NanoNet+ Annual Workshop 2021

(Klingenberg, Germany)

Top-down Fabrication of Silicon Photonic Structures by Metal Assisted Chemical Etching (MACEtch)

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HZDR

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

People Working Together

Characterization team

- M. Hollenbach
- U. Kentsch
- Dr. Y. Berencén
- PD Dr. habil. G. Astakhov

Fabrication team

- G. Schnabel
- B. Scheumann
- T. Schönherr
- C. Neisser
- J. Baratech (Summer student 2021)
- Dr. C. Fowley
- Dr. Y. Georgiev
- PD Dr. habil. A. Erbe
- Dr. W. Lee (KRISS, South Korea)

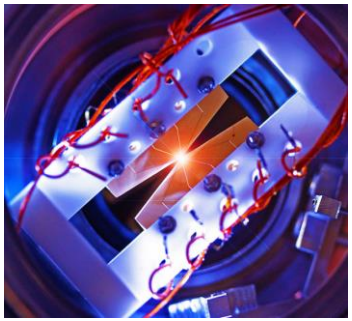
"None of us is as smart as all of us!"

DRESDEN concept HZDR

Quantum Technology

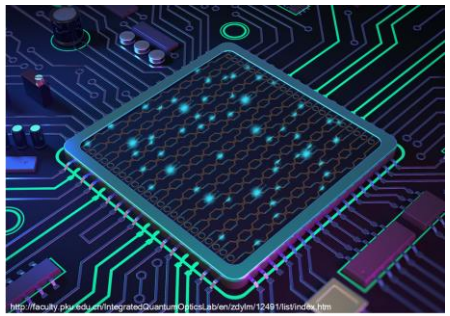
Hot topics → Quantum sensing | **Quantum communication** | Quantum computing

Hardware platforms →



Trapped ions

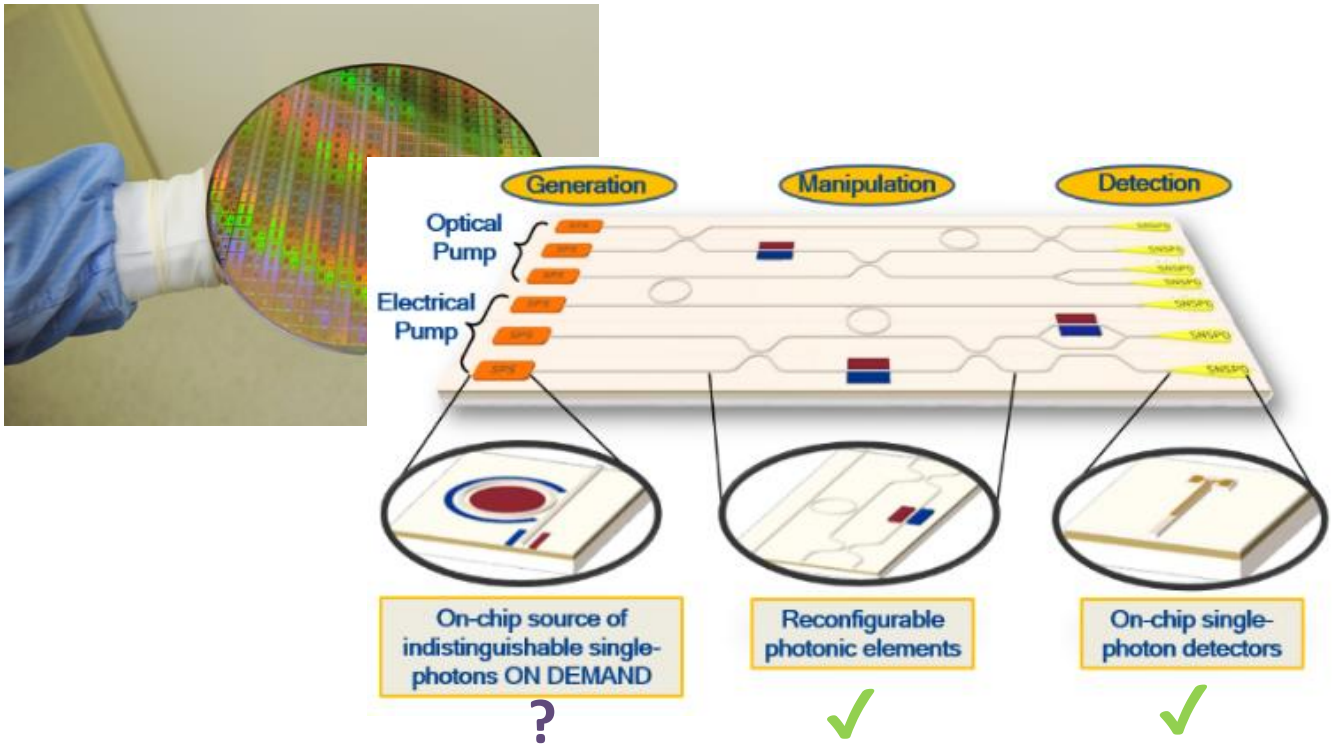
Superconducting qubits



Photonic qubits

Quantum communication using photonic qubits

Why silicon?



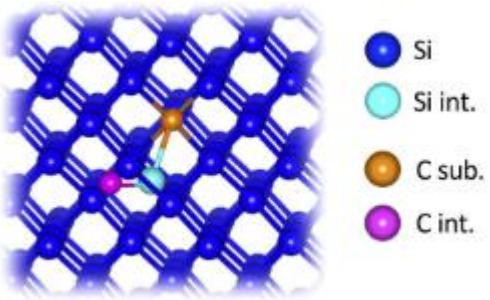
Quantum Photonic Integrated Circuit (QPIC)

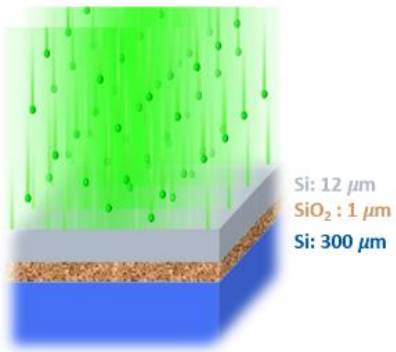
The missing link => On-chip photon source in silicon

Single-Photon Emitters in Si

G-center:

- Carbon related radiation damage
- Defect's atomic configuration

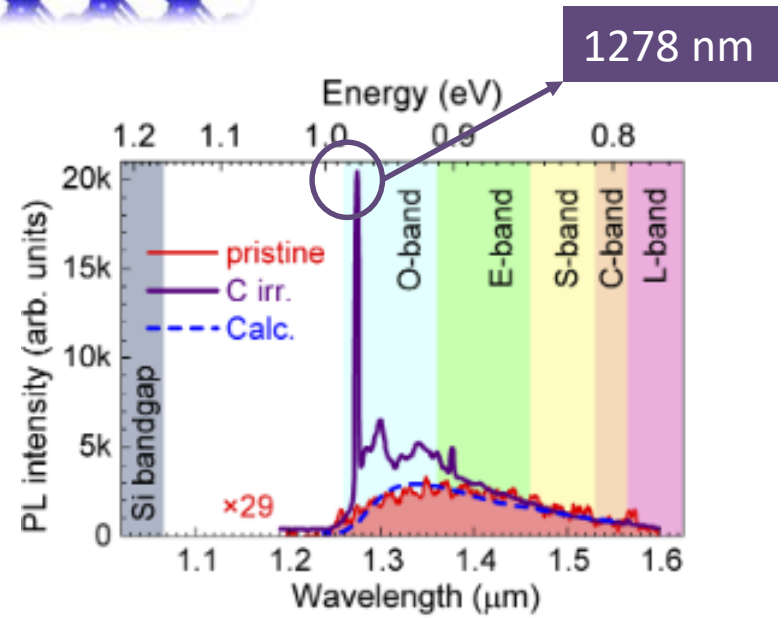




carbon implantation:

1 X 10^9 cm^{-2}, 5.5 keV, R_p ~ 20 nm

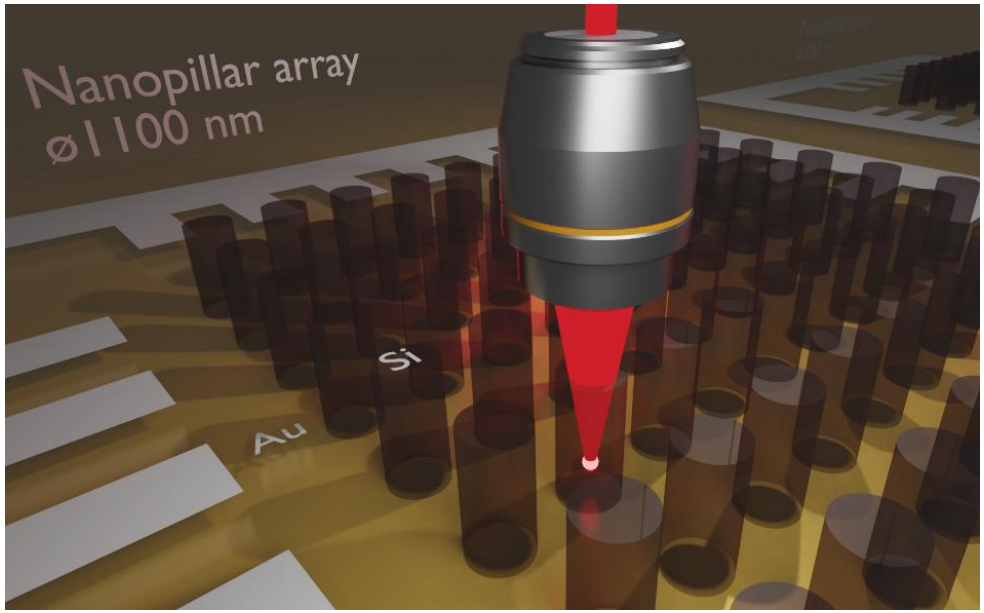
Low Temp PL



Silicon as a potential single photon source!

Opt. Express 28, 26111-26121 (2020)

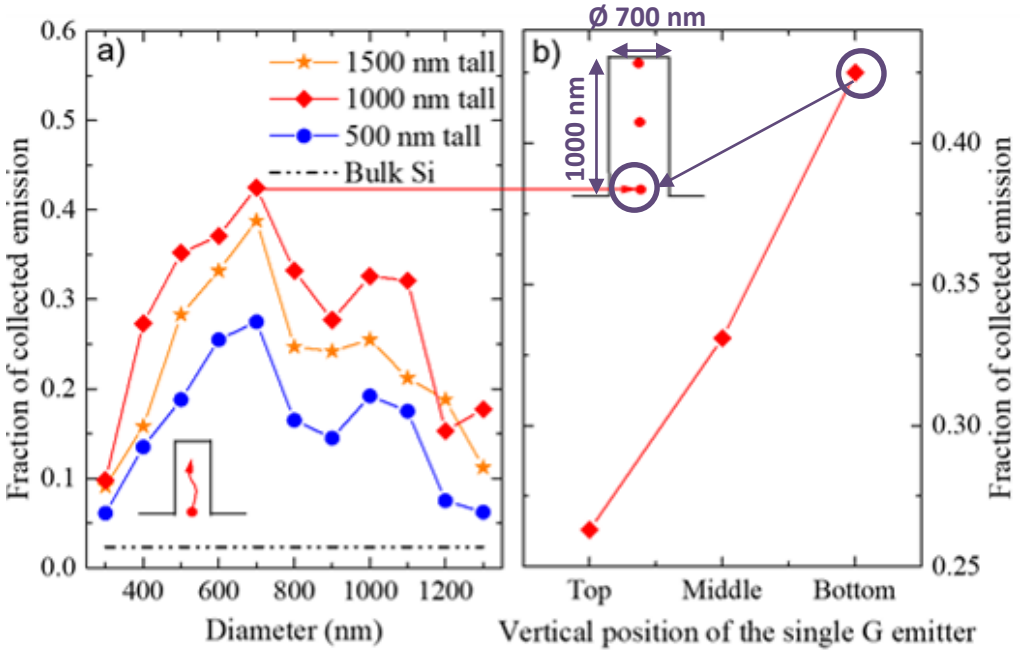
Integration of a single G-center in a photonic structure



Enhancement in PL by wave guiding

Pillar as a Photonic Structure

Designing the Pillars



COMSOL simulations

G-center at the bottom of Ø 700 nm, 1000 nm tall pillar

Fabrication Method for Pillars

Requirements:

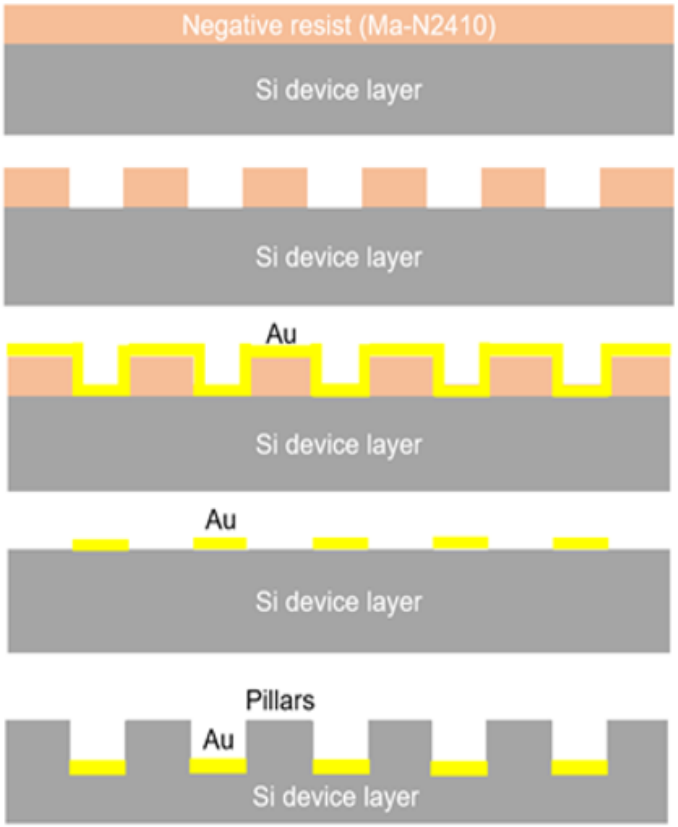
1. No lattice damage
2. Anisotropic etching
3. Smooth and uniform structures

	Wet etch	Dry etch	MACEtch
Ion induced damage	None	Mild to severe	None
Directionality	Isotropic	Anisotropic	Anisotropic
Sidewall smoothness	Smooth	Not smooth	Smooth or rough

MACEtch is more suitable.

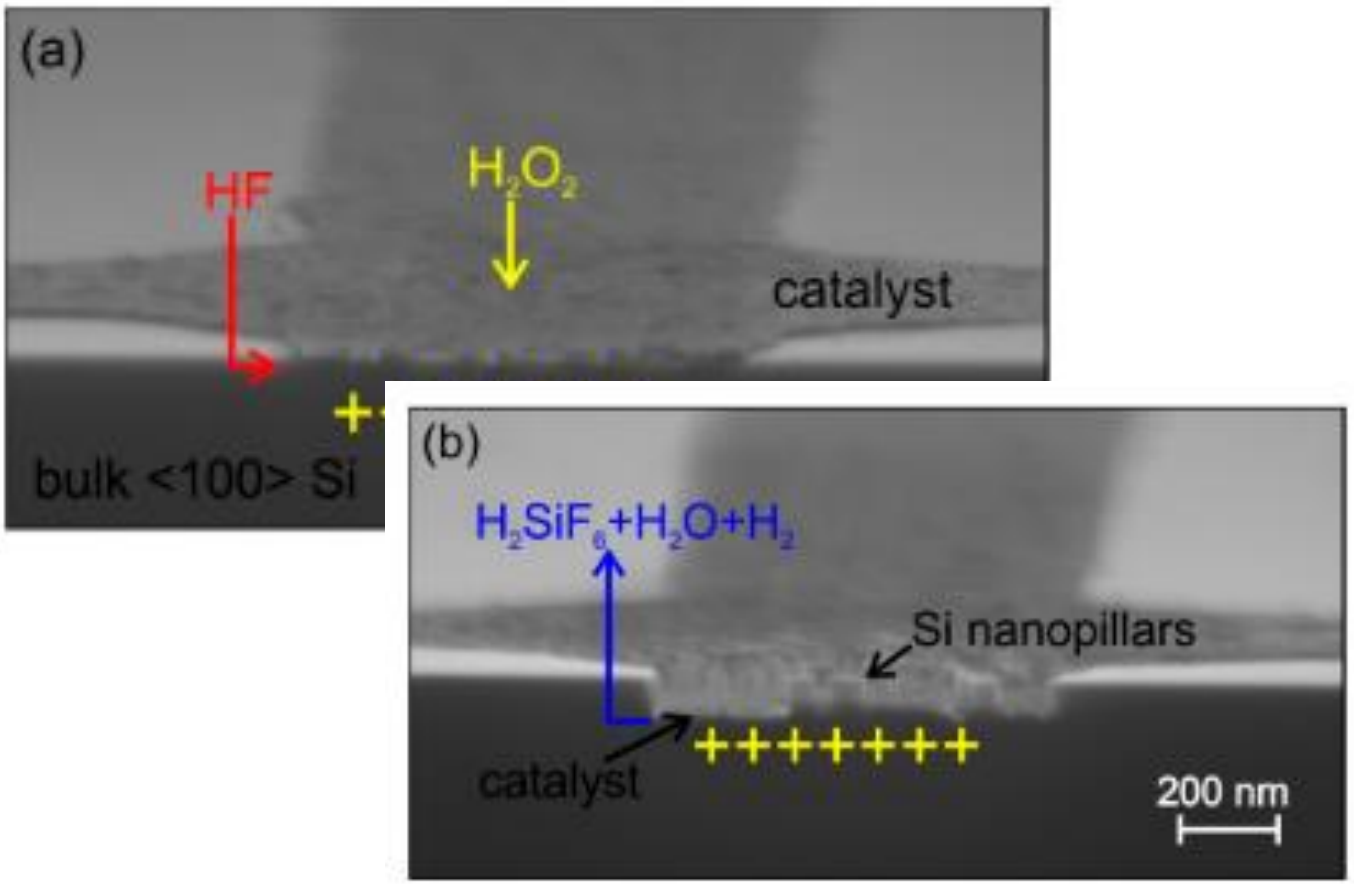
Current Opinion in Solid State and Materials Science, 16(2), 71–81 (2012)

Fabrication Steps



1. Spin coating
2. Pattern transfer by Electron Beam Lithography
3. Metal deposition
4. Lift-off
5. MACEtch

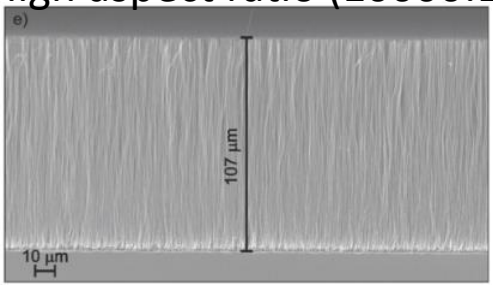
Mechanism of MACEtch



Micromachines, 11(6) (2020)

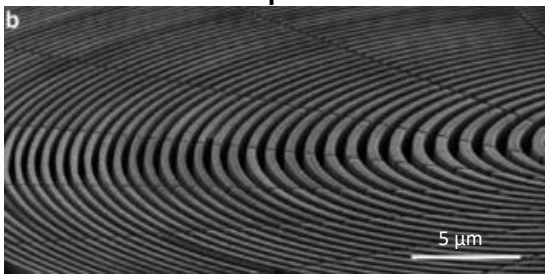
Applications of MACEtch

High aspect ratio (10000:1)



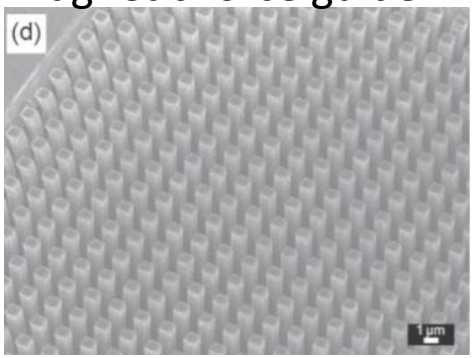
Nanoscale Horizons, 5(5), 869–879 (2020)

Zone plates



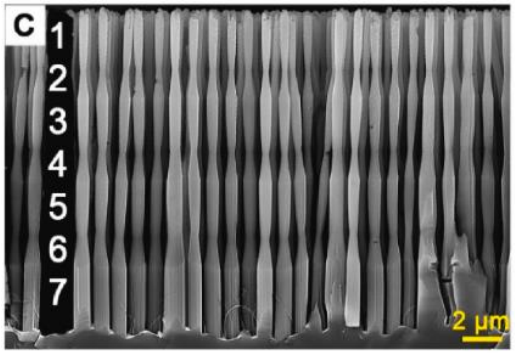
Nature Communications, *5*(May), 1–7 (2014)

Magnetic force guide



Nanotechnology, 29(28) (2018)

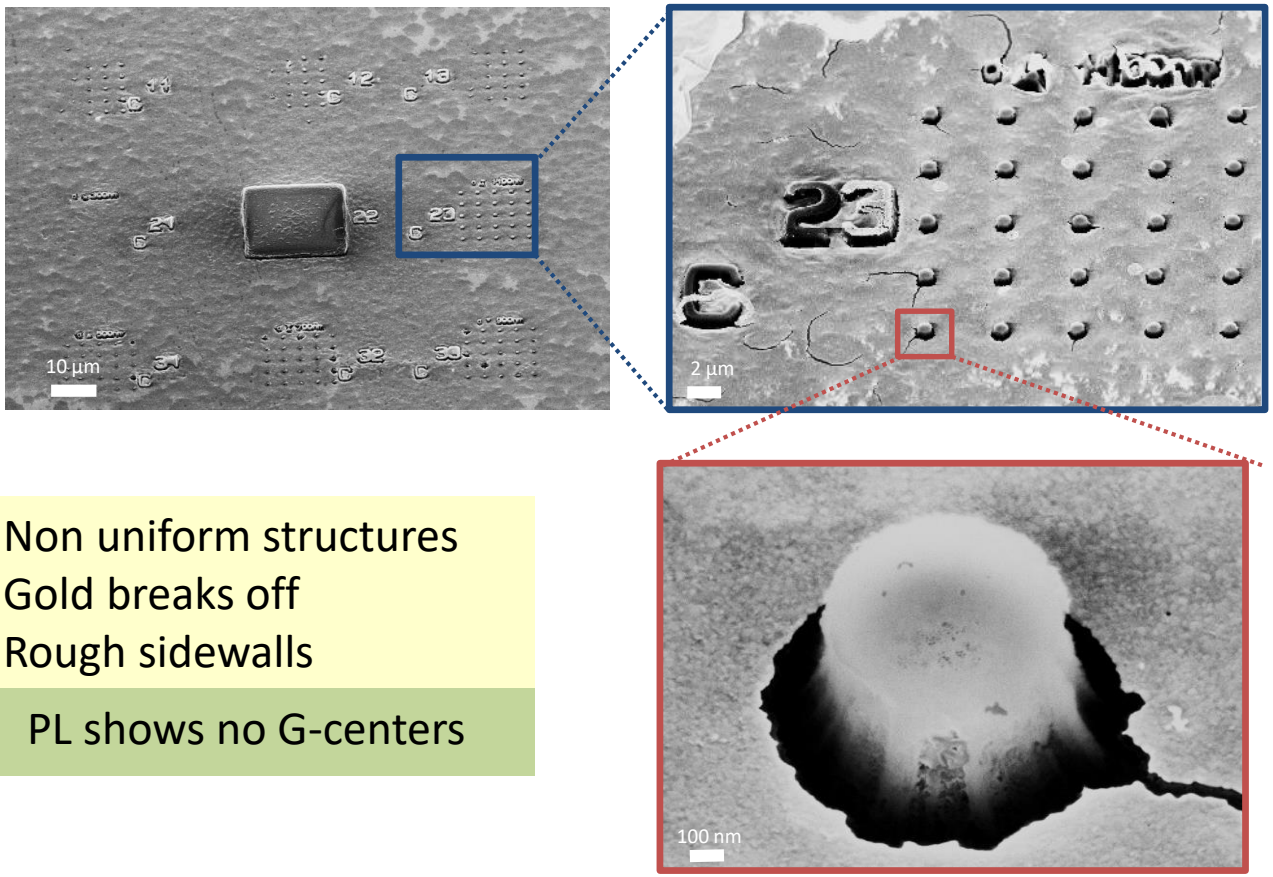
Pillars with constrictions



Nanotechnology, 29(28) (2021)

MACEtch is versatile!

Fabricated Pillars and PL for Pristine sample

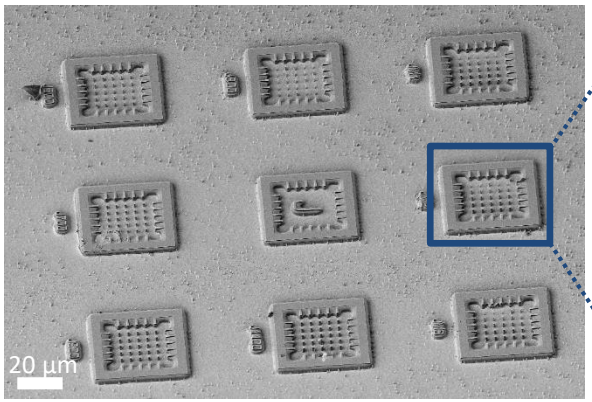


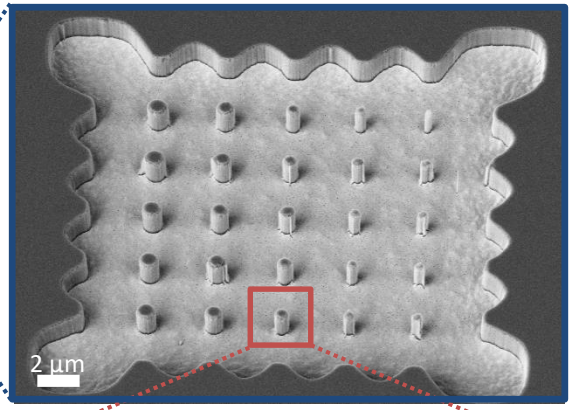
- Non uniform structures
- Gold breaks off
- Rough sidewalls
- PL shows no G-centers

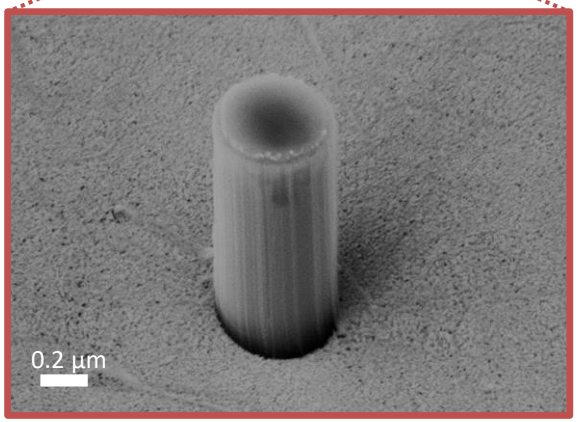
MACEtch optimization

Defect-free structures

MACEtch Optimization





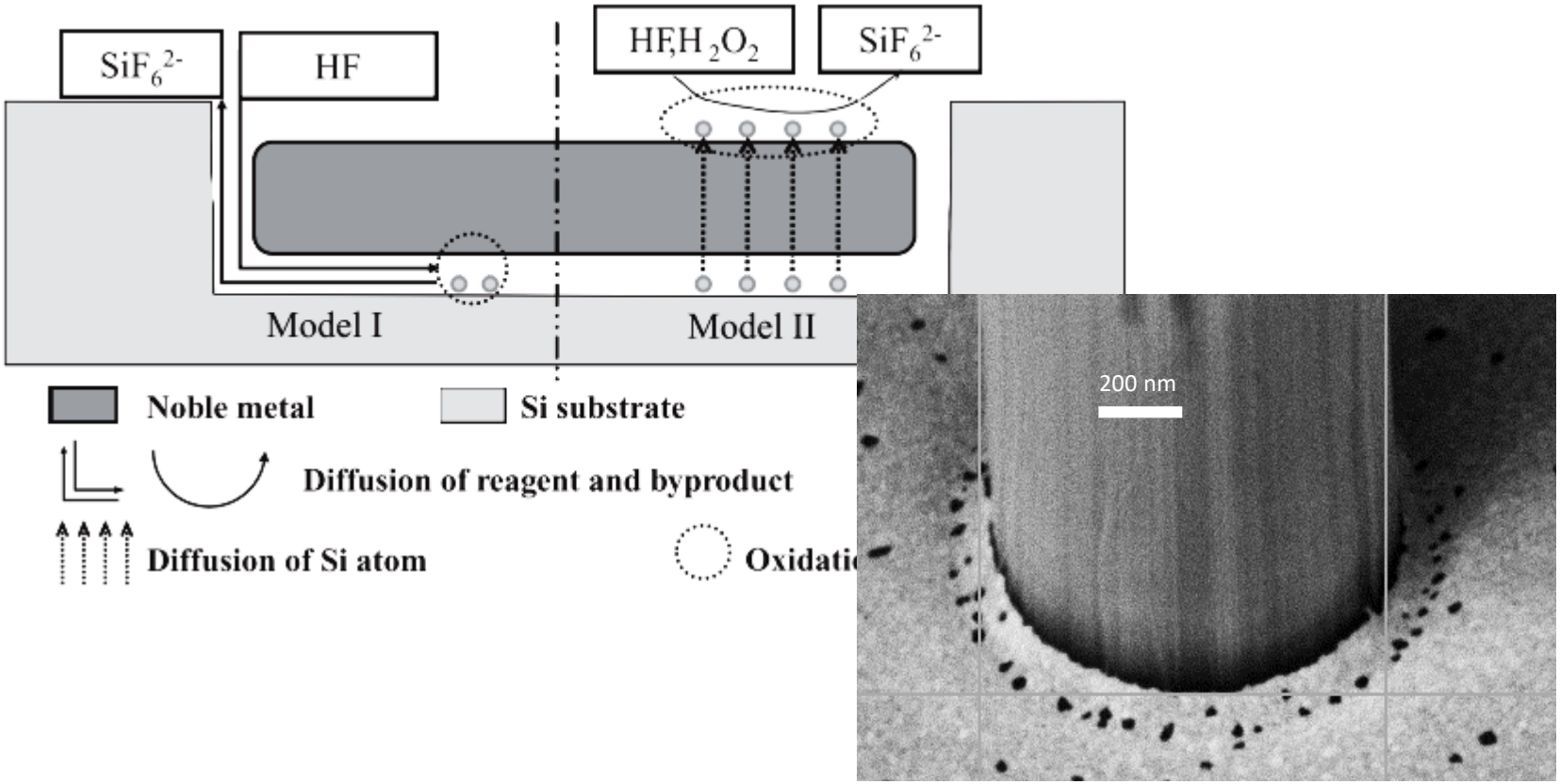


Problem : metal breaks off as during etching

Solution : Arrays of pillars separated by frames (suggestion by Dr. Woo Lee)

Smooth and uniform pillars!

Understanding MACEtch

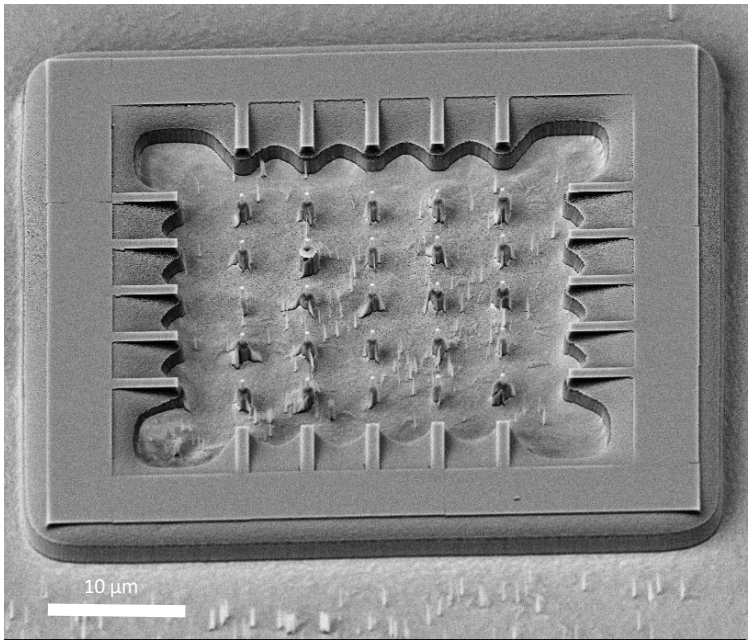


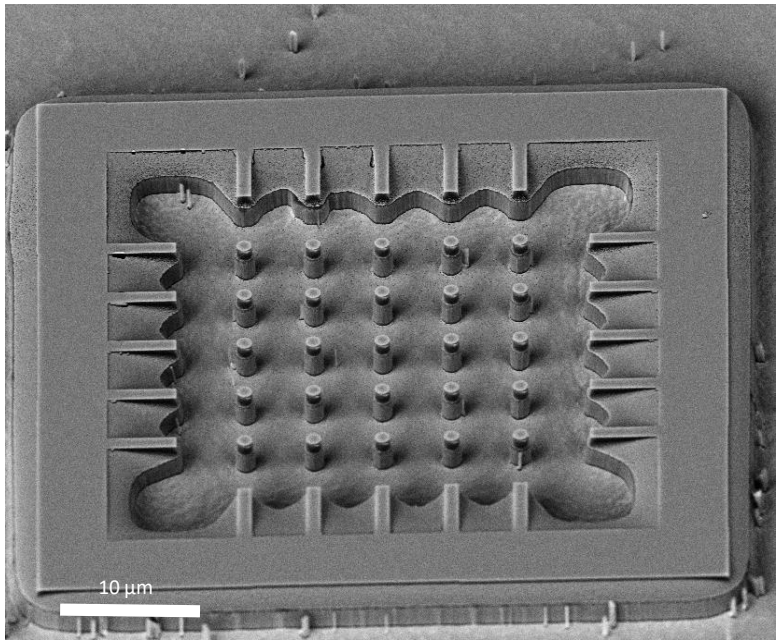
Ratio of circumference to the pitch of the structures critical

Advanced Materials, *23*(2), 285–308 (2011)

Understanding MACEtch

Separation between pillars = 5 µm





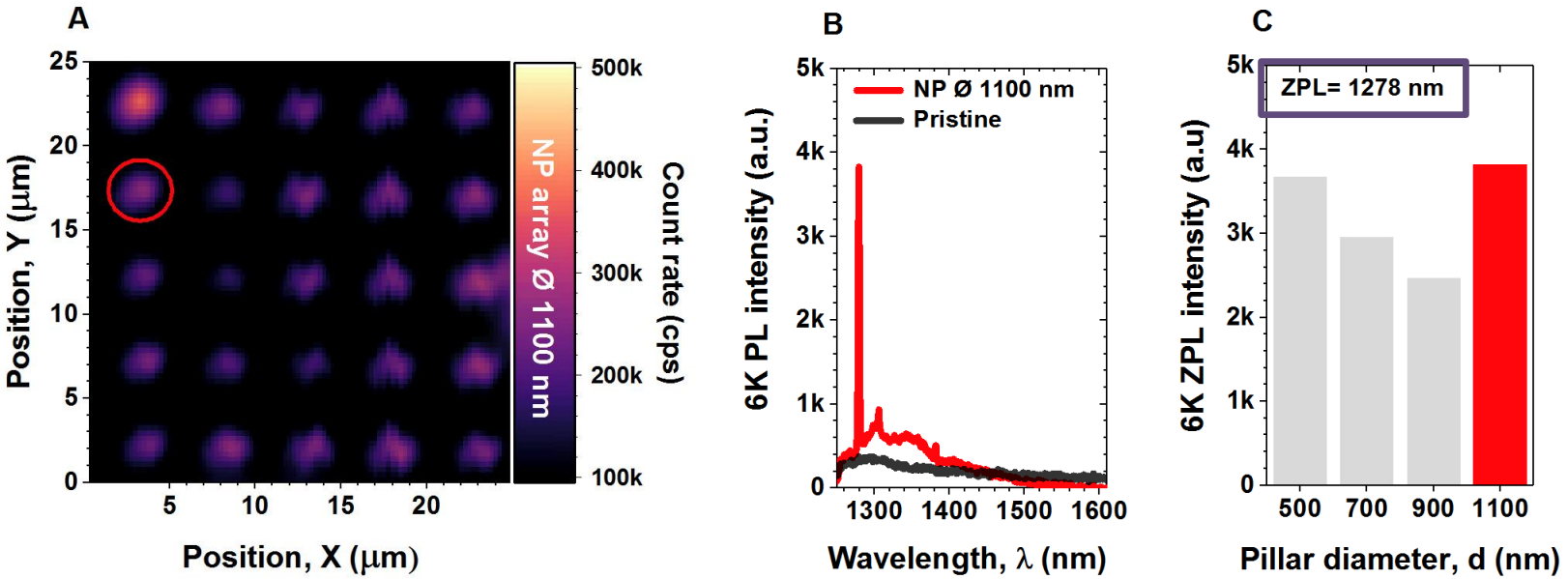
Array of Ø 300 nm pillars

Array of Ø 1100 nm pillars

Slower etching for small structures far apart

Ensembles of G-centers?

Carbon implantation post fabrication:
Fluence = 1X 10^{14} cm^{-2}, Energy = 250 keV, R_p ~ 600 nm



2D PL scan of array of Ø1100 nm pillars

Optical fingerprint of G-centre: ZPL at 1278 nm

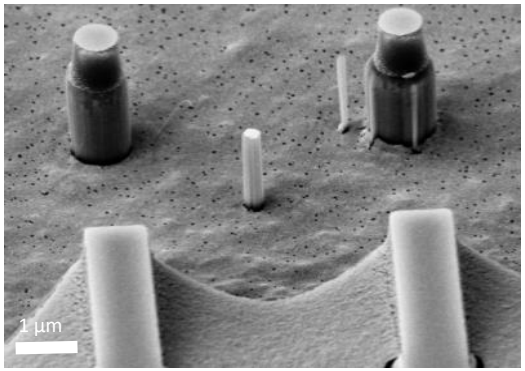
Successful fabrication of ensemble of G-centers in pillars

Manuscript in progress…

Conclusion and Outlook

- **Fabrication of defect-free pillars by MACEtch**
- **Ensembles of G-centers in Si using broad beam carbon implantation**

- **Further MACEtch optimization**
- **Ensembles to Single G-centers in pillars**
  - **Implantation parameters**
  - **Focused Ion Beam**



Towards Single Photon Emitters in Si…