

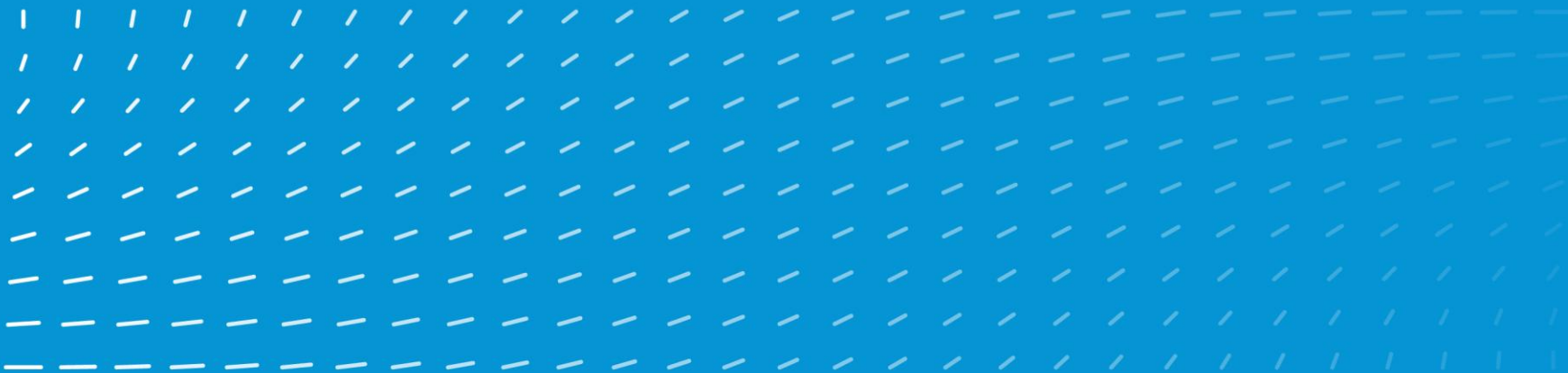
Integrated Quantum Photonics for Colour Centers in Silicon Carbide

LIN JIN

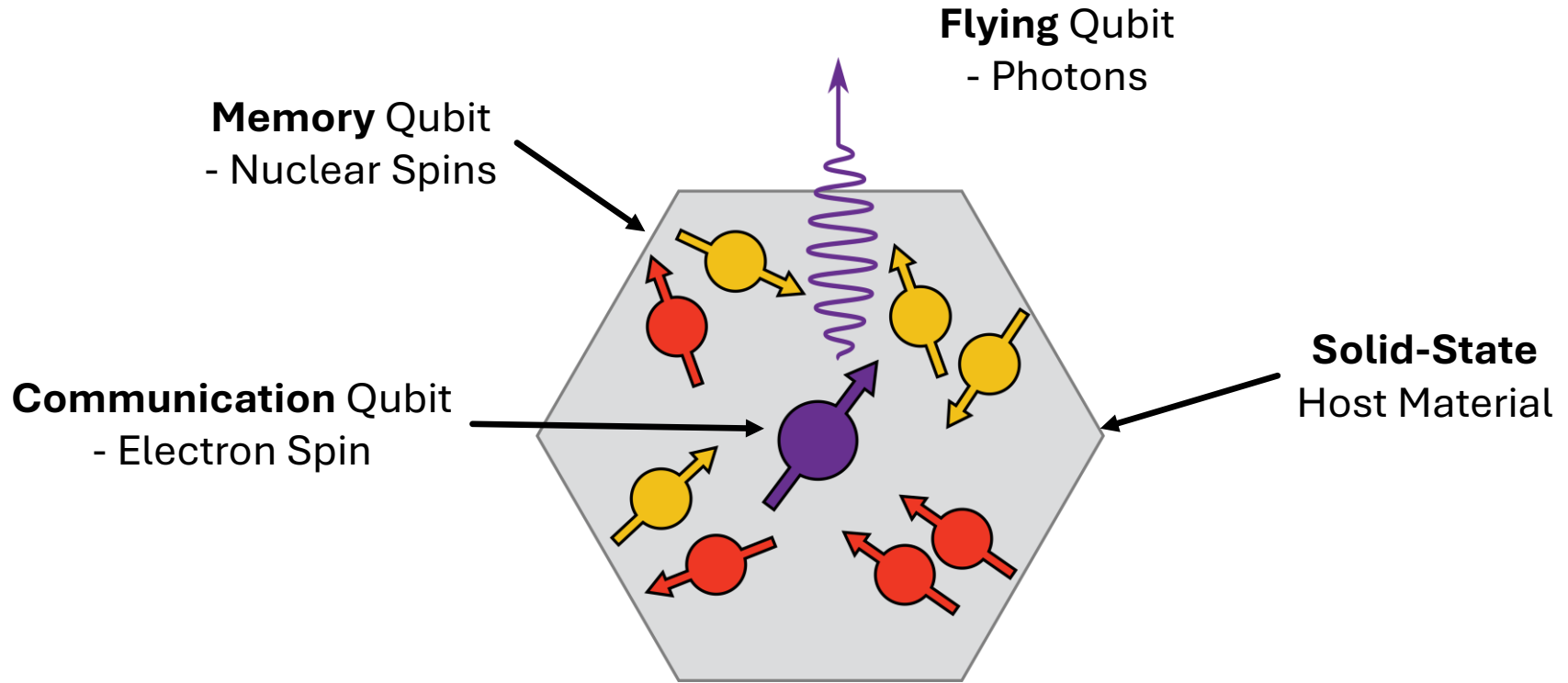
Ada Lovelace Fellow

07.09.2026

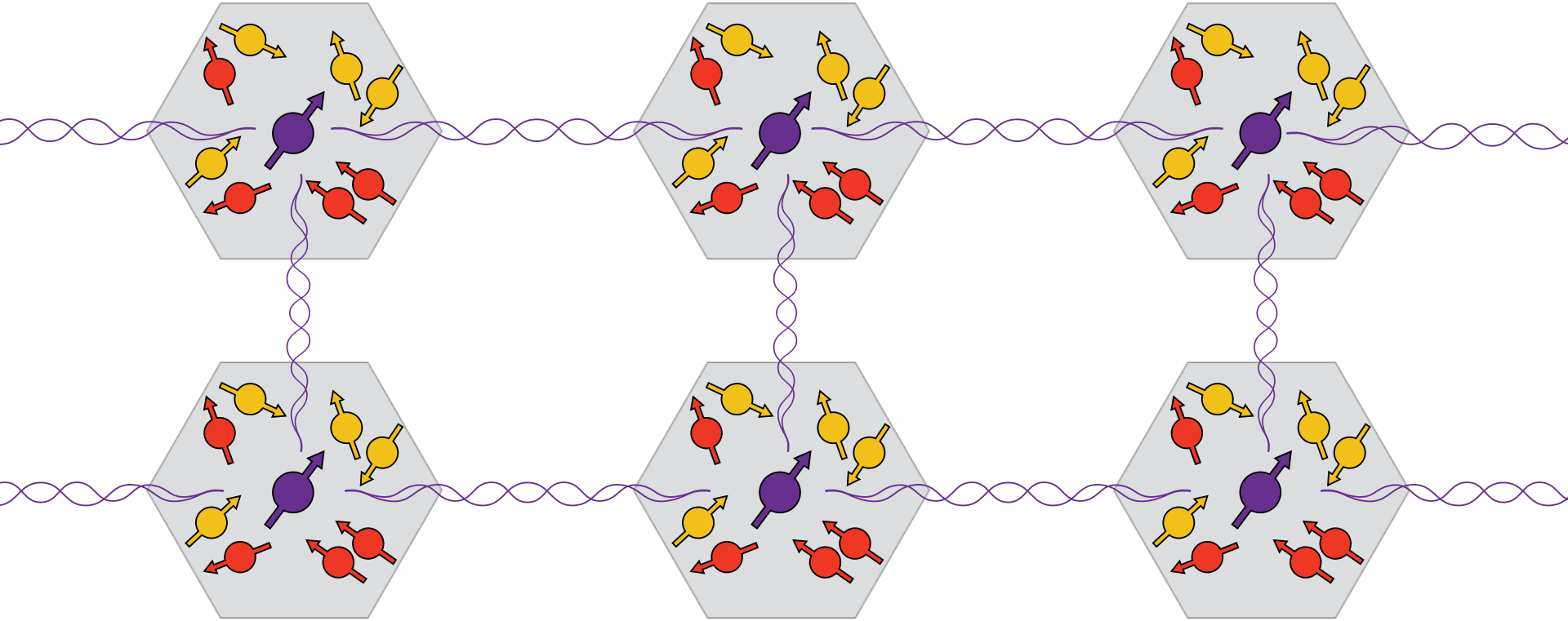
Dokkum, Netherlands



Defect in Solid State

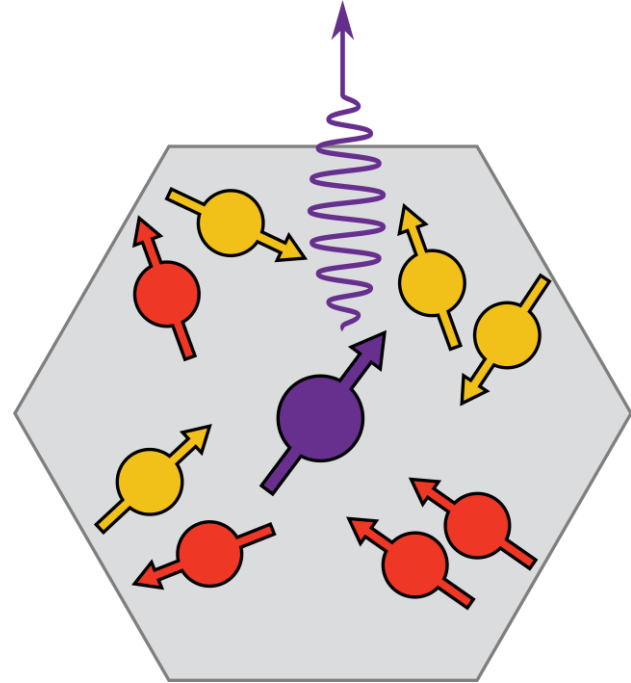


Ingredients for Quantum Applications



A Few Essentials

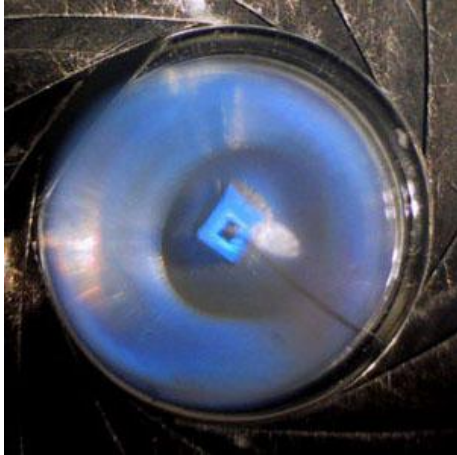
- Nanophotonic platform
- Good ZPL photon detection
- High fidelity control of qubits
-



Silicon Carbide (SiC)

Platform

1st commercial blue LED

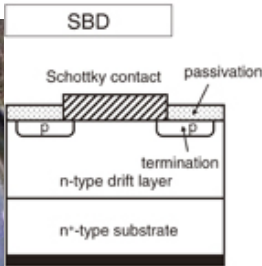
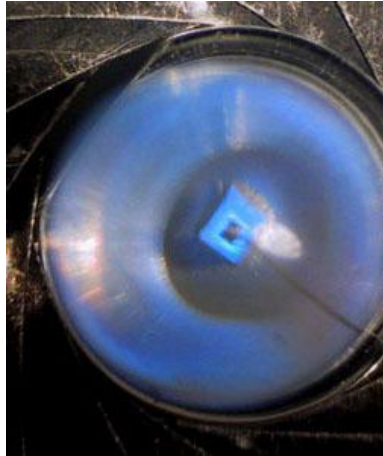


Silicon Carbide (SiC)

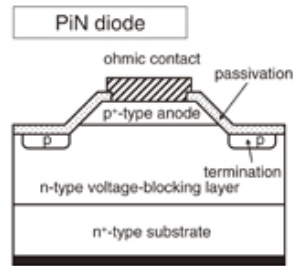
Platform

1st commercial blue LED

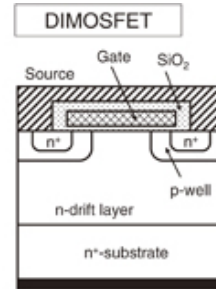
Power devices^[1]



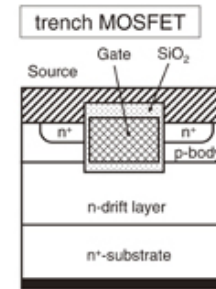
ohmic contact
(a)



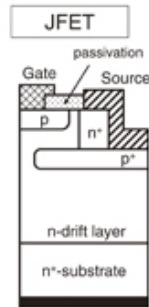
ohmic contact
(b)



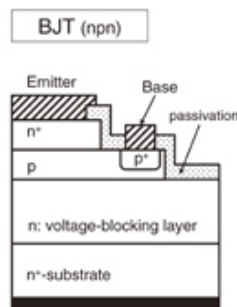
Drain
(c)



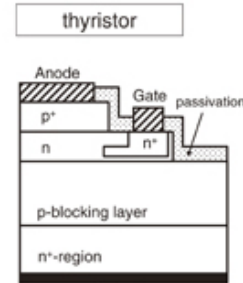
Drain
(d)



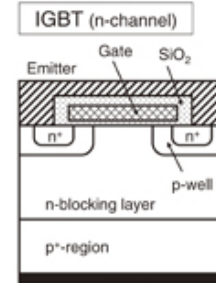
Drain
(e)



Collector
(f)



Cathode
(g)

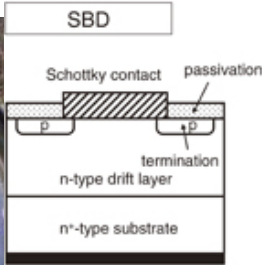
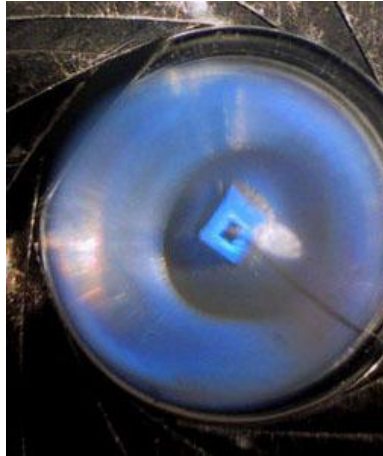


Collector
(h)

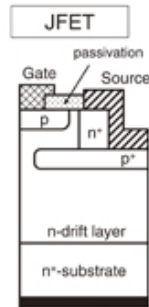
Silicon Carbide (SiC)

Platform

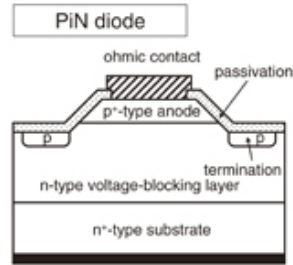
1st commercial blue LED



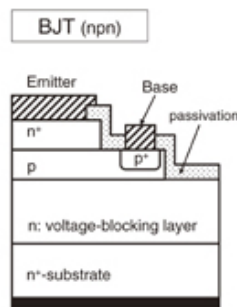
ohmic contact
(a)



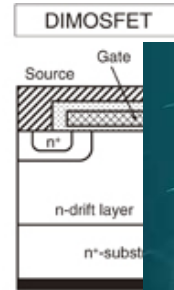
Drain
(e)



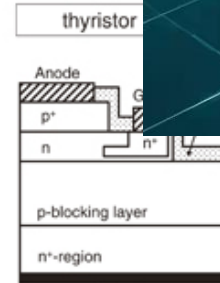
ohmic contact
(b)



Collector
(f)

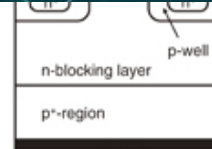
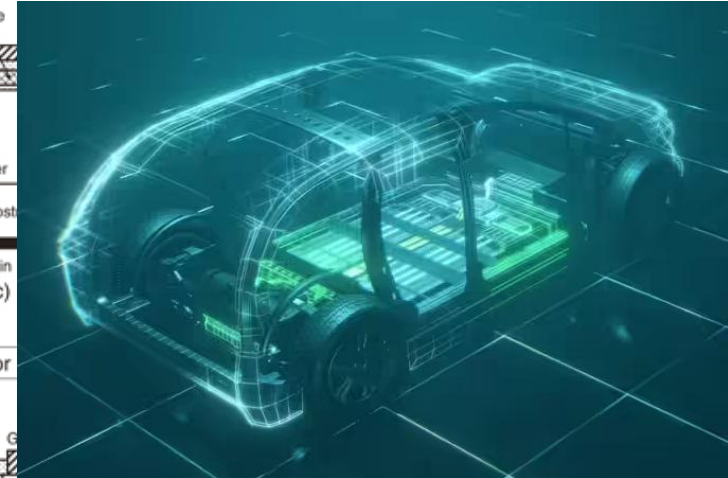


Drain
(c)



Cathode
(g)

trench MOSFET



Collector
(h)

Silicon Carbide (SiC)

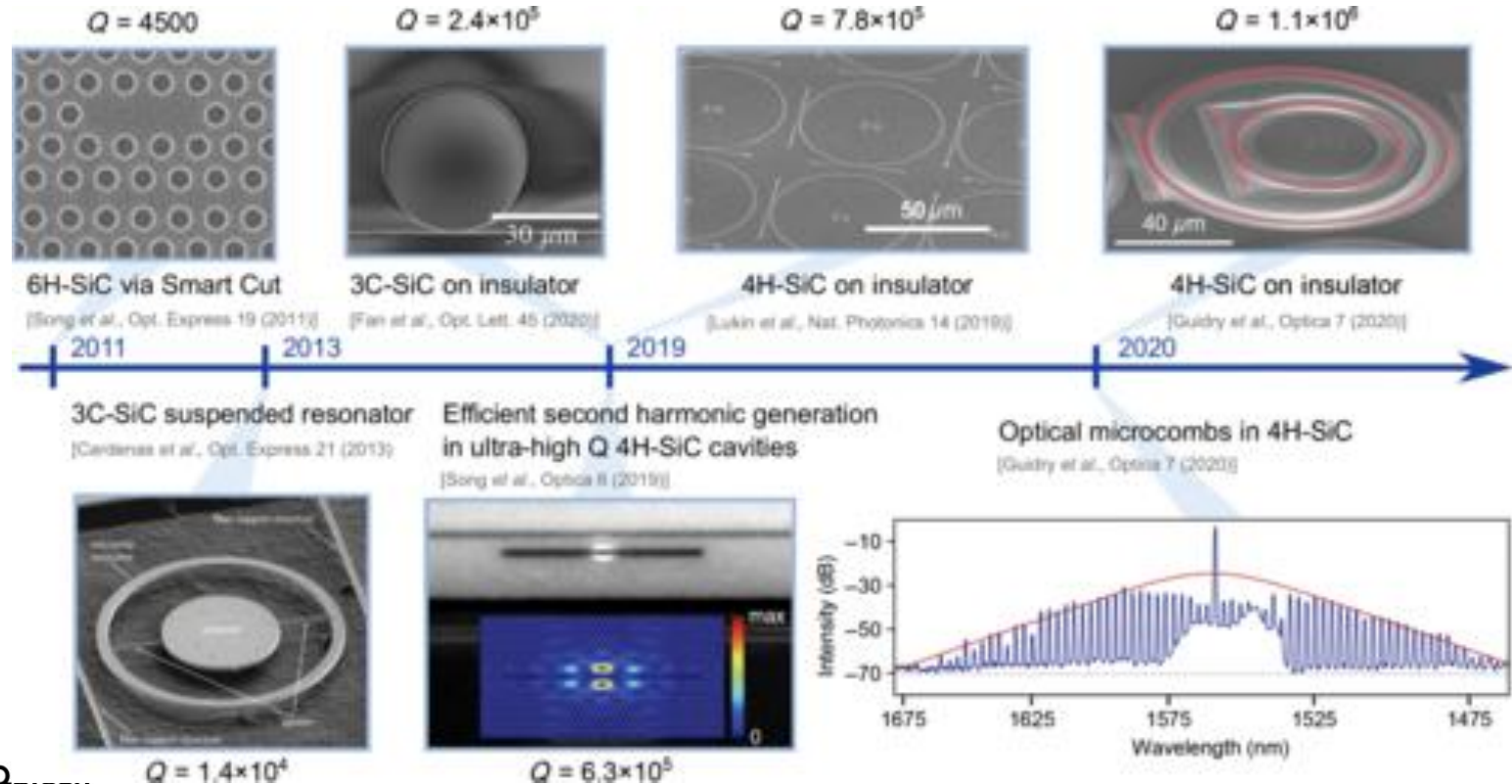
Platform

- Large-size wafers available
- Foundry ready
- CMOS compatible



Silicon Carbide (SiC)

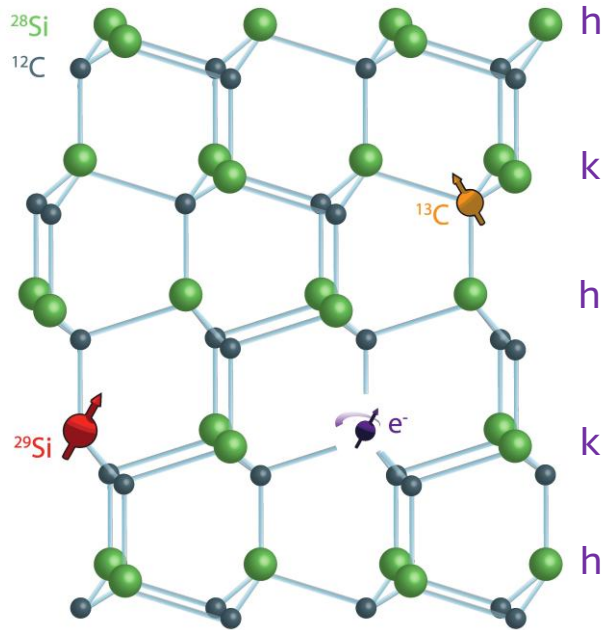
Nanophotonic Platform



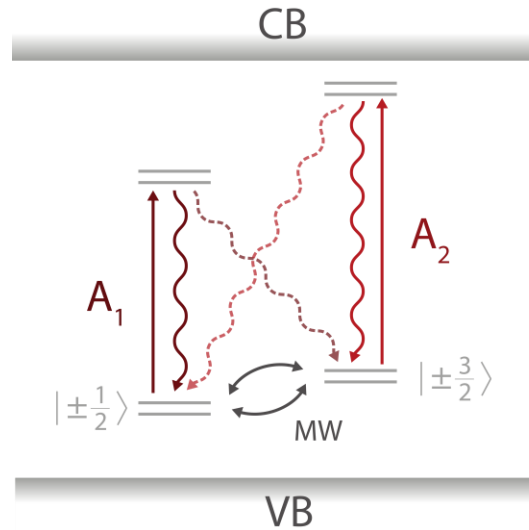
Q.....

V2 Defects in 4H-SiC

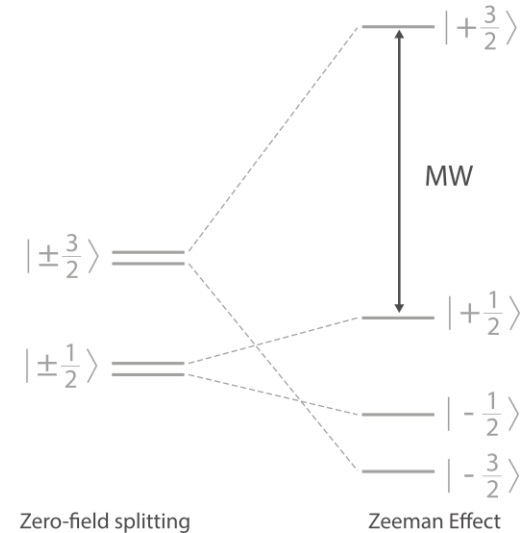
Two nuclear species



A1 / A2 transition



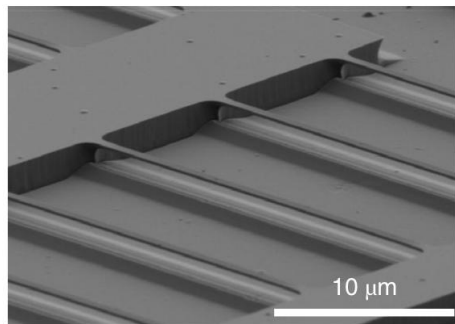
Spin 3/2



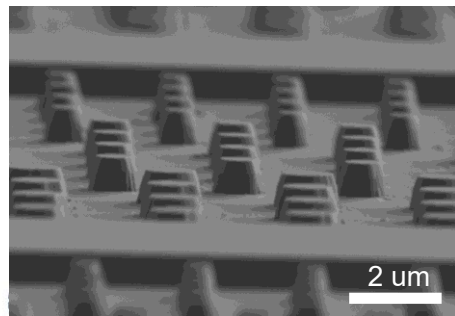
V2 Defects in 4H-SiC

Optical Stability

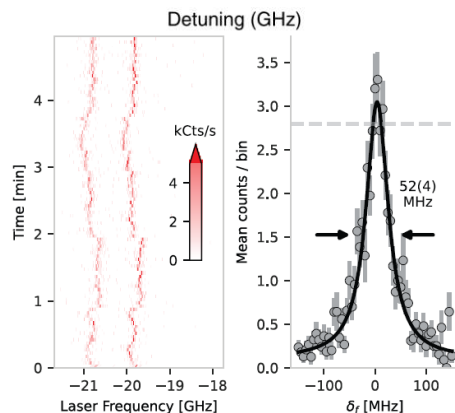
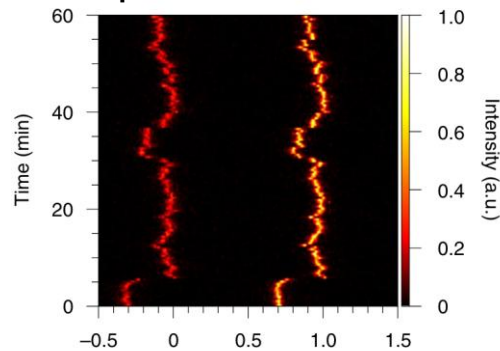
Stable optical lines in photonics



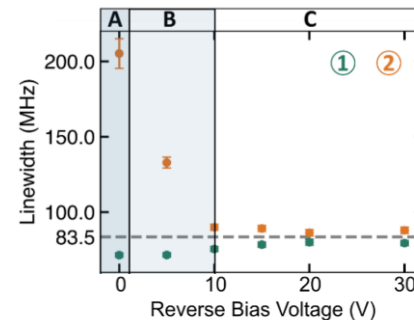
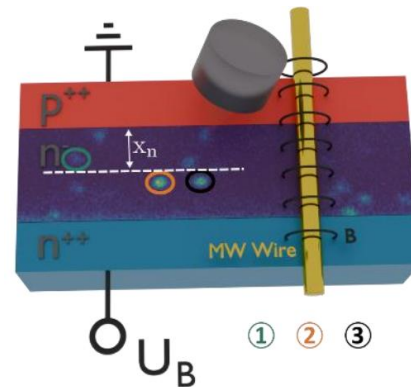
[1]. Babin et al. Nature Materials (2022)



[2]. L. Feiji, et al., Nano Lett. (2026) 26 (28): 9143–9150

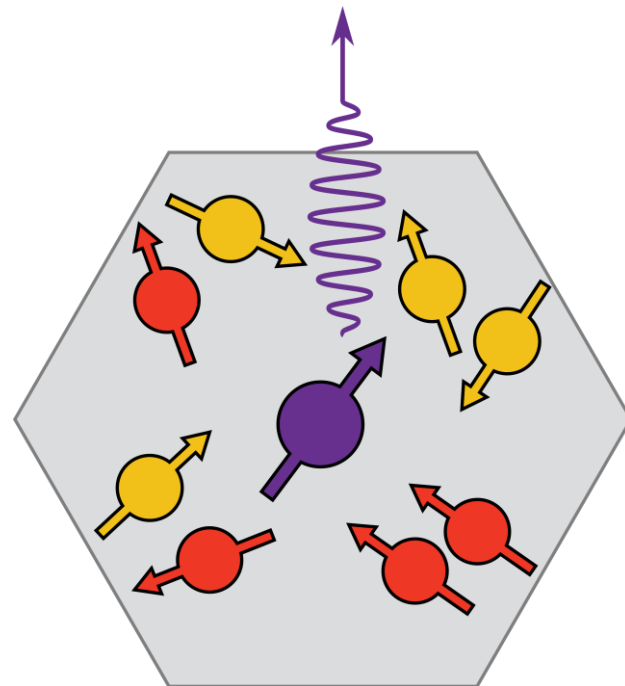


Improve stability with PiN-diodes



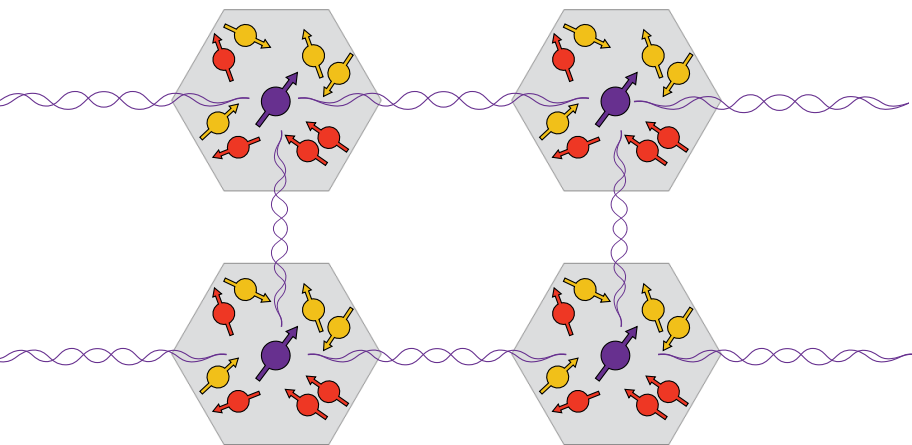
A Few Essentials

- **Nanophotonic platform**
- Good ZPL photon detection
- High fidelity control of qubits
-



Challenge

ZPL Photon Detection Probability



RESEARCH ARTICLE | JULY 01 2024

Thresholds for the distributed surface code in the presence of memory decoherence

Sébastien de Bone  ; Paul Möller  ; Conor E. Bradley  ; Tim H. Taminiau; David Elkouss 

 Check for updates

+ Author & Article Information

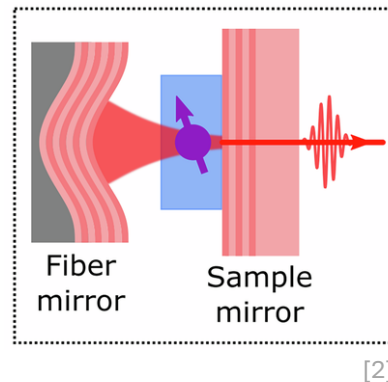
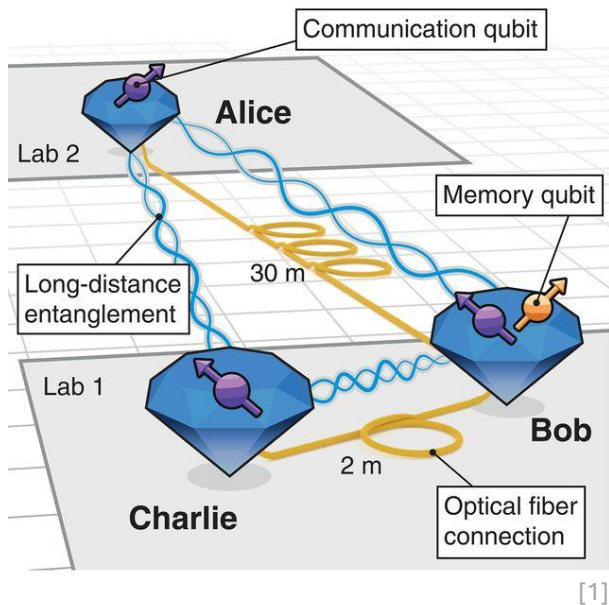
AVS Quantum Sci. 6, 033801 (2024)

<https://doi.org/10.1116/5.0200190> Article history 

$$\eta_{link}^* = \frac{r_{ent}}{r_{dec}} \approx 1e^3$$

Challenge

ZPL Photon Detection Probability



$$\eta_{link}^* < 1$$

ZPL photon detection $P_{det} \sim 0.5\%$

Challenge

ZPL Photon Detection Probability

Probability that the color center in bulk emits a ZPL photon:

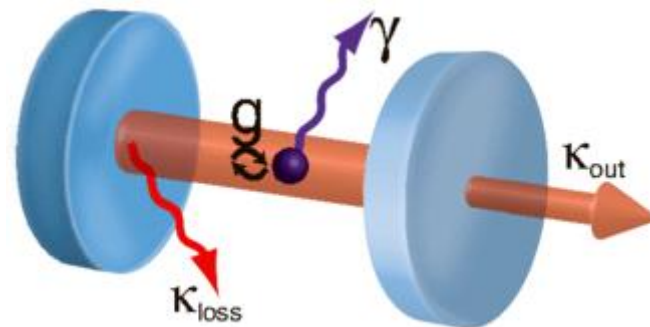
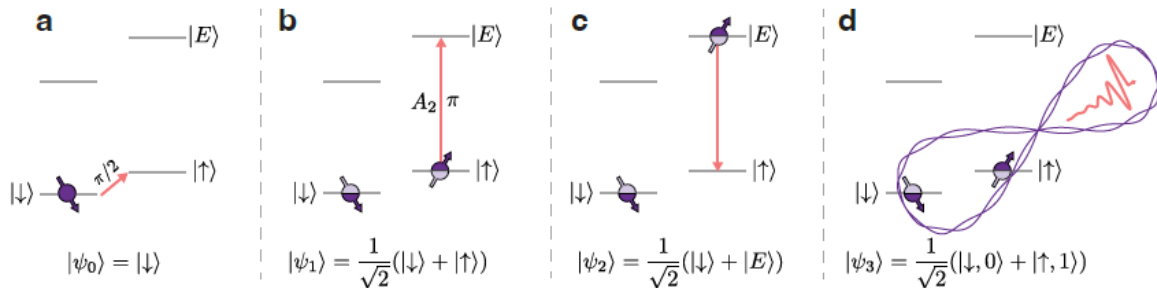
$$\beta_0 = \eta_{DW}\eta_{QE}$$

Purcell enhancement:

$$F_P = \frac{3}{4\pi^2} \left(\frac{\lambda}{n}\right)^3 \frac{Q_{tot}}{V} \zeta_{polarization} \zeta_{spatial}$$

Cooperativity:

$$C \propto F_P \beta_0$$



Challenge

ZPL Photon Detection Probability

Probability that the emitter decays into the cavity mode:

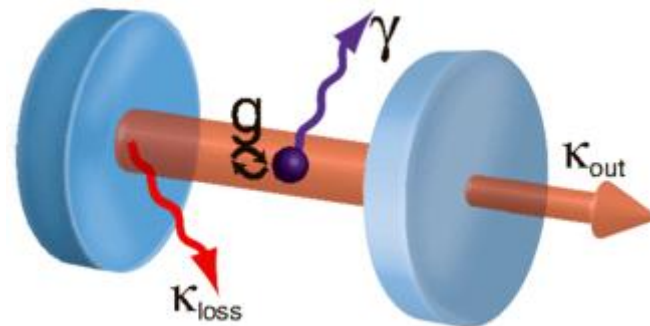
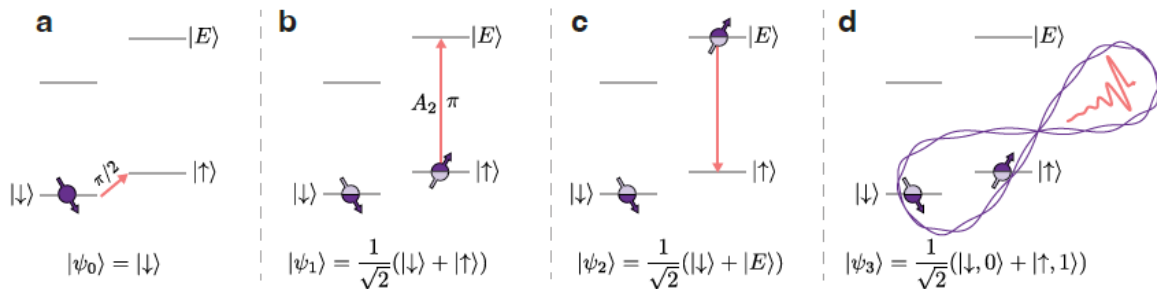
$$\beta = \frac{C}{C + 1}$$

Probability that a photon inside the cavity couples to the waveguide:

$$\eta_{out} = \frac{\kappa_{out}}{\kappa_{out} + \kappa_{loss}} = \frac{Q_{int}}{Q_{int} + Q_{ext}}$$

Coupling efficiency:

$$\eta_{cp}$$



Motivation

ZPL Photon Detection Probability

Analytic expression for quantifying the probability:

$$\beta_e = \beta \eta_{out} \eta_{cp} = \frac{c}{c+1} \frac{Q_{int}}{Q_{int} + Q_{ext}} \eta_{cp}$$

Photonic Crystal Nanobeam Cavity

Coupler

WG Realization & Photon Collection

Fab. method

- Bulk SiC
- SiCOI

Coupling

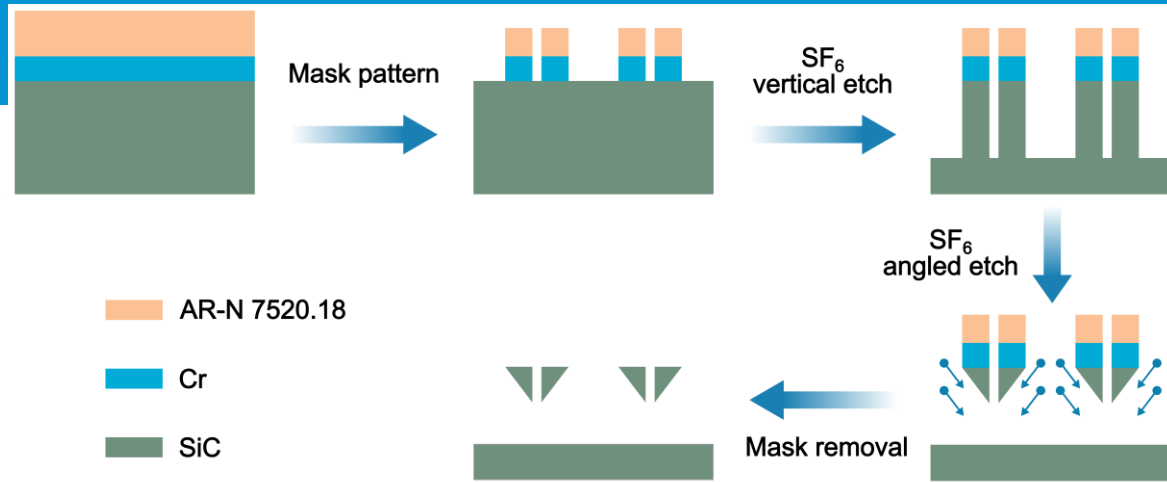
- 3D TIR coupler
- Tapered fiber

SiCOI Fishbone Cavities

- Cavity design, fab. & characterization
- Q_{int} vs. Q_{ext}

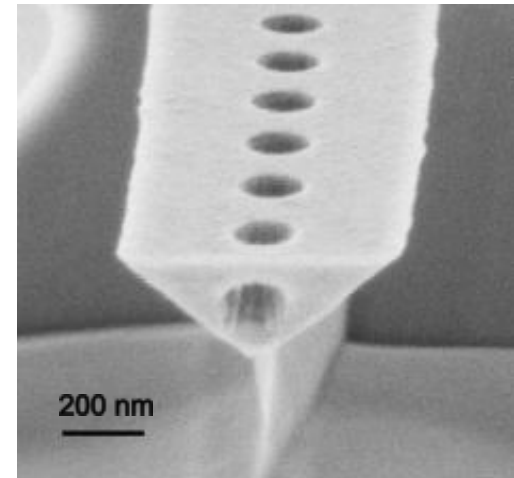
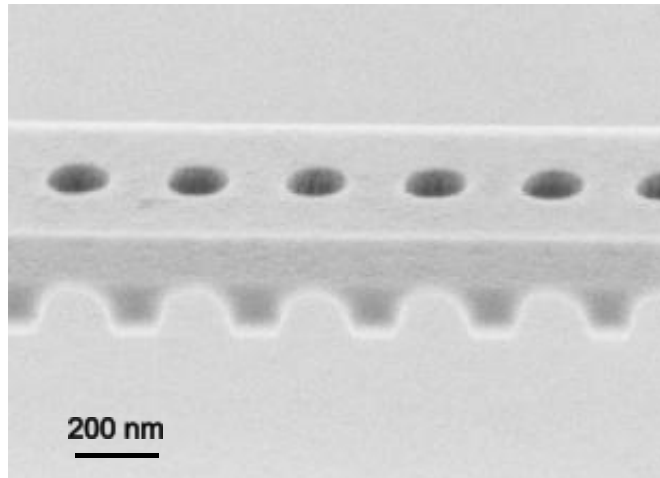
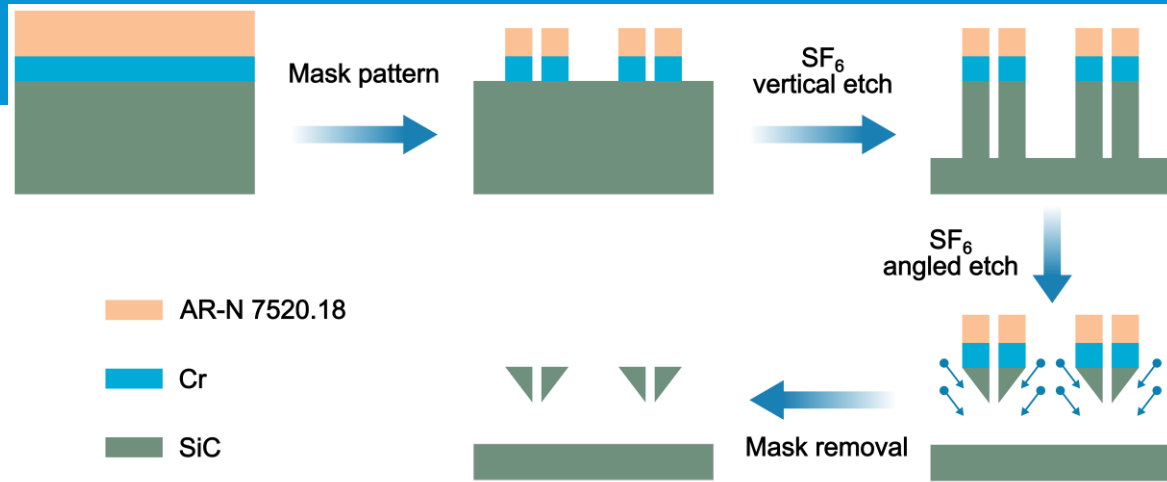
Fabrication

Bulk SiC



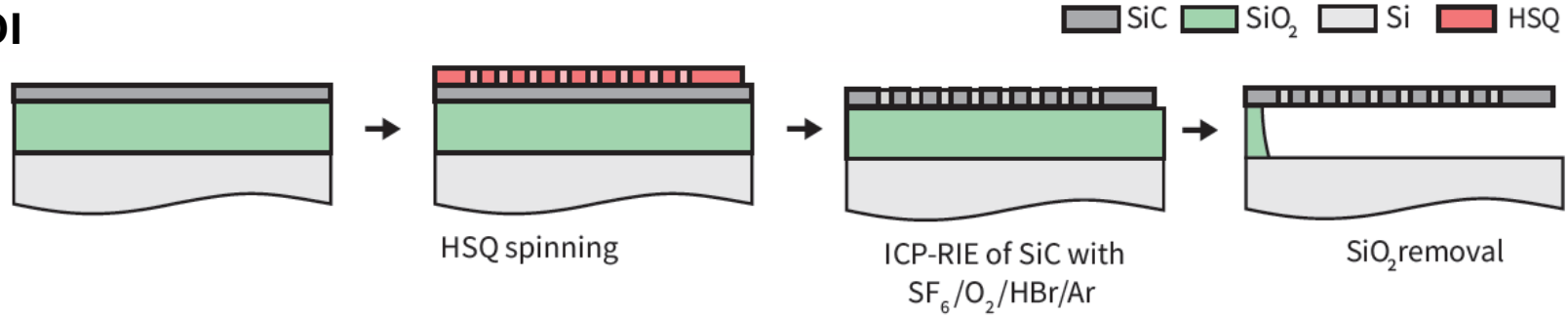
Fabrication

Bulk SiC



Fabrication

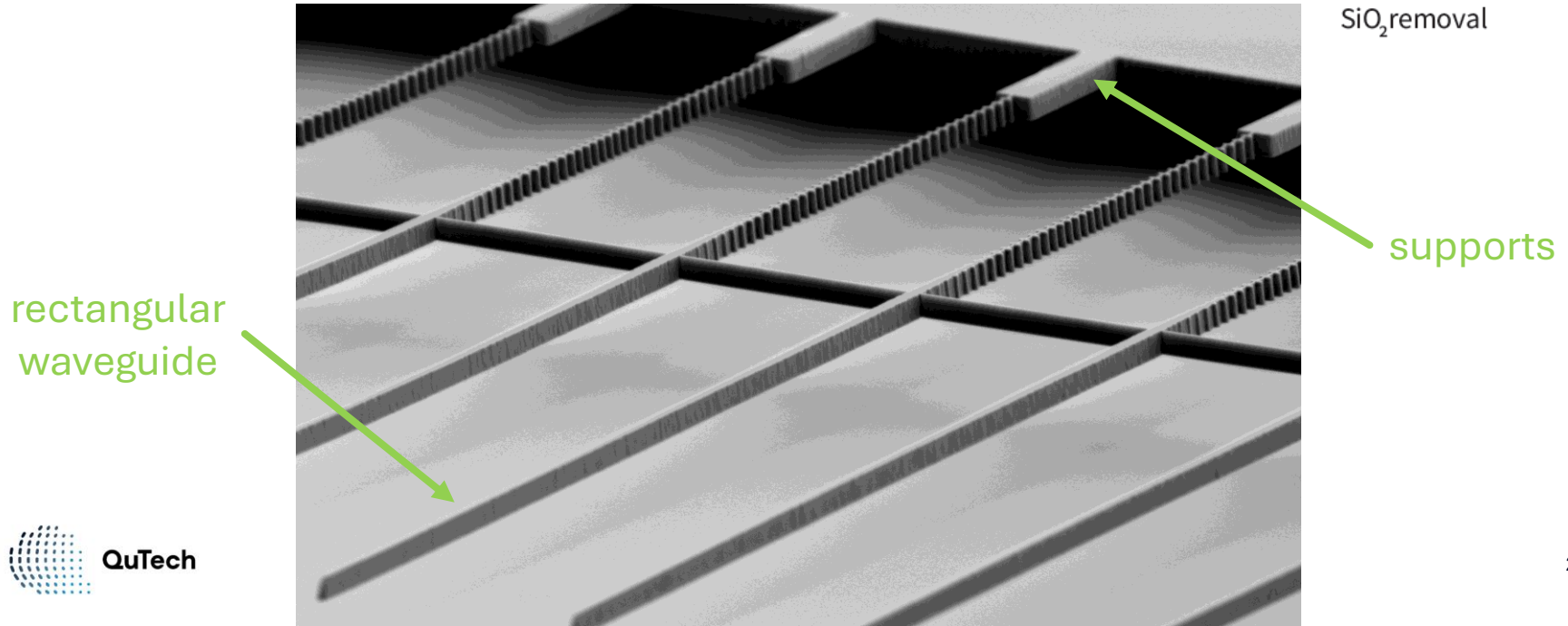
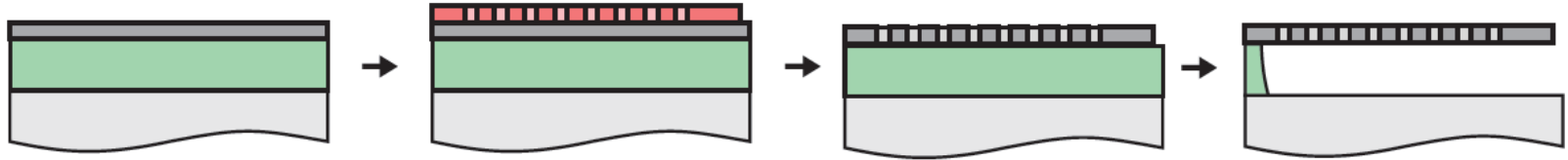
SiCOI



Fabrication

SiCOI

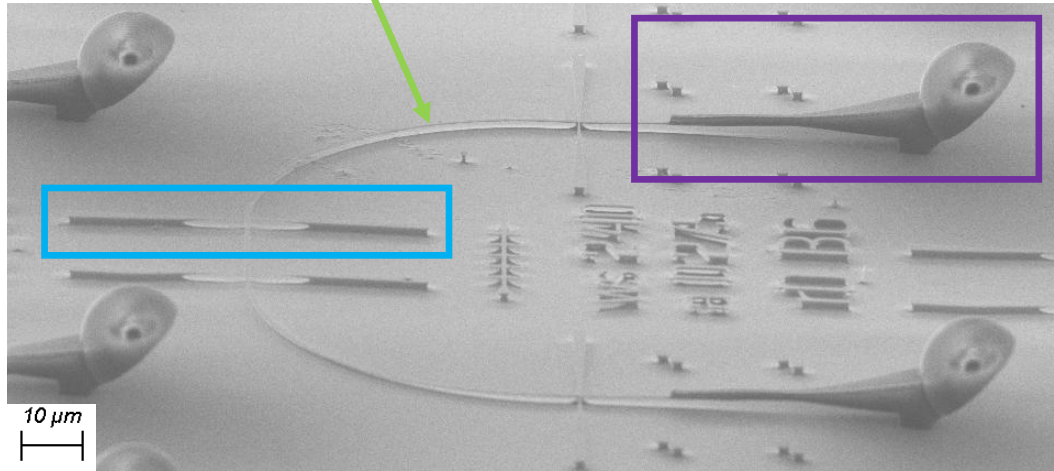
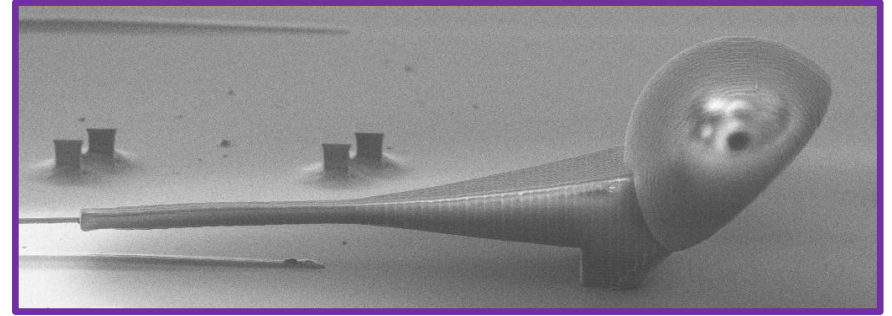
■ SiC ■ SiO₂ ■ Si ■ HSQ



Signal Collection

TIR 3D Couplers

suspended SiC WG
triangular cross-section



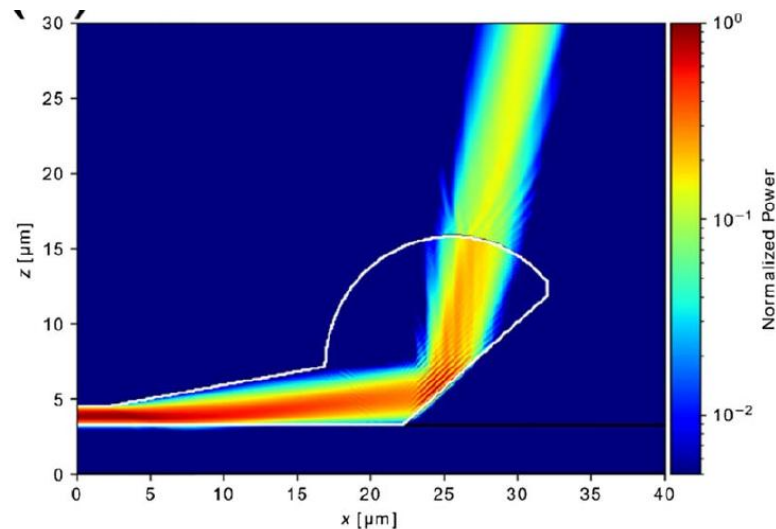
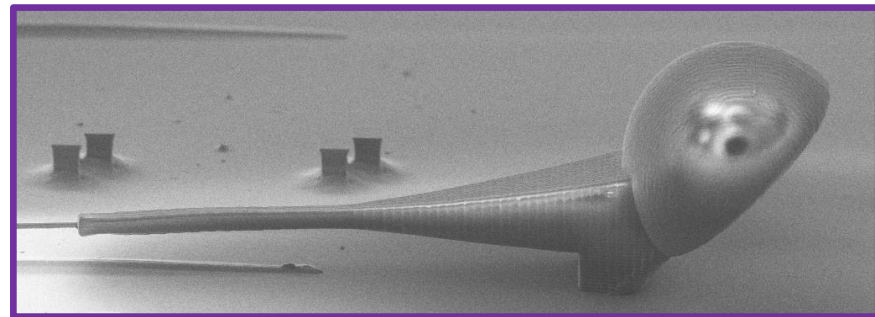
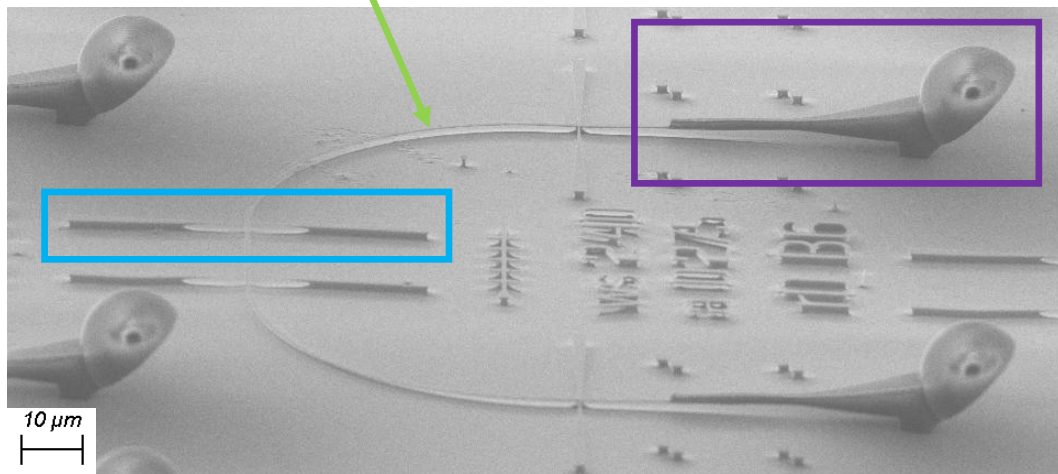
QuTech

cross support

Signal Collection

TIR 3D Couplers

suspended SiC WG
triangular cross-section



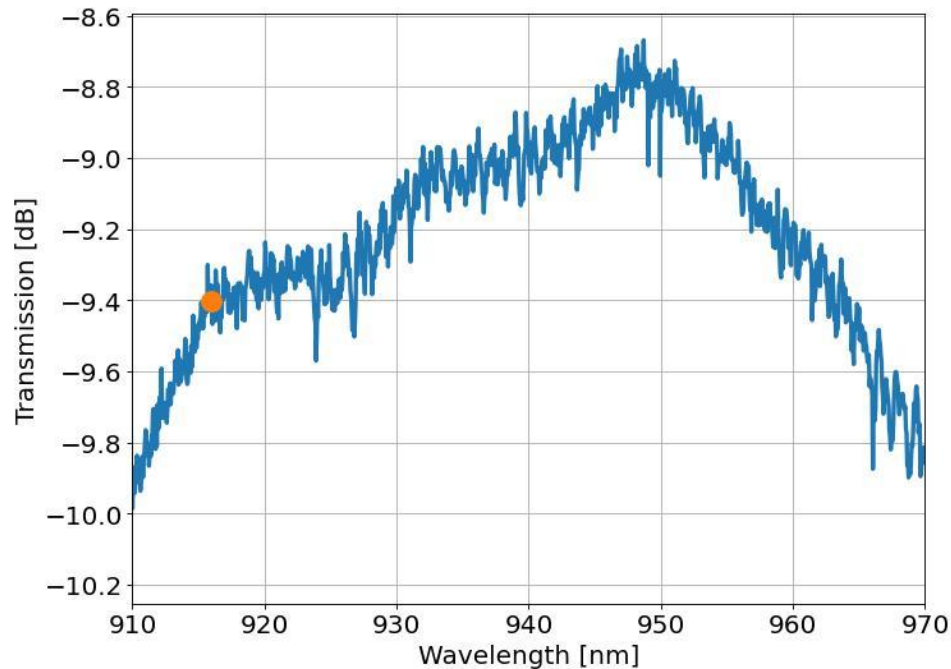
QuTech

cross support

Signal Collection

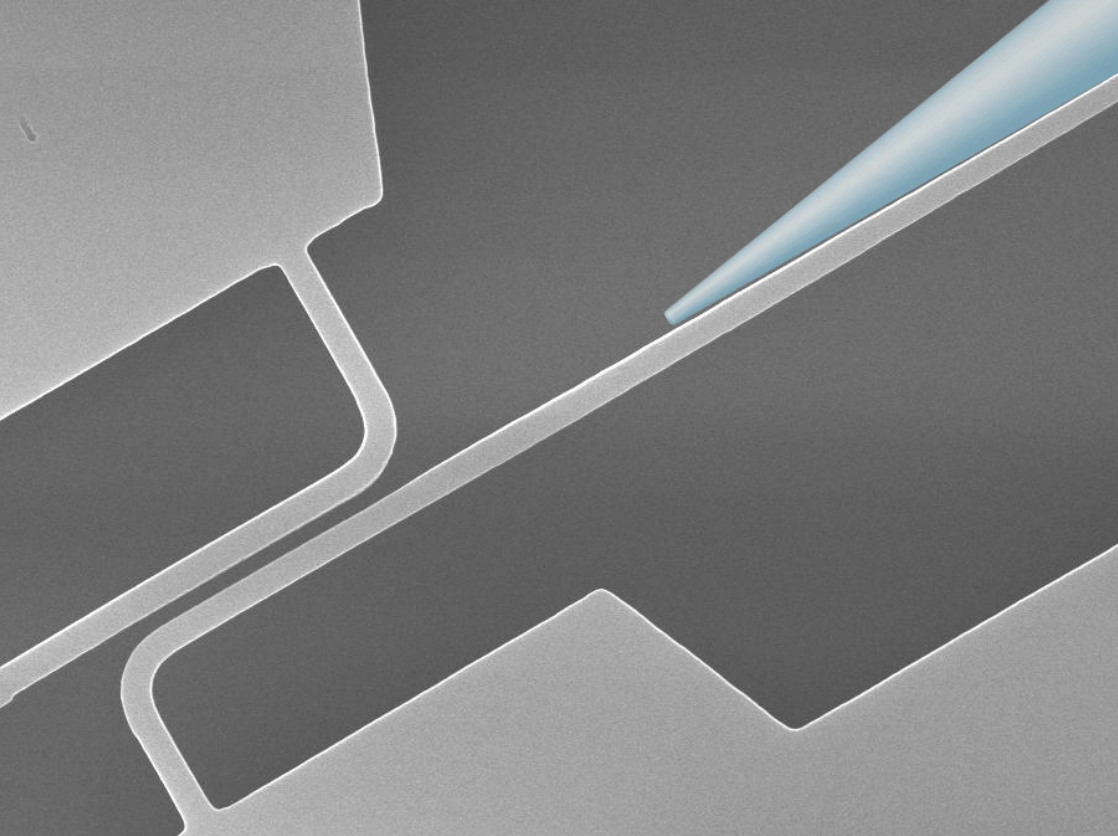
TIR 3D Couplers

- Transmission @ 916 nm: -9.4 dB
- Coupling efficiency: ~30%



Signal Collection

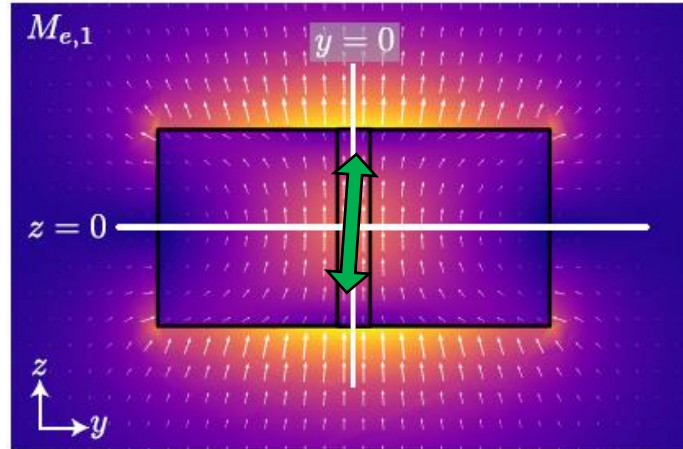
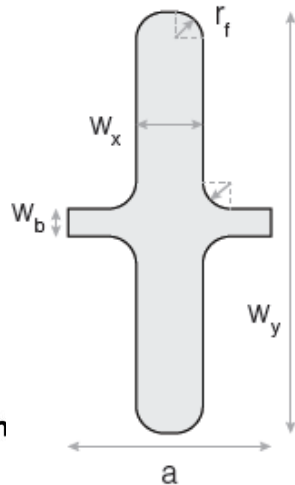
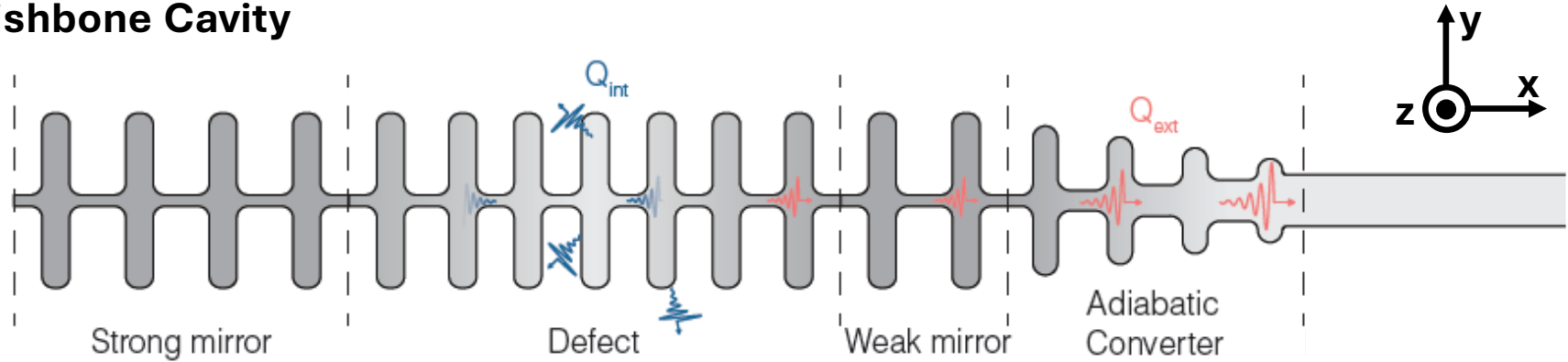
Tapered Fiber



- Transmission @ broadband
- Coupling efficiency > 90%

Photonic Crystal Cavity in SiC

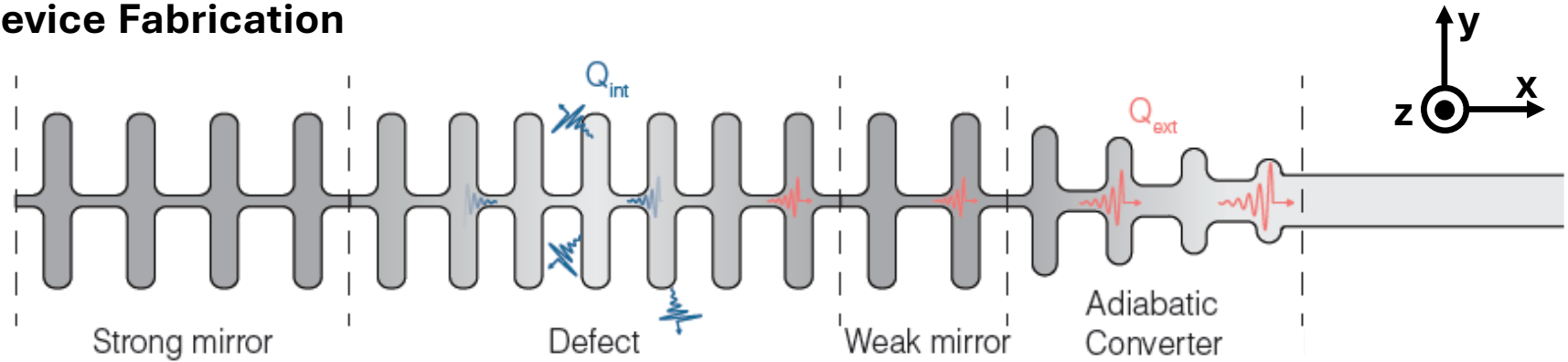
Fishbone Cavity



$$C \propto \zeta_{polarization}$$

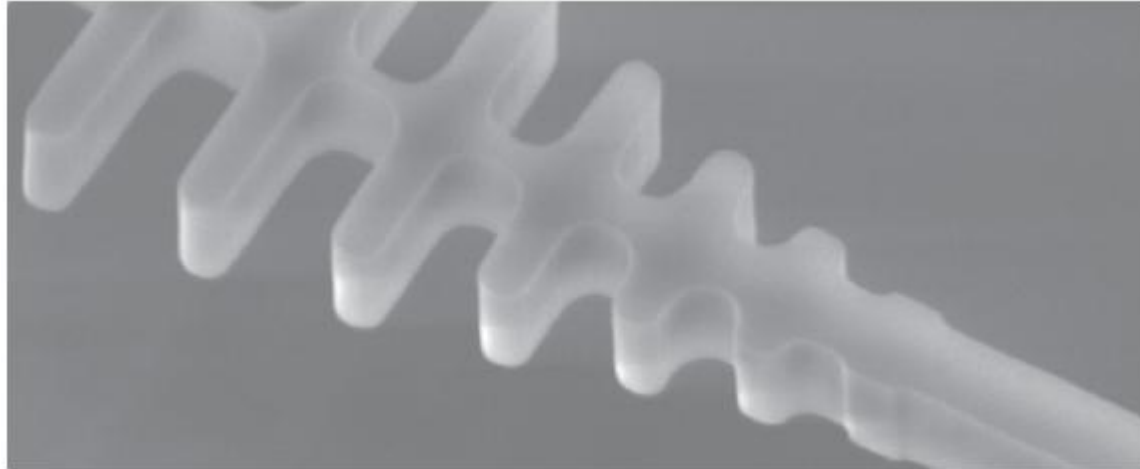
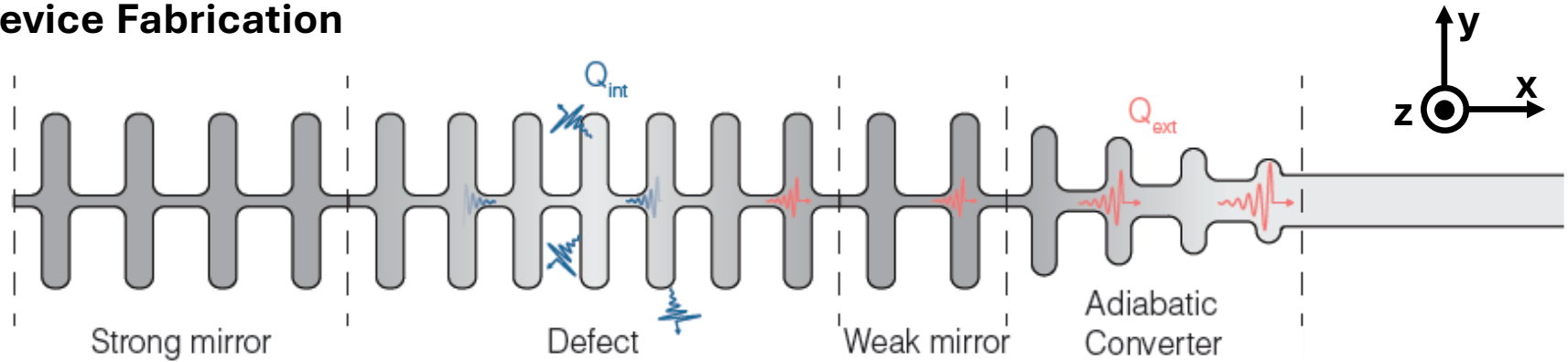
Fishbone Cavity

Device Fabrication



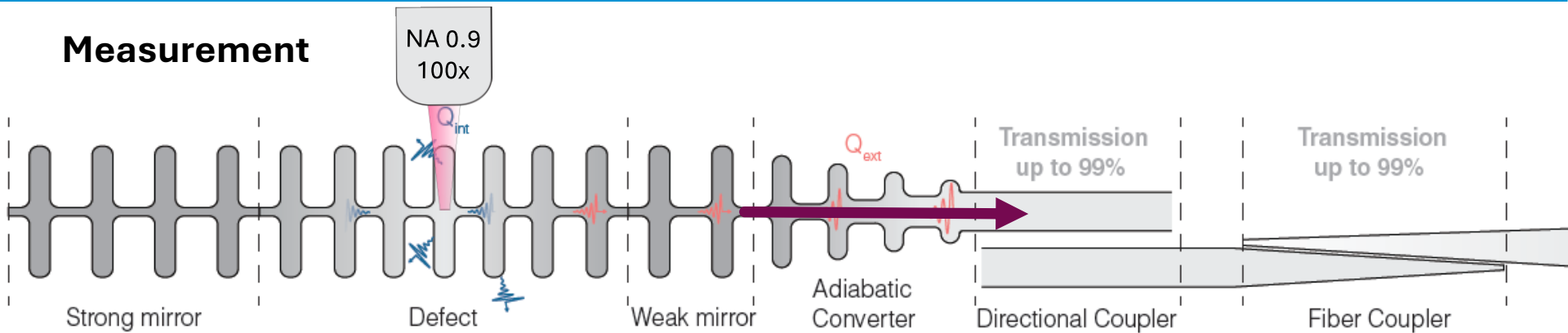
Fishbone Cavity

Device Fabrication

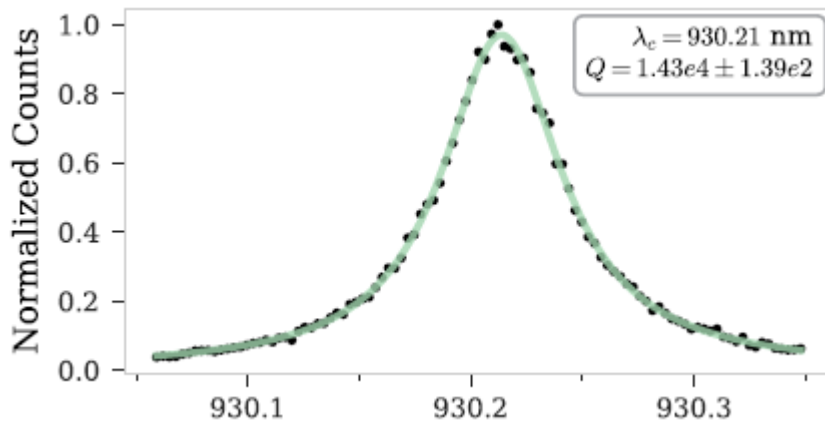


Fishbone Cavity

Measurement

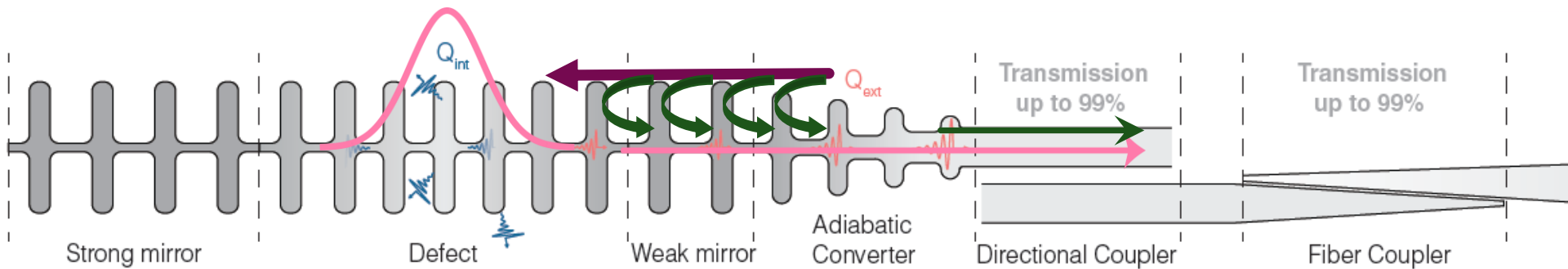


- Top-excitation & fiber collection
- Q_{tot} obtained

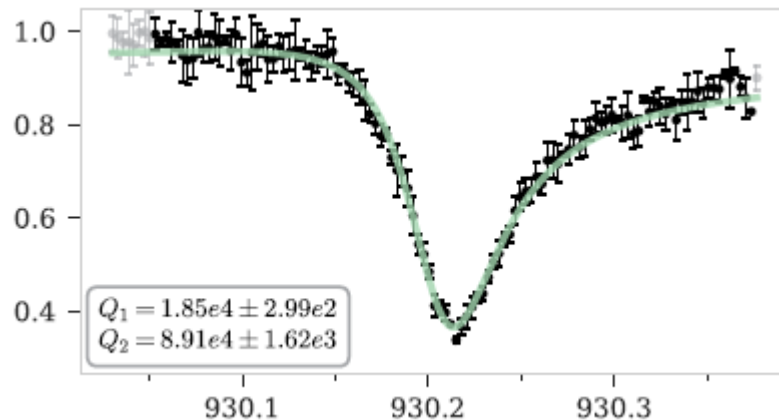


Fishbone Cavity

Measurement

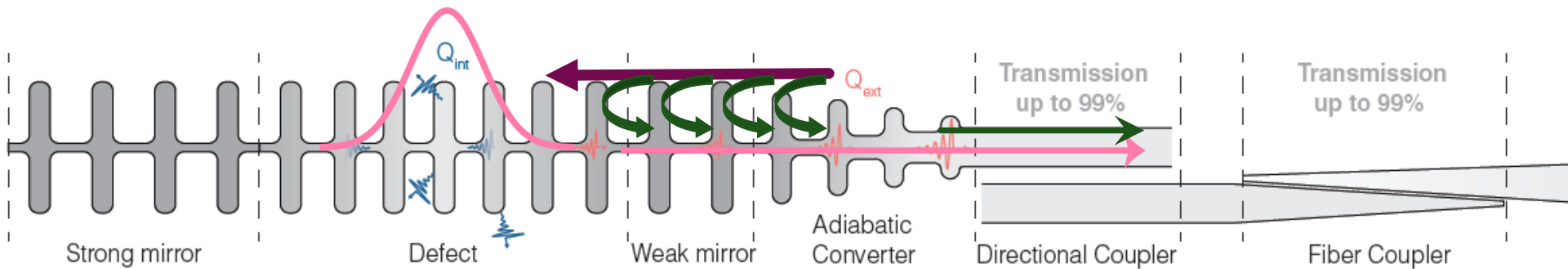


- Fiber-based excitation & collection
- Asymmetric reflection spectrum



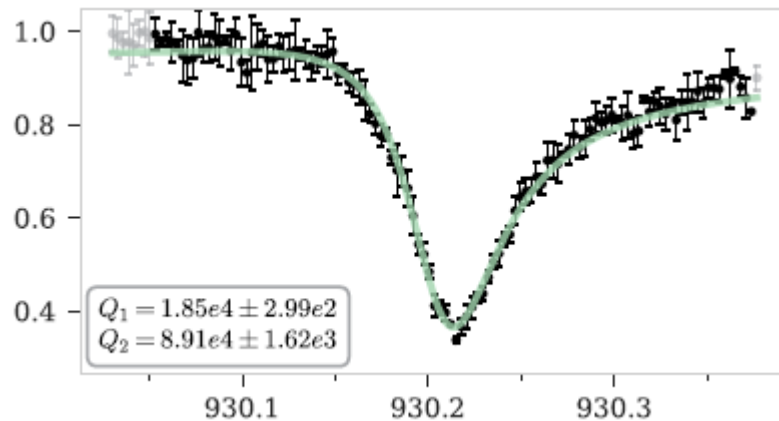
Fishbone Cavity

Measurement



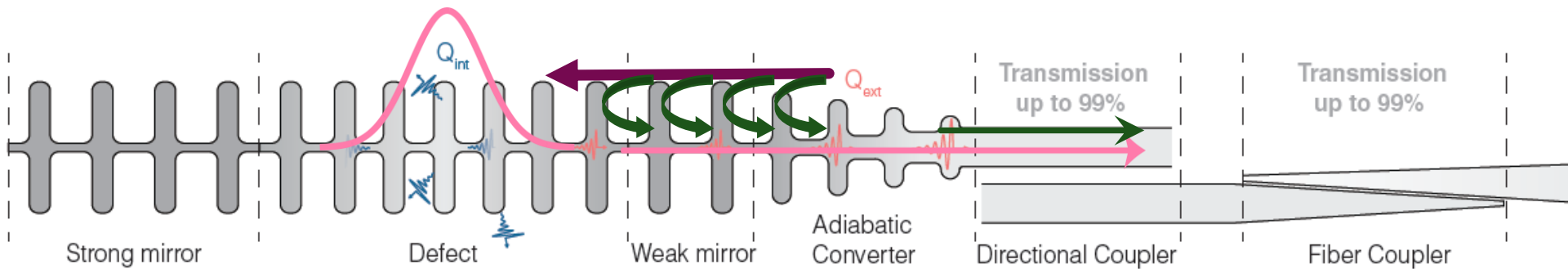
- Diameter correction method (DCM)

$$R(\omega) = \left| 1 - \frac{Q_{tot}}{|\tilde{Q}_{ext}|} \frac{2}{1 + 2iQ_{tot} \frac{\omega_0 - \omega}{\omega_0}} \right|^2$$



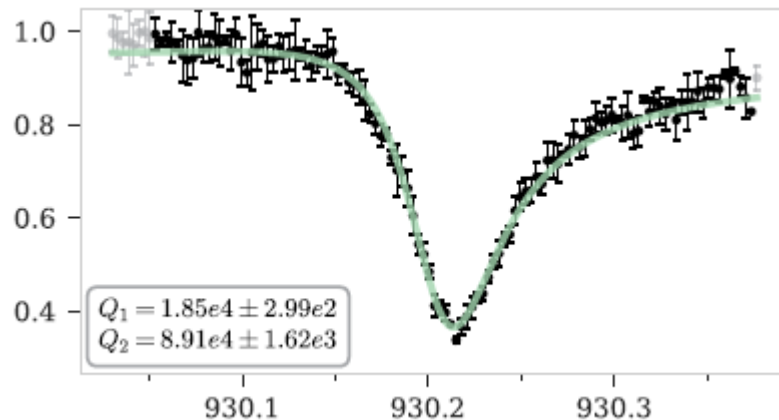
Fishbone Cavity

Measurement



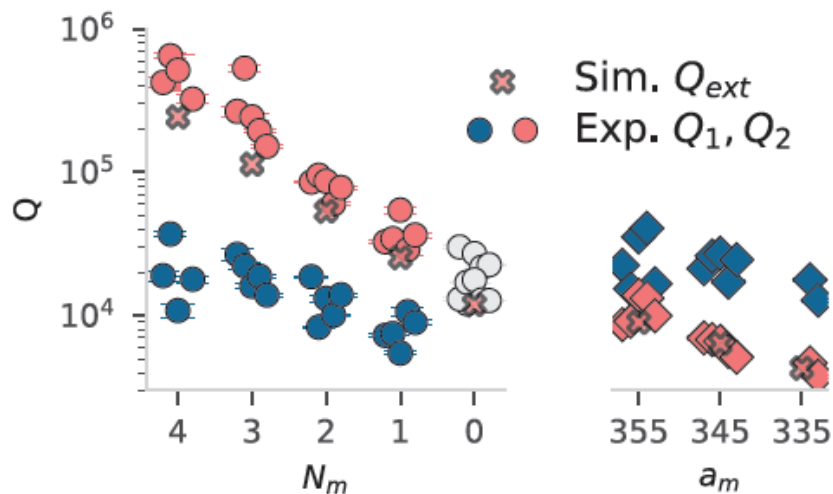
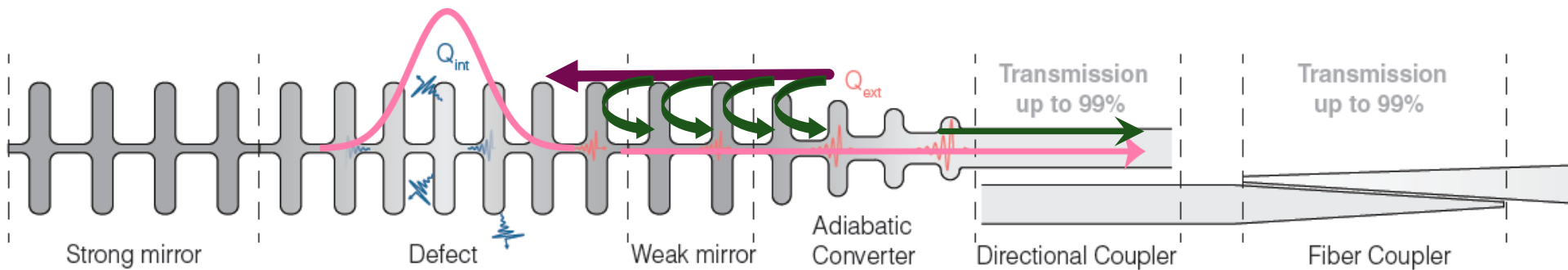
$$R(\omega) = \left| 1 - \frac{Q_{tot}}{|\tilde{Q}_{ext}|} \frac{2}{1 + 2iQ_{tot} \frac{\omega_0 - \omega}{\omega_0}} \right|^2$$

$$\rightarrow \eta_{out} = \frac{Q_{int}}{Q_{int} + Q_{ext}}$$



Fishbone Cavity

Measurement



Fishbone Cavity

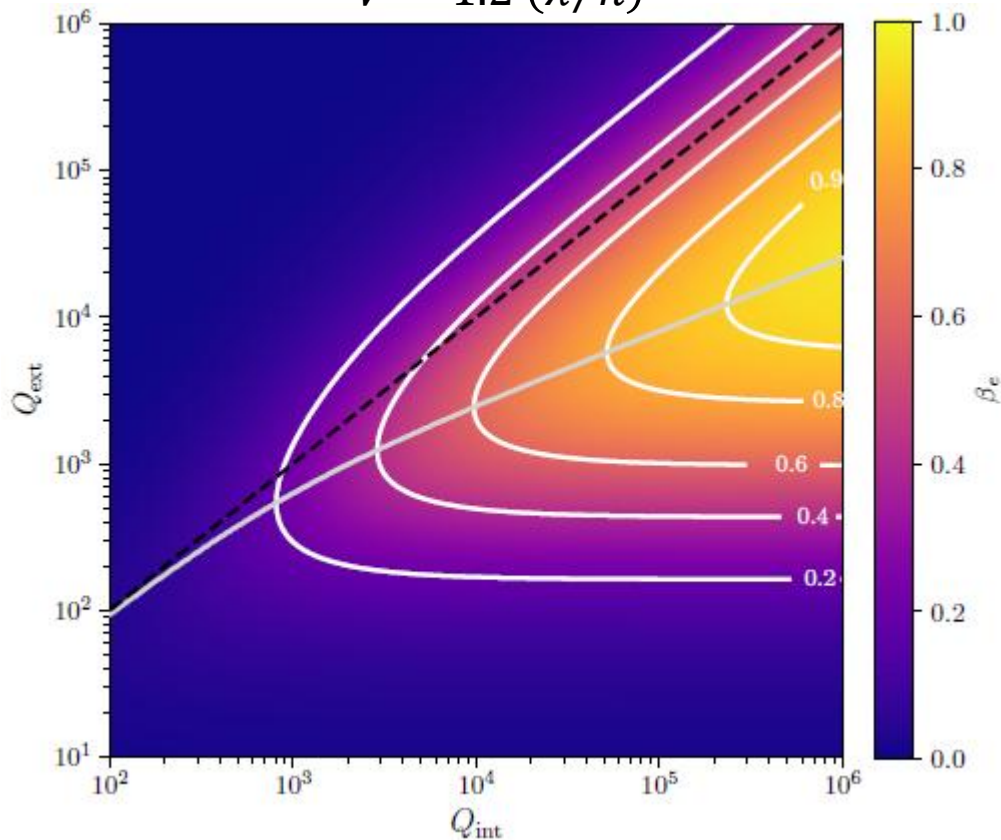
Q_{int} vs. Q_{ext}

$$\beta_e \propto \frac{C}{C+1} \frac{Q_{int}}{Q_{int} + Q_{ext}}$$

- Optimal Q_{ext} depends on Q_{int}
- Generally, lies in the range from 10^3 to 10^4 for realistically achievable Q_{int}
- $\rightarrow$ cavity should be over-coupled ($Q_{int} > Q_{ext}$)

$$\zeta_{polarization} \zeta_{spatial} = 0.4$$

$$V = 1.2 (\lambda/n)^3$$

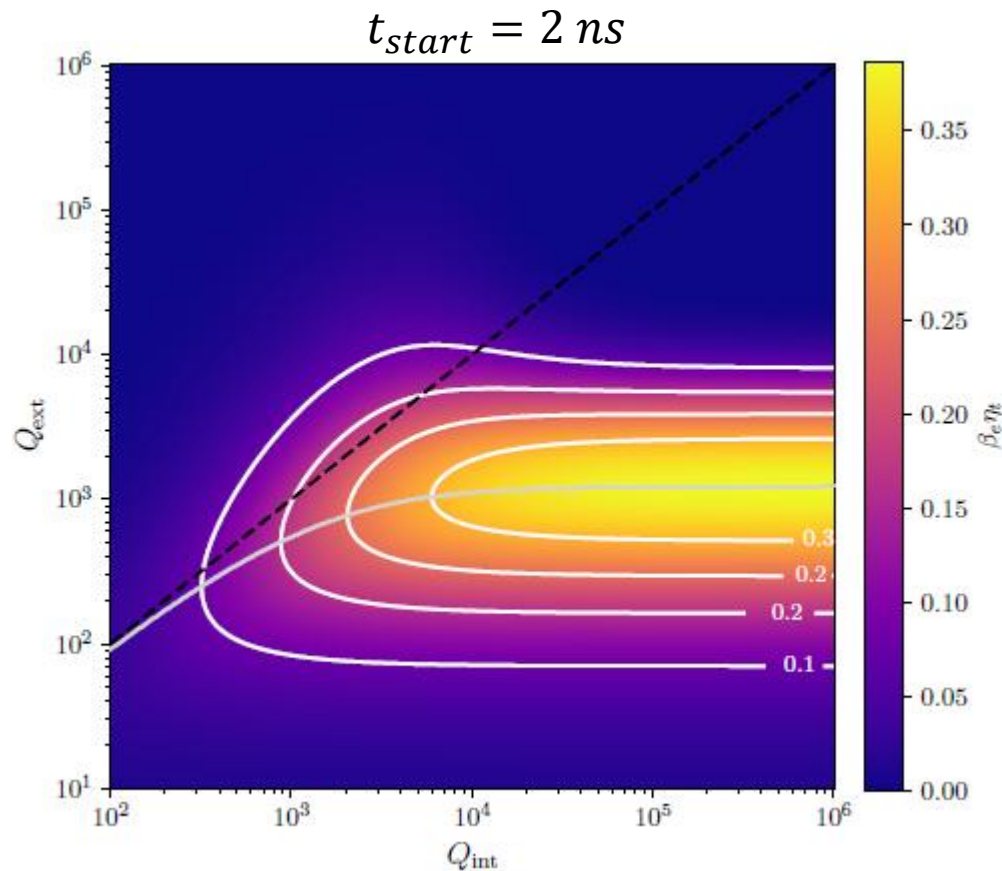


Fishbone Cavity

Q_{int} vs. Q_{ext}

- Distinguish ZPL photon from the optical π pulse photons
- Probability η_t that the photon arrives at the detector outside the time-filtering window t_{start} :

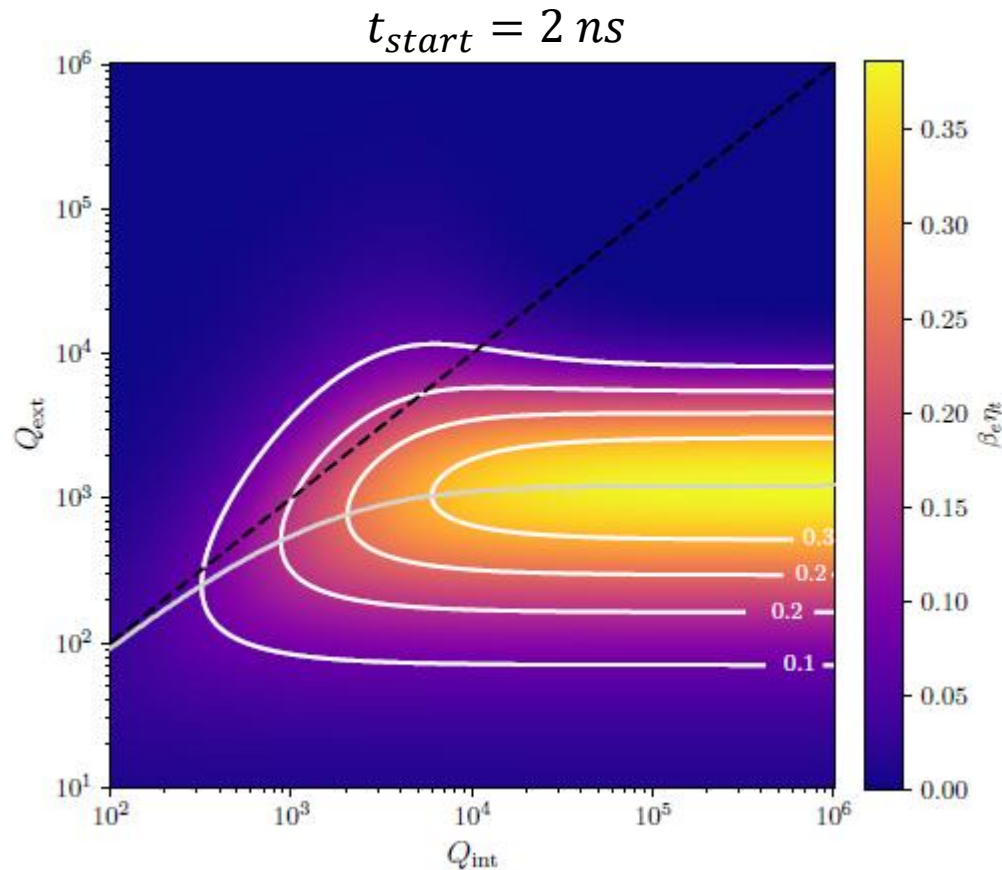
$$\eta_t = \frac{\int_{t_{start}}^{\infty} A e^{-t/\tau} dt}{\int_0^{\infty} A e^{-t/\tau} dt} = e^{-t_{start}/\tau(C)}$$



Fishbone Cavity

Optimal Purcell Factor

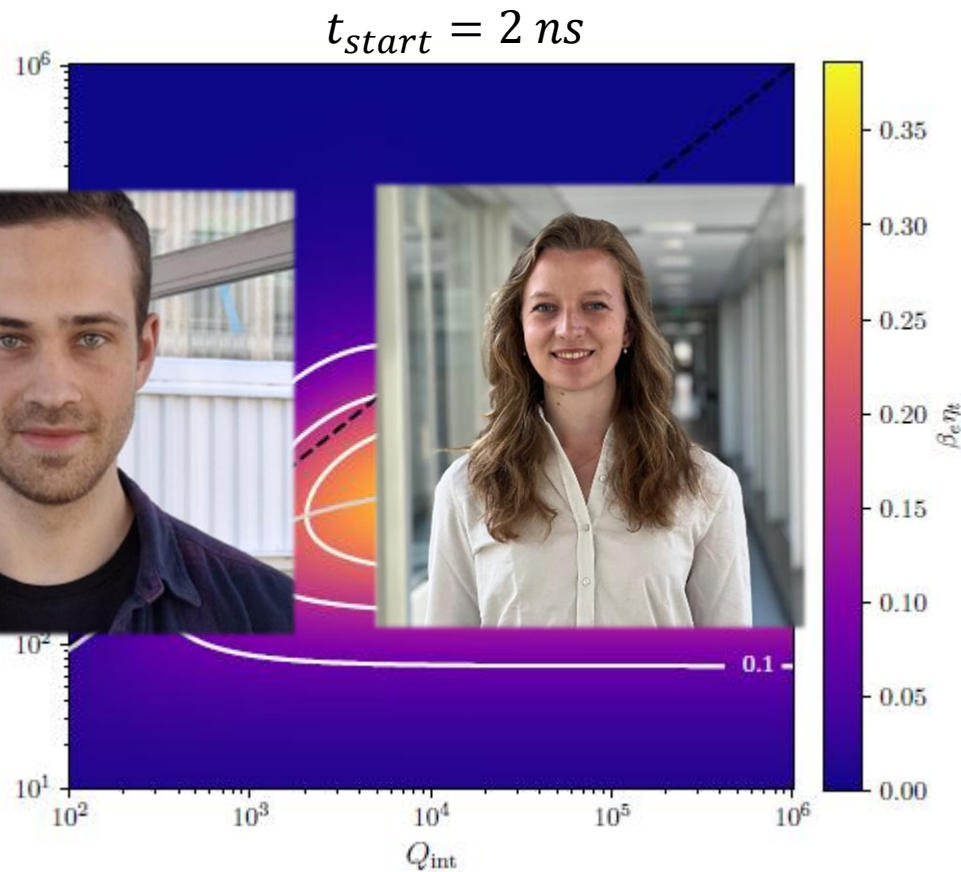
- Assumes instantaneous excitation
- Cross excitation not considered
- Double excitation not considered



Fishbone Cavity

Q_{int} vs. Q_{ext}

- As
 - Cr
 - Do
- s exc
inside
onsic



Summary

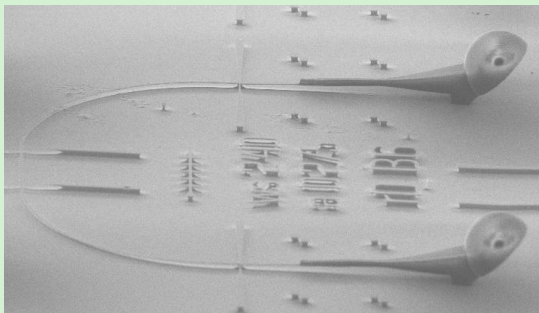
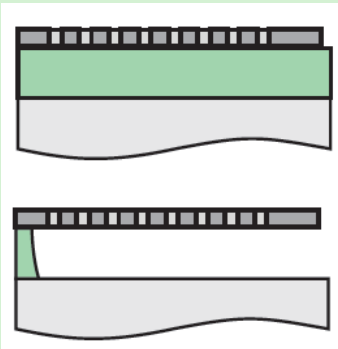
WG Realization & Photon Collection

Fab. method

- Bulk SiC
- SiCOI

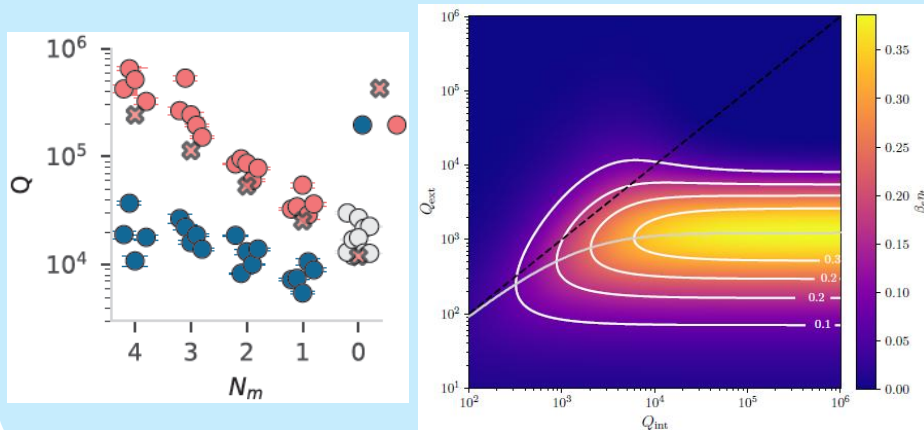
Coupling

- 3D TIR coupler
- Tapered fiber



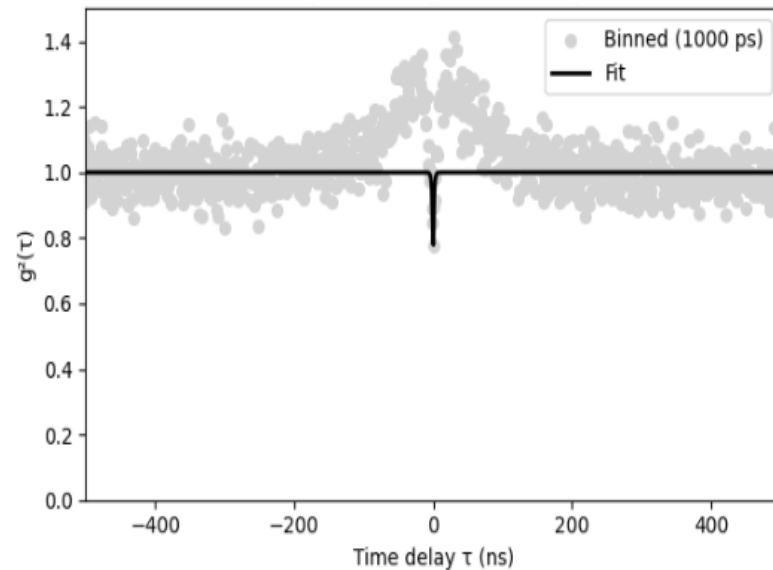
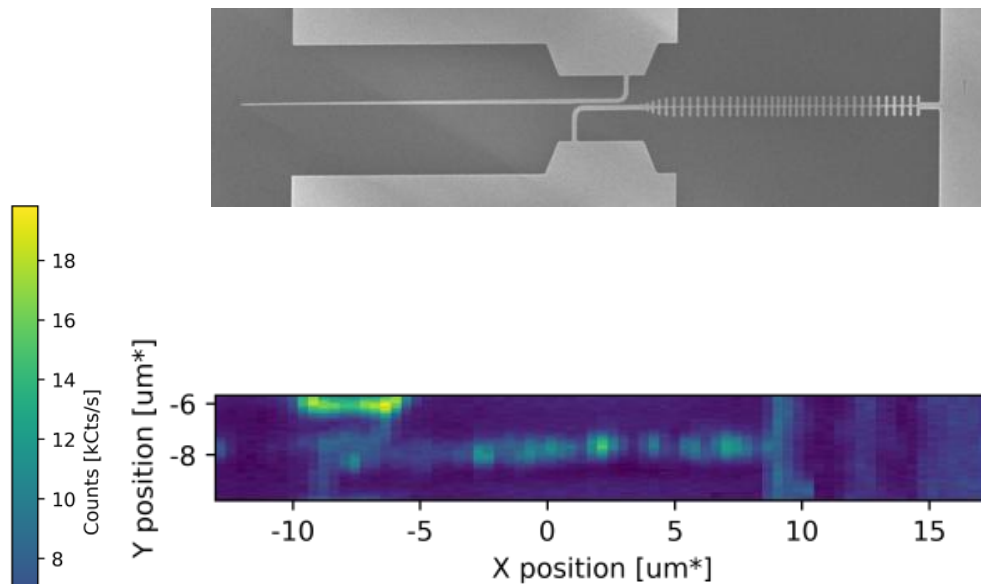
SiCOI Fishbone Cavities

- Cavity design, fab. & characterization
- Q_{tot} vs. Q_{int} vs. Q_{ext}



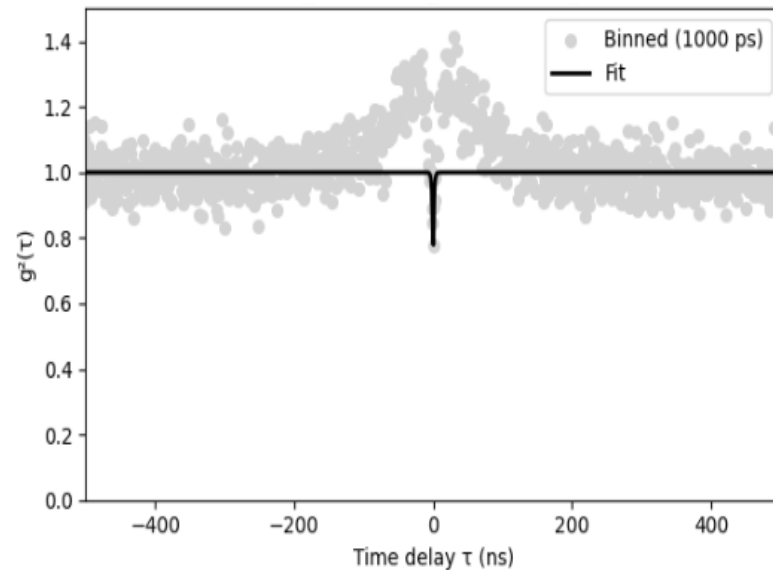
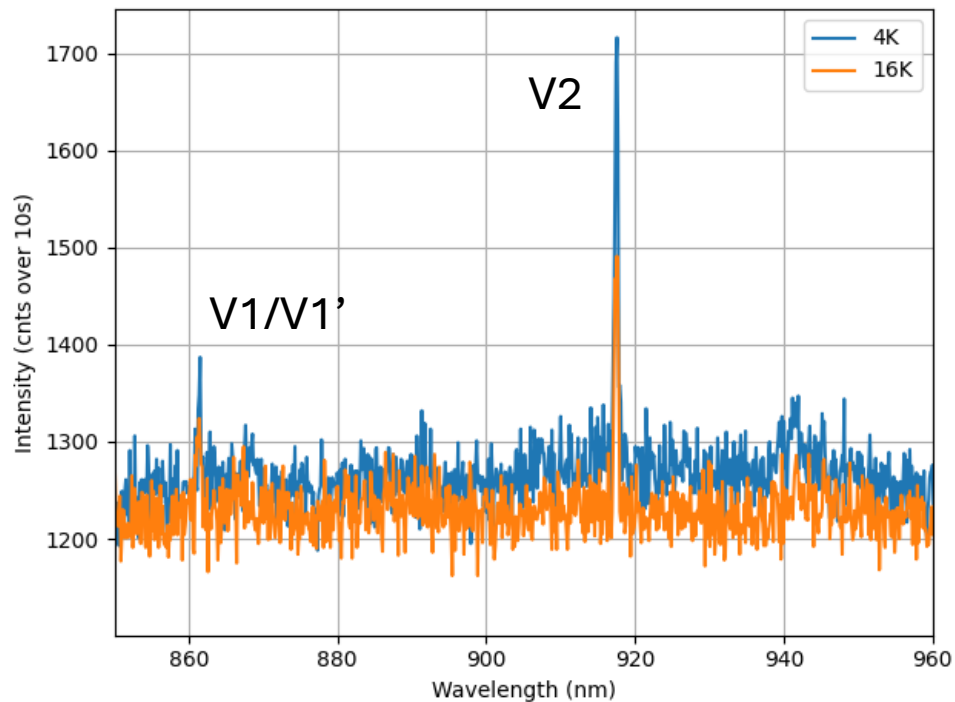
What's Next

Characterization of Native V2 in Cavity



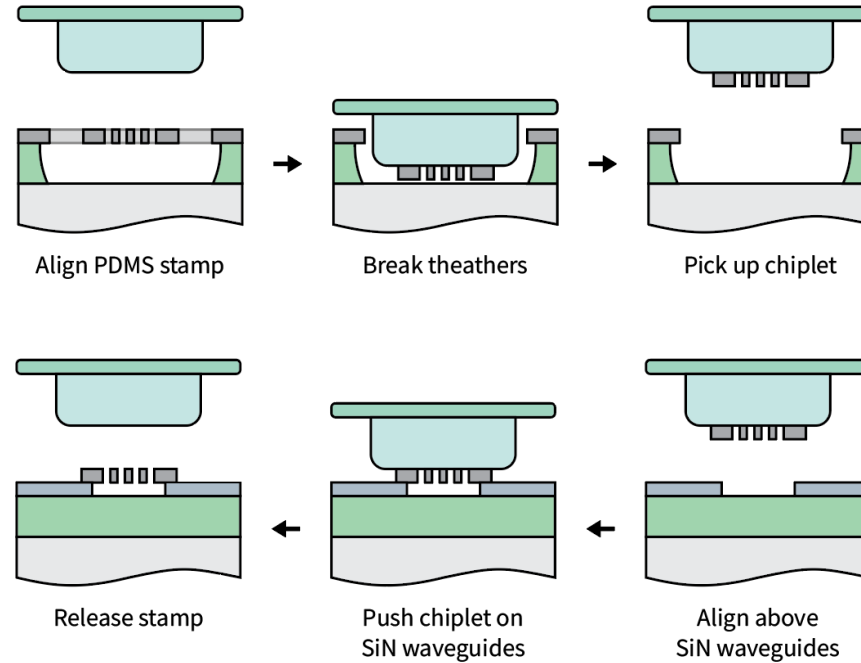
What's Next

Characterization of Native V2 in Cavity



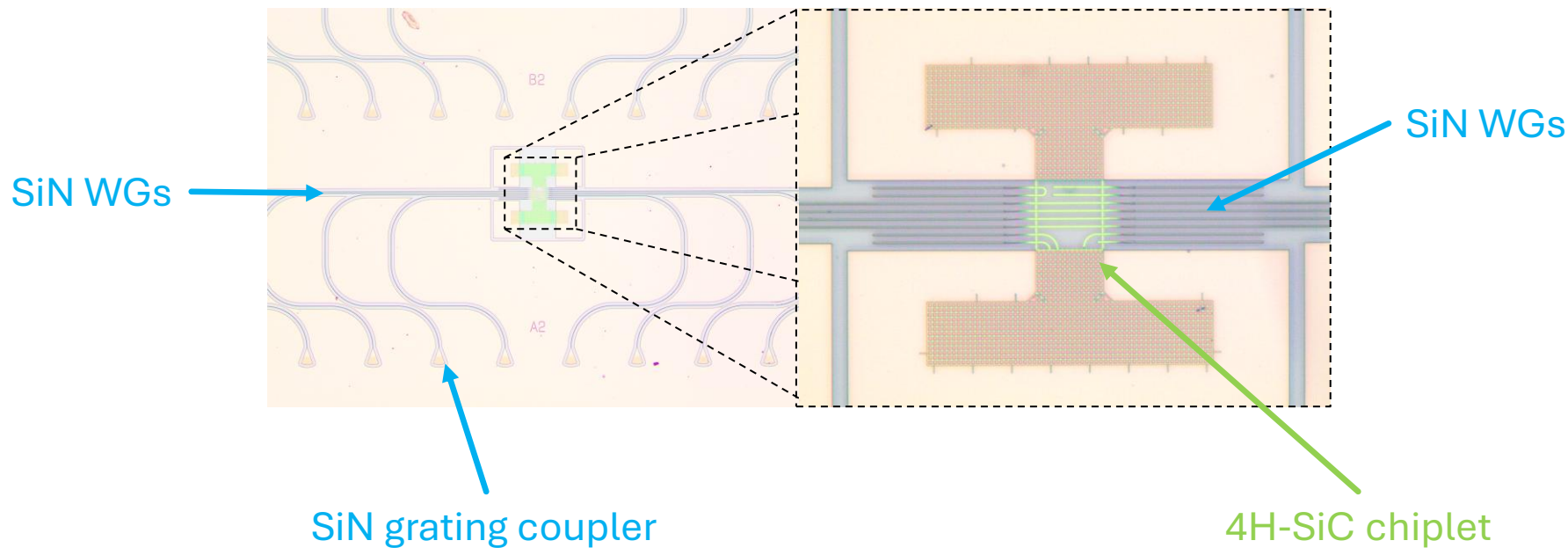
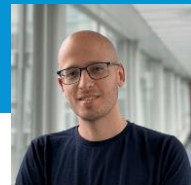


Hybrid Integration



What's Next

Hybrid Integration

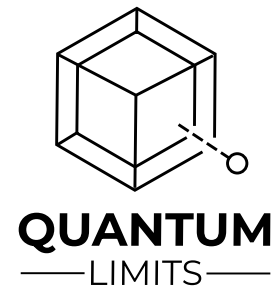


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SiC Team



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Backup Slides

Photonic Waveguide

