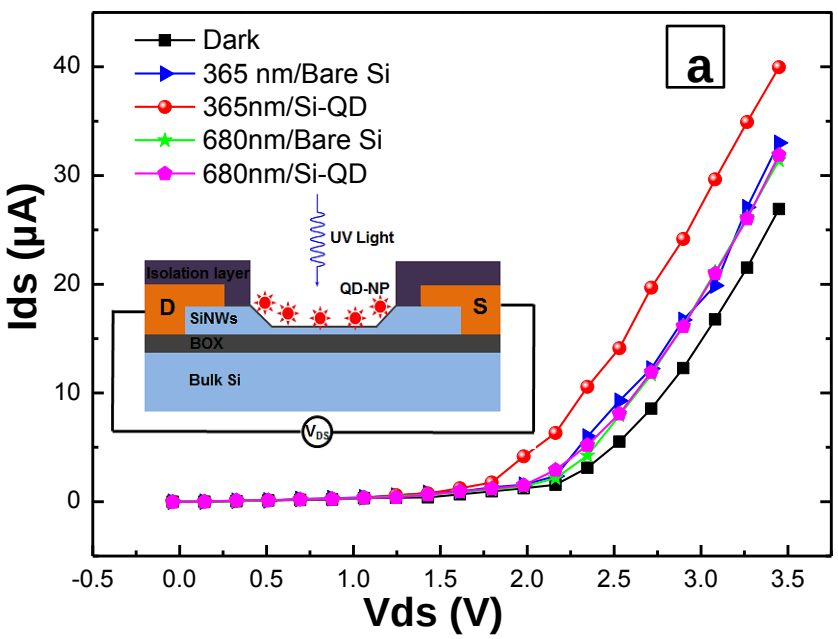


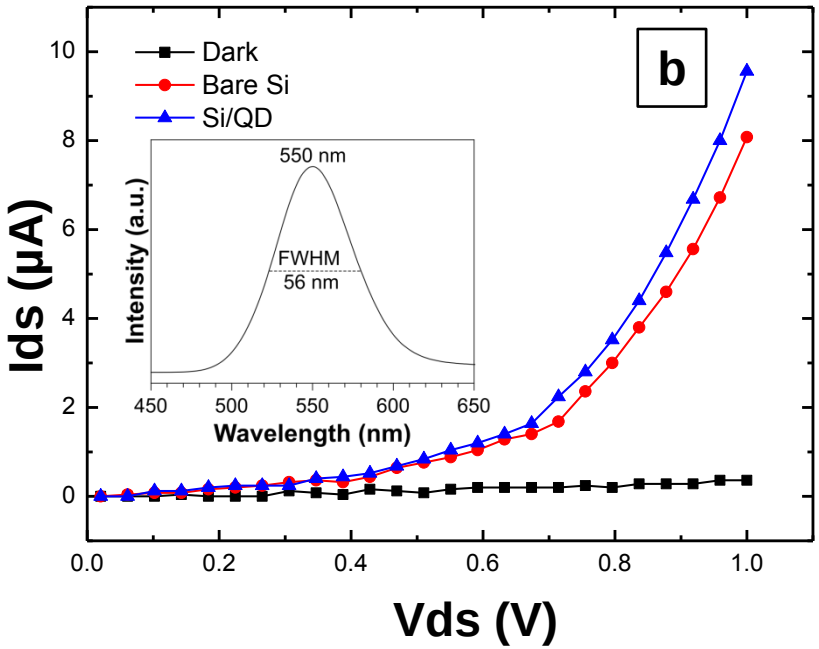


- ✓ Broad light detection spectrum: 254 nm → 680 nm
- ✓ Thermal stability: 0°C → 70°C
- ✓ Long-term stable measurement: 20 mins

→ Highly photo-responsive and stable ultrathin SiNWs

Quantum dot – SiNWs hybrids





- ✓ 10 nm CdTe quantum dots nanoparticle were successfully synthesised
- ✓ ~ 59 ± 10% improvement in photocurrent response of QD-SiNWs measure under 365 nm UV light due the QDs emitting in the visible region.
- ✓ Initial measurement on solar full spectrum (300 → 1400 nm; 100 mW/cm^2) show ~20 % increasing in photocurrent response

→ Fast, stable and highly photoresponsive new nanostructures based on quantum dots - SiNWs hydrids have been developed

Conclusion and Outlook

☑ A novel and straight-forward top-down fabrication of functional ultrathin SiNWs has been developed

☑ The fabricated ultrathin SiNWs have demonstrated ultrahigh photo-responsivity, high photosensitivity, stability, durability and fast response

☑ QD modified SiNWs have shown an improvement of the photocurrent measured under UV light while preserving their performance in visible light

➡ Potential to apply this novel process to fabricate sub-10 nm thin SiNWs

➡ Exciting applications for opto-electronics and photovoltaics hydrid systems

Acknowledgements

- Dr. Dirk Mayer, Dr. Venesa Maybeck, Dr. Stefan Trellenkamp - Forschungszentrum Jülich, Germany
- Dr. Xuan Thang Vu - University of Applied Sciences Kaiserslautern, Germany
- Dr. Tong Duy Hien - Nanosens Research Co., Netherland
- Asso/Prof. Steve Madden - Australian National University, Australia
- This work was performed in part at the SA and ACT nodes of the Australian National Fabrication Facility, a company established under the National Collaborative Research Infrastructure Strategy to provide nano and micro-fabrication facilities for Australia's researchers.

Thank for the financial support from:

+ Australian Technology network – German Academic Exchange Service (DAAD) award

+ NH&MRC 631939 research project