Superconducting single photon detectors integrated on crystalline silicon carbide

<u>Francesco Martini</u>

Alessandro Gaggero, Francesco Mattioli and Roberto Leoni

IFN-CNR, Rome, Italy

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Overview

- Introduction on Photonic Quantum Technologies
- Why 3C Silicon Carbide?
- Design
- Results
- Conclusion & Perspectives

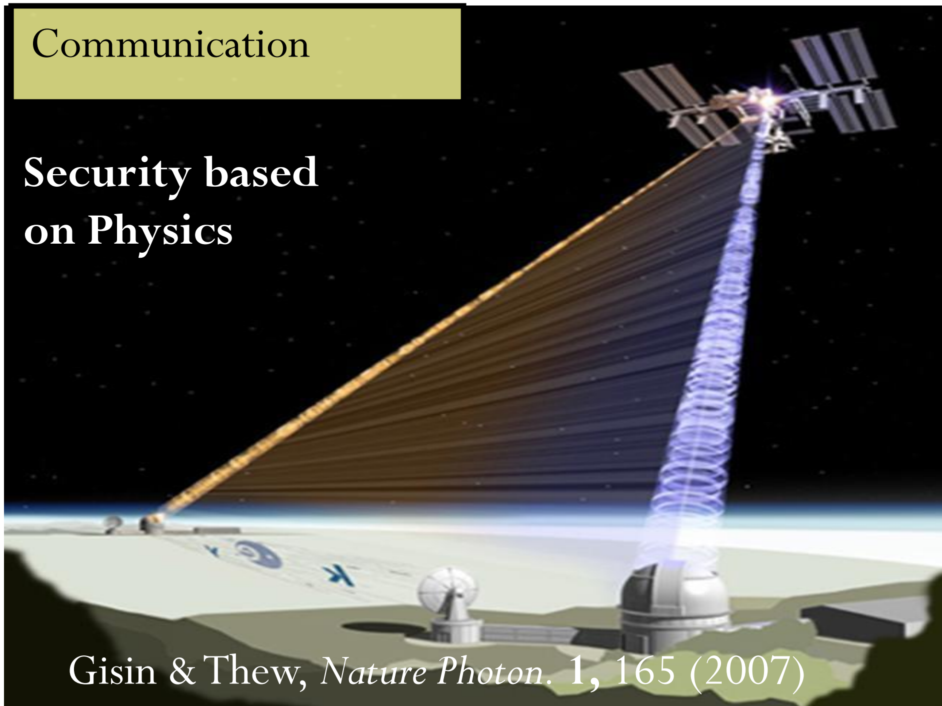
Photonic Quantum Technologies

- Quantum system can be used to encode and manipulate information

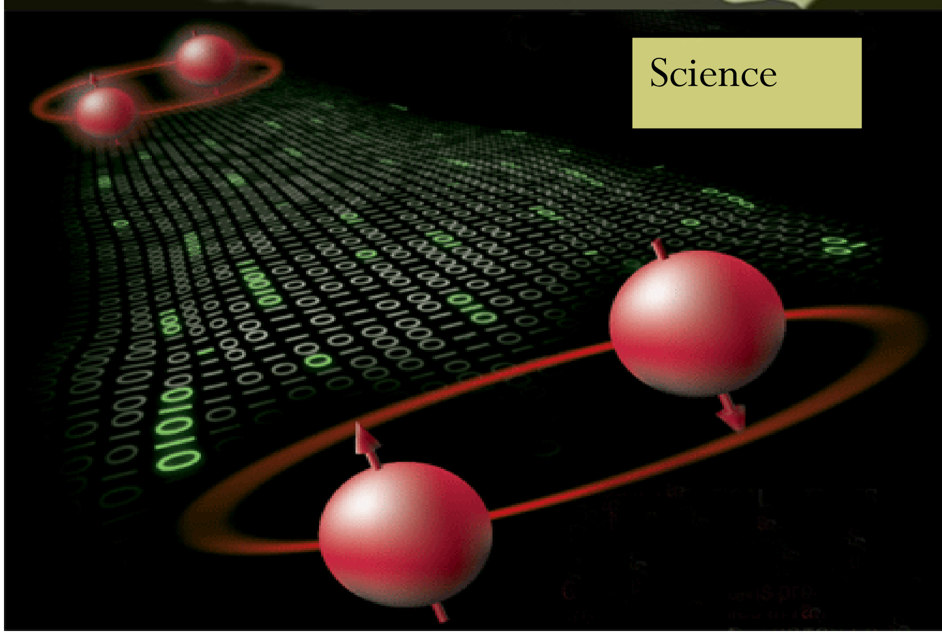
$$|\psi\rangle = \cos\theta\,|0\rangle + e^{i\phi}\sin\theta\,|1\rangle \Longrightarrow \textbf{Qubit}$$

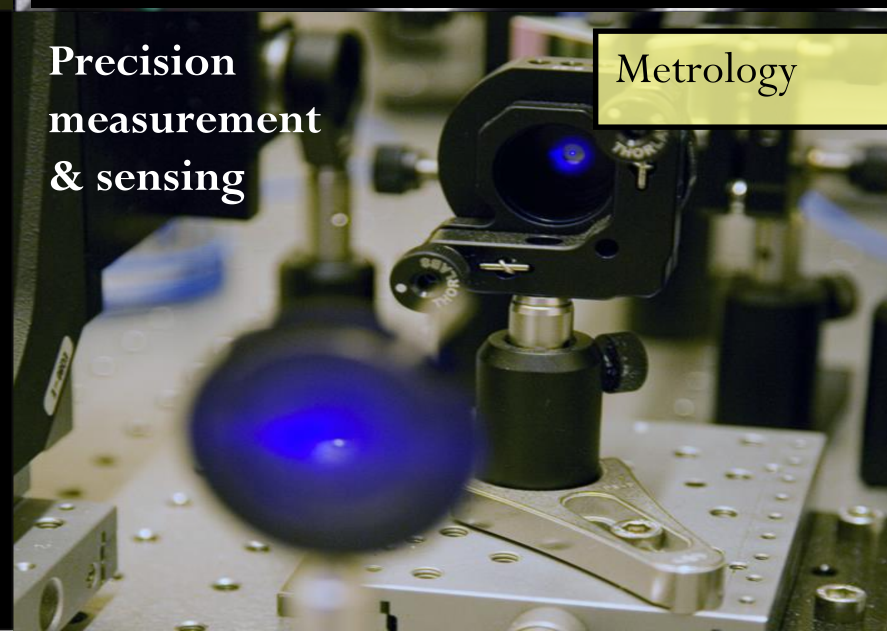
- Many candidate as quantum system (N-V centers, trapped ions, superconductive qbits, spins in Qdot, etc)

- Non classical state of light have low decoherence and are easy to manipulate


Communication
Security based on Physics
Gisin & Thew, *Nature Photon.* **1,** 165 (2007)


Computation
Tremendous power
Ladd, Jelezko, Laflamme, Nakamura, Monroe, O'Brien, *Nature* **464,** 45 (2010)


Science


Precision measurement & sensing
Metrology


Kodak
lens cleaning
paper

Photonic Quantum Technologies

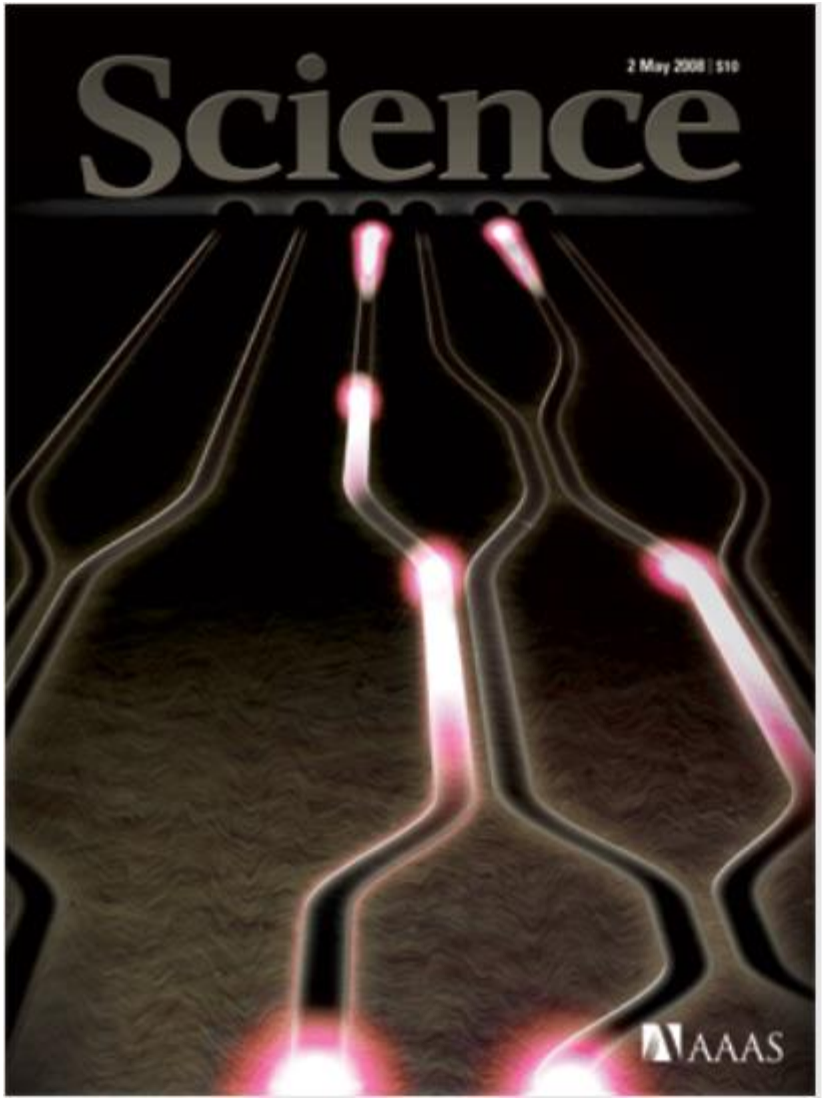
Growing complexity

↓

<u>Integrated circuit</u>

Advantages

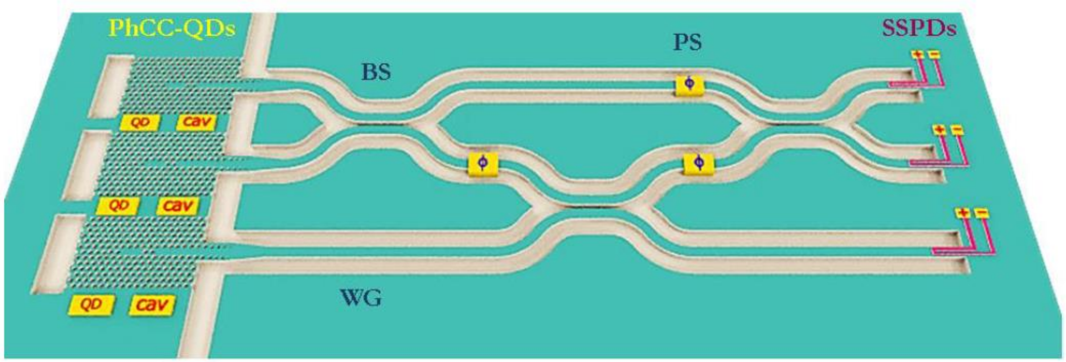
- Scalability
- Stability
- Bandwith
- High efficiency



[*] Politi, Alberto, et al. Science 320.5876 (2008): 646-649.

MANIPULATION OF QUANTUM STATE OF LIGHT

- A complete quantum photonic integrated platform has to perform three key operations: (I) generation, (II) manipulation and (III) detection of single photons.
- The realization of complex optical schemes consisting of many components requires the introduction of photonic technologies to achieve the desired scalability, stability and miniaturization of the device.



(I) Quantum dot (QD) and photonic crystal (PhC)
(II) beams splitters (BSs) and phase-shifters (PSs)
(III) SNSPDs

probabilistic CNOT gate, Courtesy of Dr. Petruzzella, TUe

Why 3C-SiC?

3C Silicon Carbide

Silicon compatible material	→	Well-known process technologies
Epitaxial layers commercially available	→	Vantages in fabrication
High 2nd non-linear coefficient	→	Efficient generation of non-classical state of light
First order electro-optic coefficient	→	Fast optical switches
Refractive index of 2.6	→	High EM field confinement
Wide bandgap	→	No two-photon absorption
Thermal growth of SiO2	→	High quality optical cladding
Di-vacancy point defect	→	Additional resource for QI

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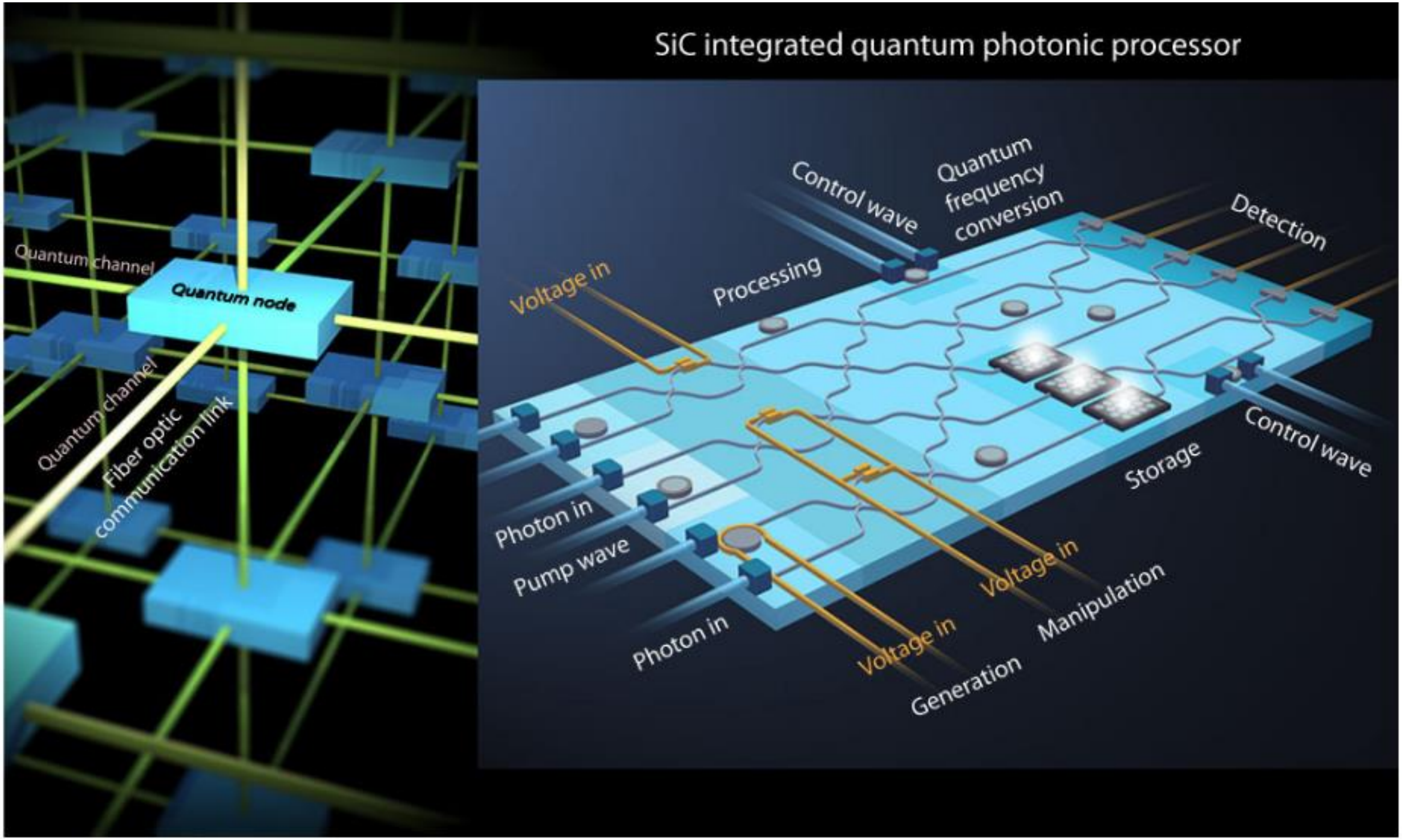
Why 3C-SiC?



http://www.rochester.edu/newscenter/2-million-nsf-grant-to-add-efficiency-to-integrated-quantum-photonics-175132/

Why 3C-SiC?

nature COMMUNICATIONS

Article | OPEN | Published: 07 May 2013

Polytype control of spin qubits in silicon carbide

Abram L. Falk, Bob B. Buckley, Greg Calusine, William F. Koehl, Viatcheslav V. Dobrovitski, Alberto Politi, Christian A. Zorman, Philip X.-L. Feng & David D. Awschalom

nature materials

Letter | Published: 01 December 2014

Isolated electron spins in silicon carbide with millisecond coherence times

David J. Christle, Abram L. Falk, Paolo Andrich, Paul V. Klimov, Jawad Ul Hassan, Nguyen T. Son, Erik Janzén, Takeshi Ohshima & David D. Awschalom

nature International journal of science

Letter | Published: 02 November 2011

Room temperature coherent control of defect spin qubits in silicon carbide

William F. Koehl, Bob B. Buckley, F. Joseph Heremans, Greg Calusine & David D. Awschalom

Research Article Vol. 25, No. 10 | 15 May 2017 | OPTICS EXPRESS 10735
Optics EXPRESS

Linear integrated optics in 3C silicon carbide

FRANCESCO MARTINI AND ALBERTO POLITI*
Department of Physics and Astronomy, University of Southampton, Southampton, SO17 1BJ,UK
*A.Politi@soton.ac.uk

Research Article Vol. 26, No. 20 | 1 Oct 2018 | OPTICS EXPRESS 25814
Optics EXPRESS

High-Q integrated photonic microresonators on 3C-SiC-on-insulator (SiCOI) platform

TIANREN FAN, HESAM MORADINEJAD, XI WU, ALI A. EFTEKHAR, AND ALI ADIBI*
School of Electrical and Computer Engineering, Georgia Institute of Technology, 777 Atlantic Drive NW, Atlanta, Georgia 30332, USA
*ali.adibi@ece.gatech.edu

ACS Photonics Letter
Cite This: ACS Photonics XXXX, XXX, XXX–XXX pubs.acs.org/journal/apchd5

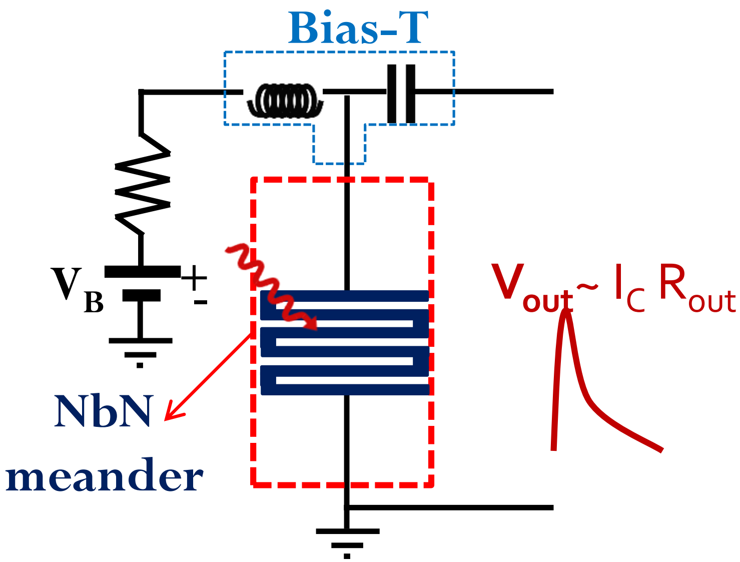
High-Q/V Photonic Crystal Cavities and QED Analysis in 3C-SiC

APPLIED PHYSICS LETTERS 113, 231106 (2018)

High-Q-factor nanobeam photonic crystal cavities in bulk silicon carbide

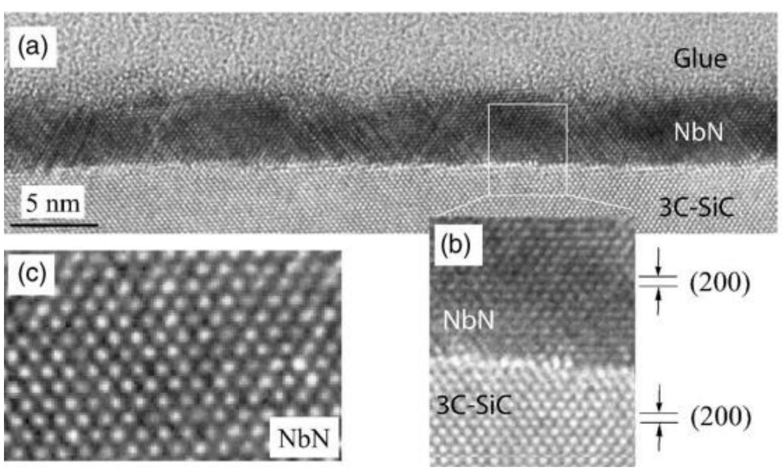
Bong-Shik Song,[1,2,a)] Seungwoo Jeon,[1] Heungjoon Kim,[2] Dongyeon Daniel Kang,[1] Takashi Asano,[1,a)] and Susumu Noda[1,a)]
[1]*Department of Electronic Science and Engineering, Kyoto University, Kyoto 615-8510, Japan*
[2]*Department of Electrical and Computer Engineering, Sungkyunkwan University, Suwon 16419, South Korea*

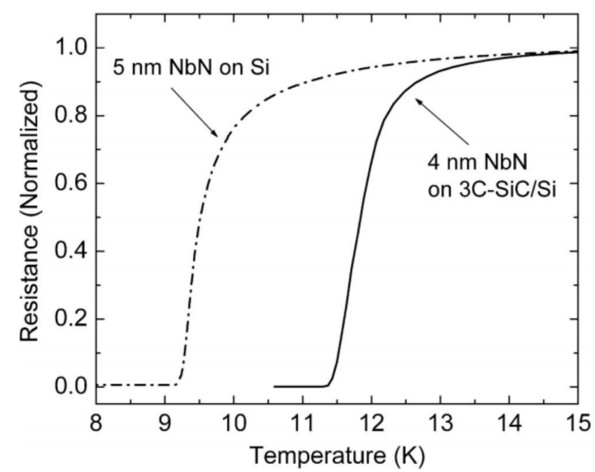
SNSPDs on SiC



- single photon counting from X-ray to MIR
- low dark count rate
- low jitter <100 ps (record 12 ps),
- fast count rates ~GHz;
- Integration in photonic circuits (PICs)

Gol’tsman et al., Appl. Phys Lett. 75, 705 (2001)





J. R. Gao et al., “Monocrystalline NbN Nanofilms on a 3C-SiCSi Substrate,” Applied Physics Letters 91, no. 6 (2007): 3–6, doi:10.1063/1.2766963

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Design

$$SDE = \eta_{\mathrm{Int}} \cdot \eta_{\mathrm{Abs}} \cdot \eta_{\mathrm{Cou}}$$

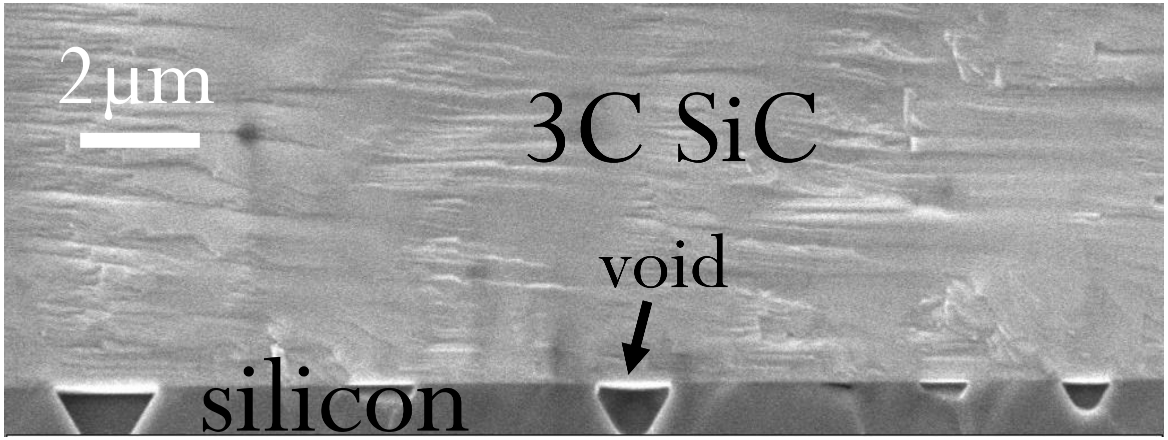
η_{Int} Depends on the temperature and on the material properties

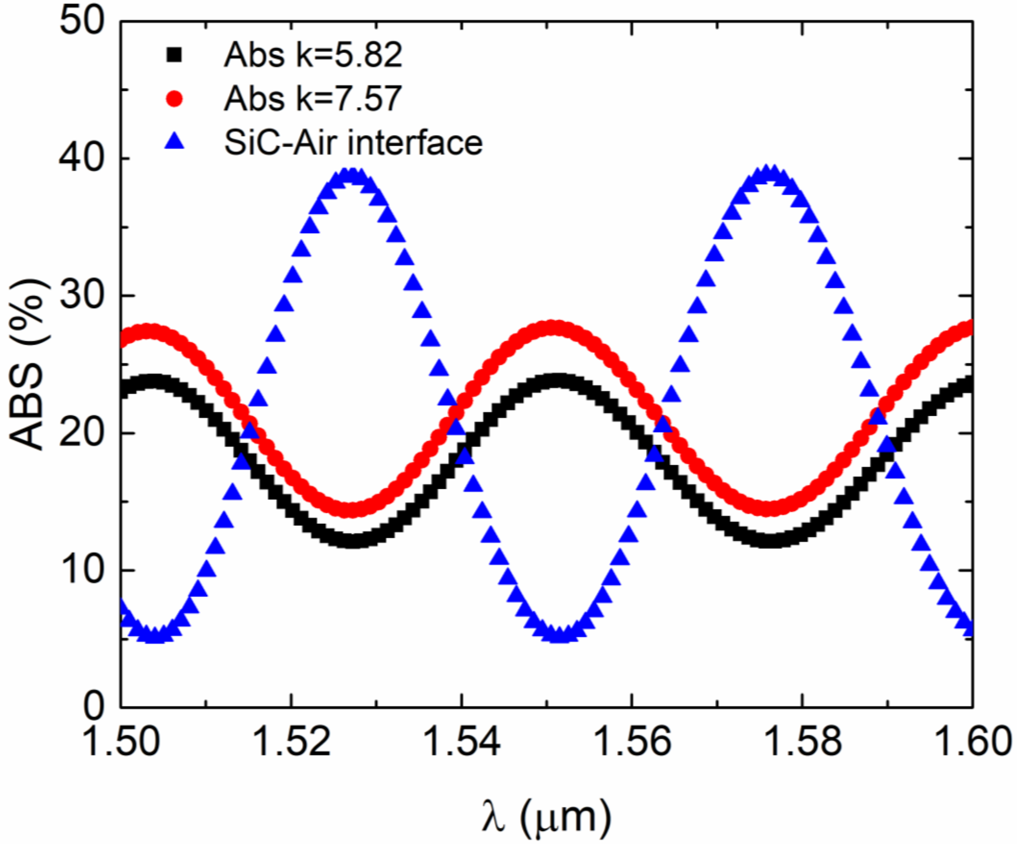
η_{Abs} Probability of absorbing a photon

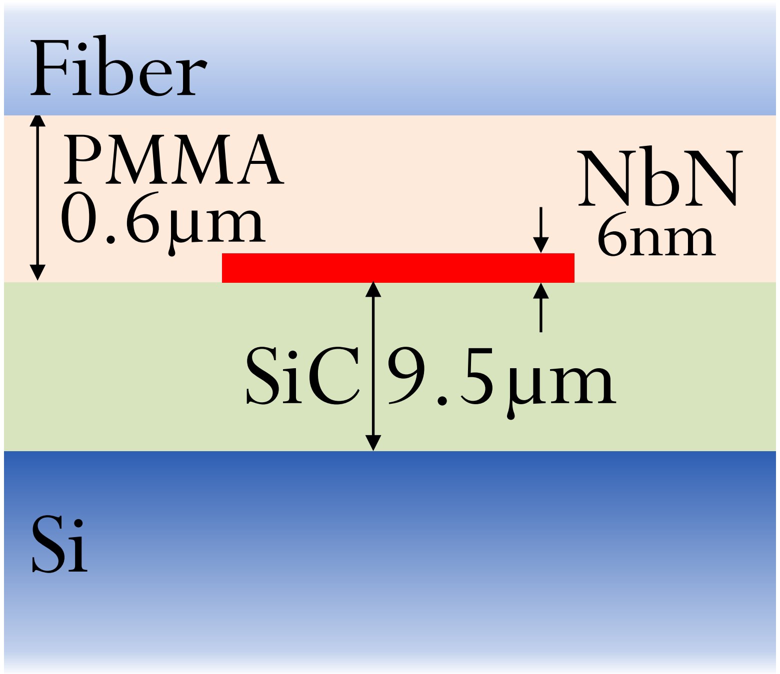
η_{Cou} Efficiency on coupling the photon in the meander area

Design

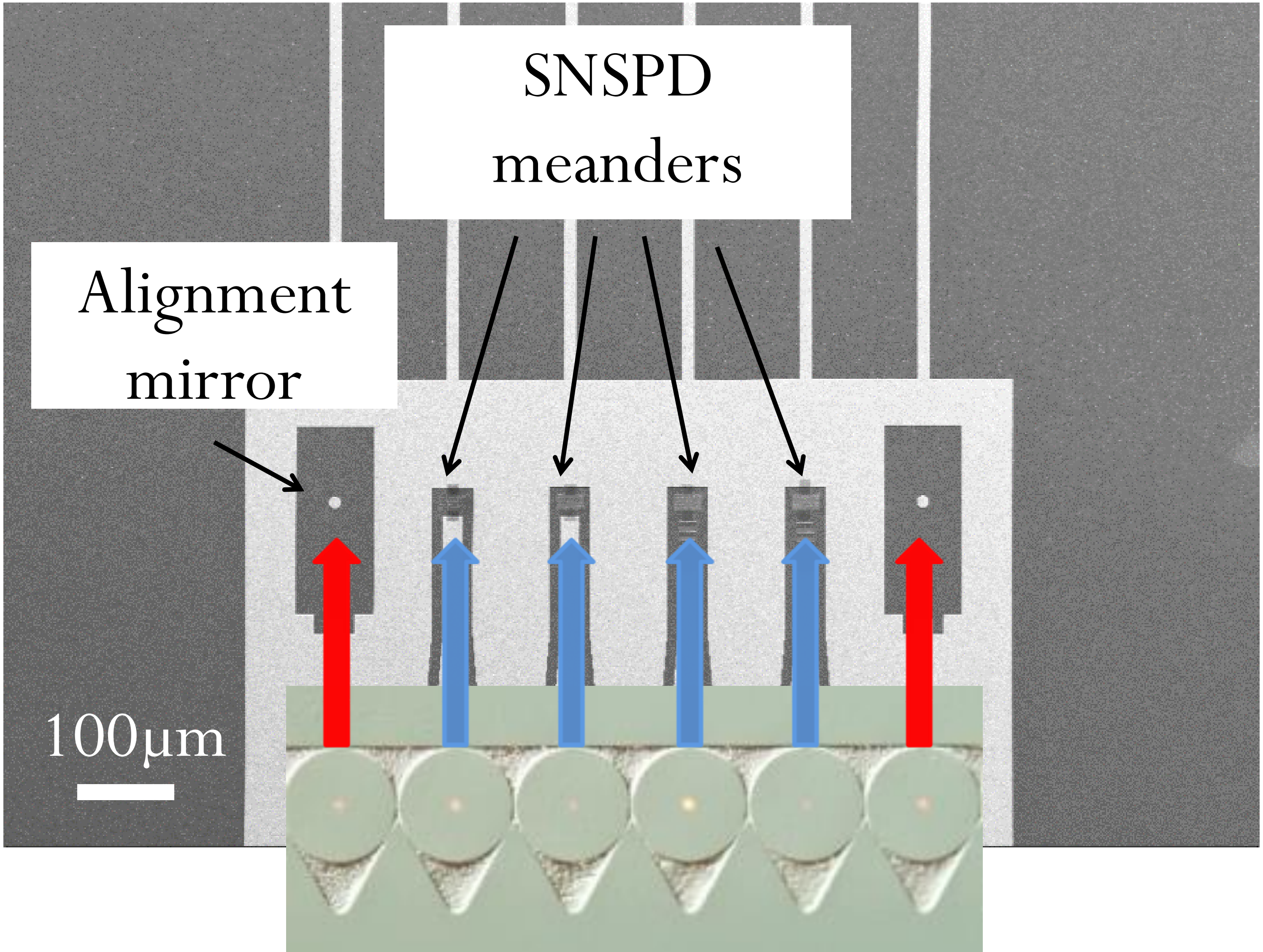
η_{Abs}



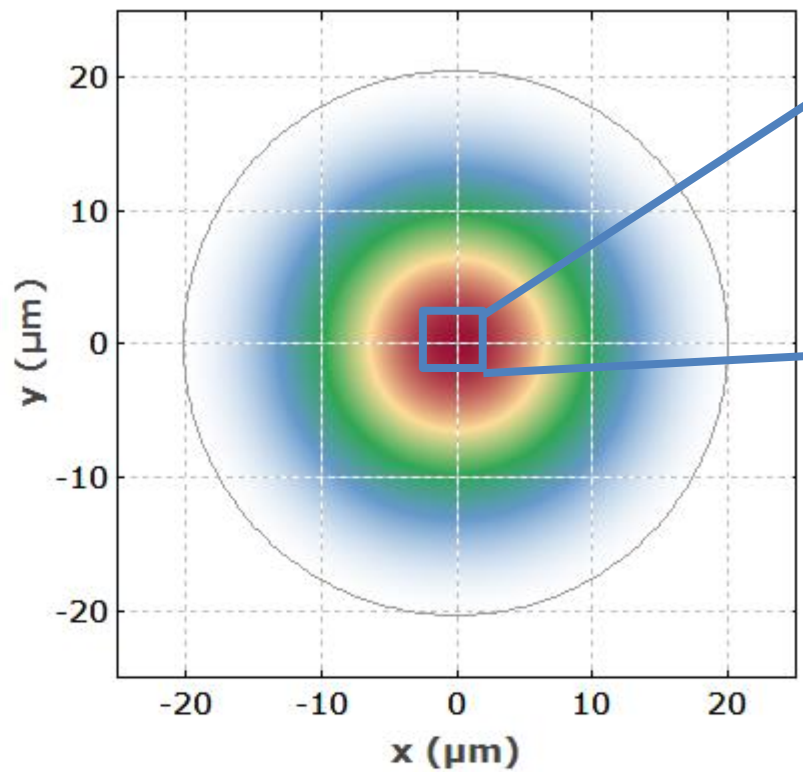


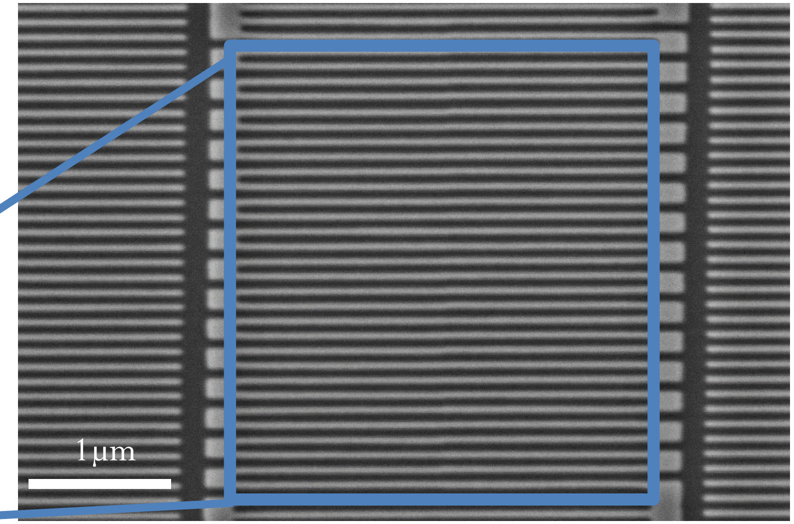


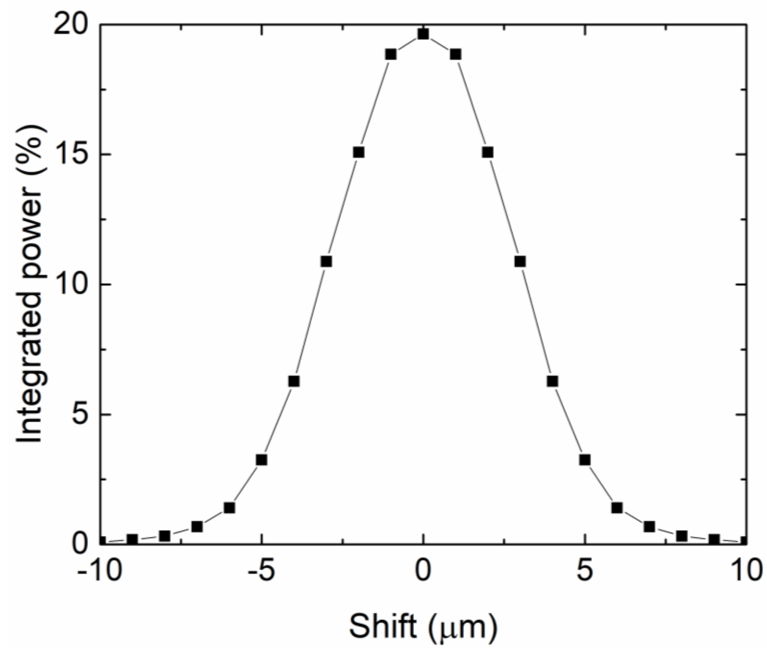
Design



Design η_{Cou}







$$SDE = 4.8\text{-}5.5\%$$

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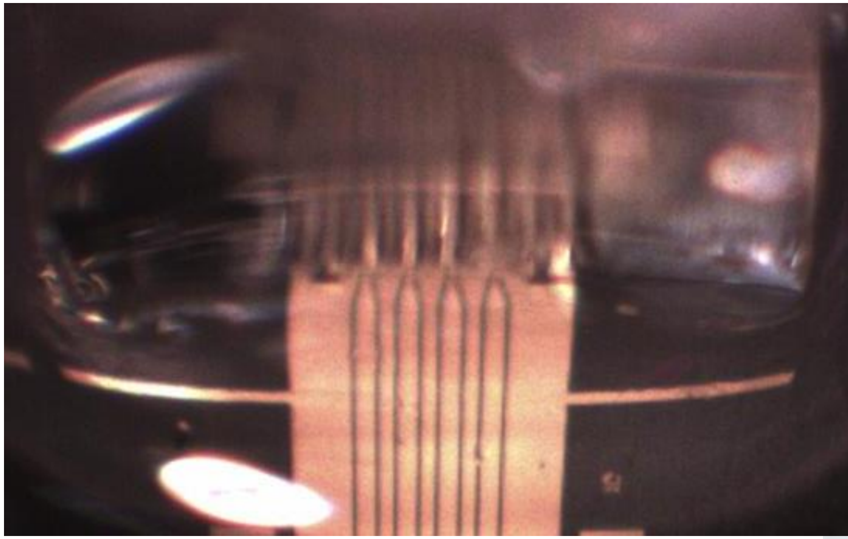
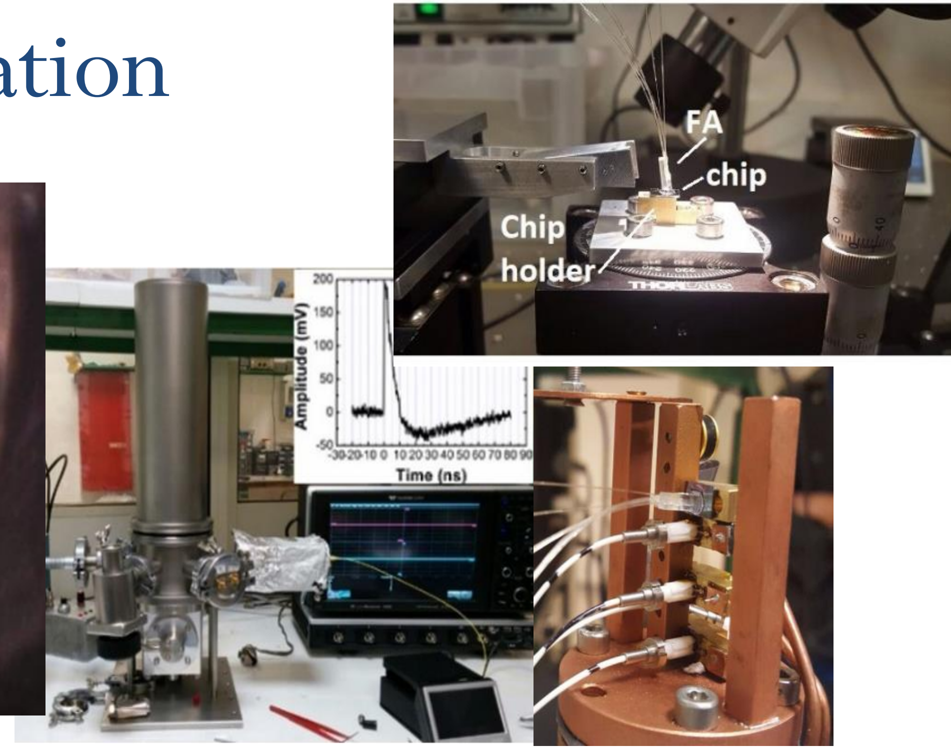
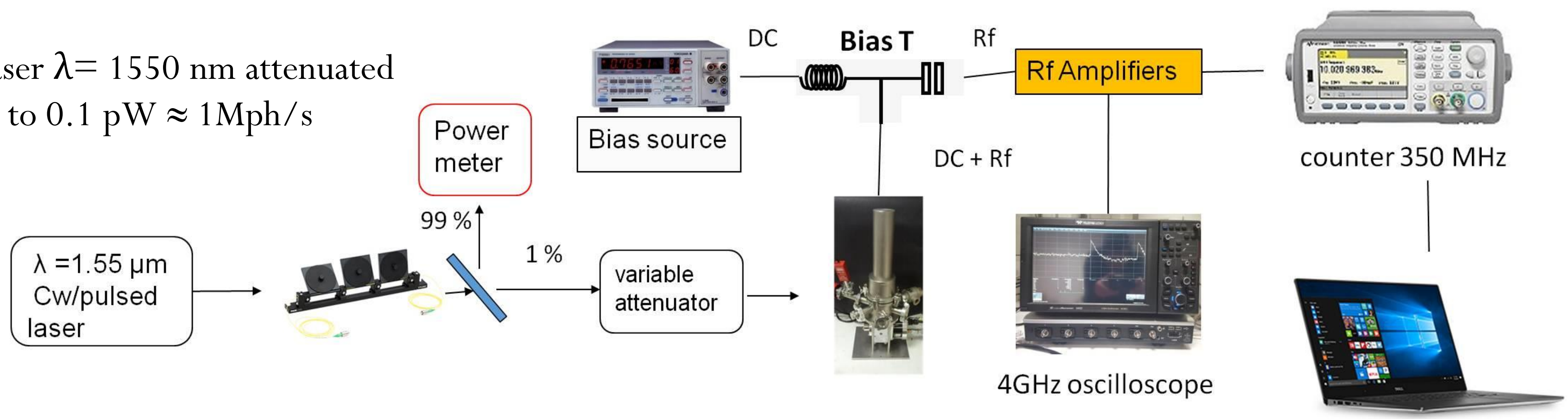
SNSPDs characterization





Cw laser λ= 1550 nm attenuated down to 0.1 pW ≈ 1Mph/s



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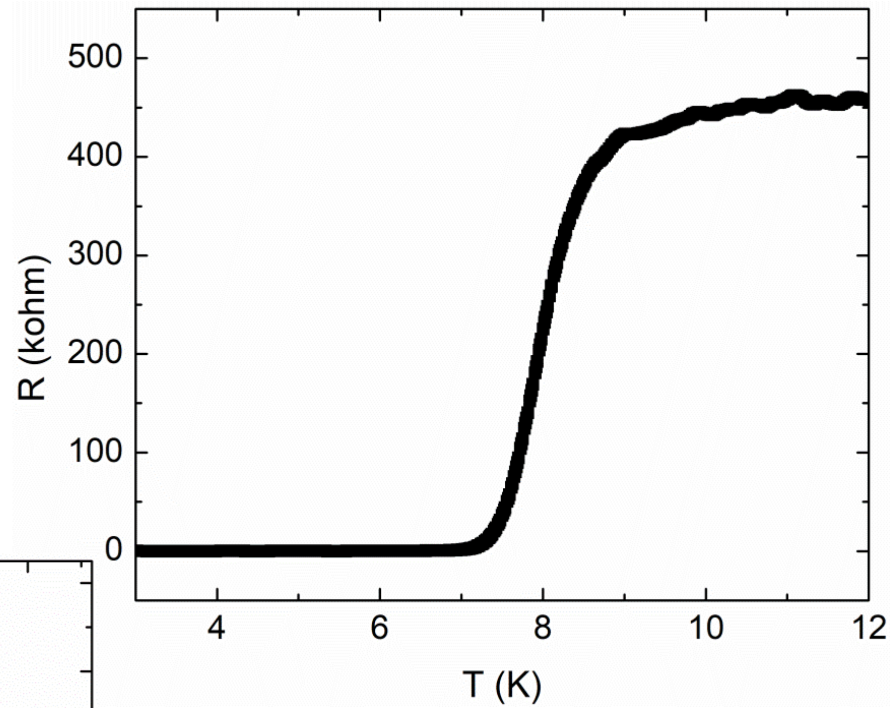
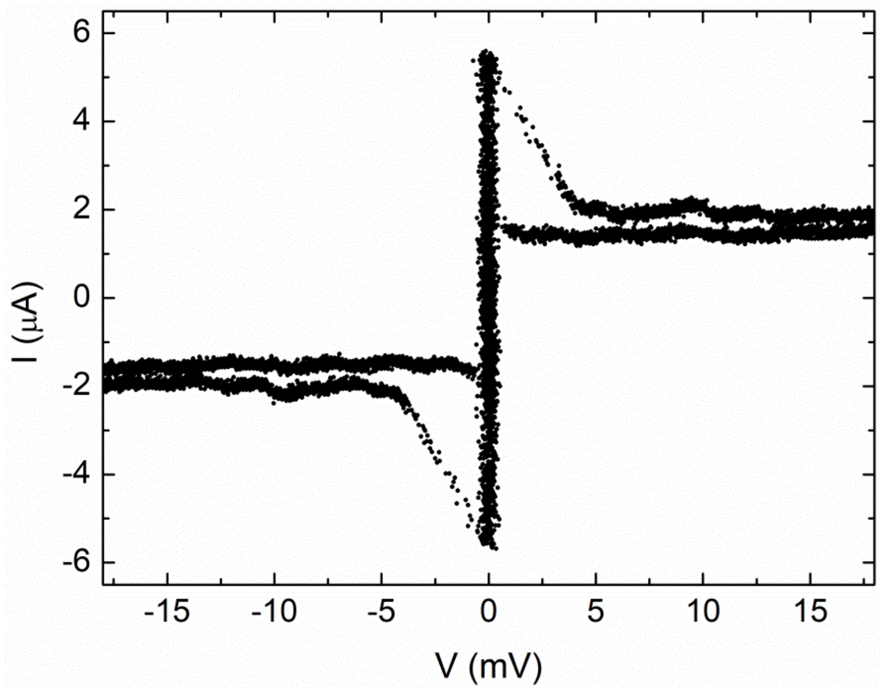
Results

$T_c = 8K$

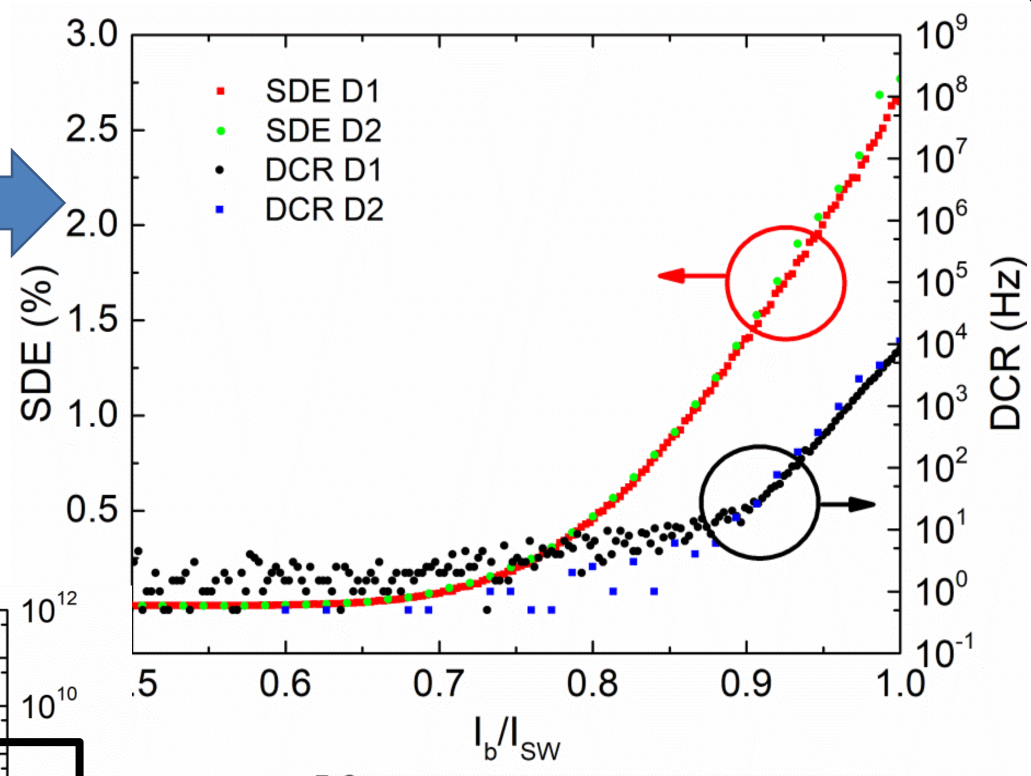




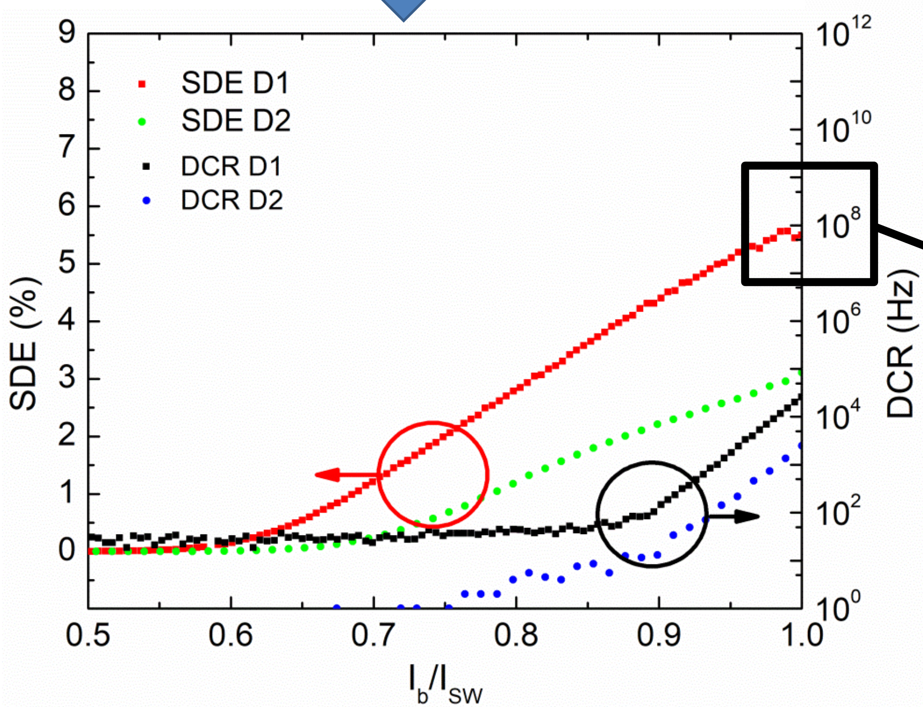
$I_c = 6\mu A$

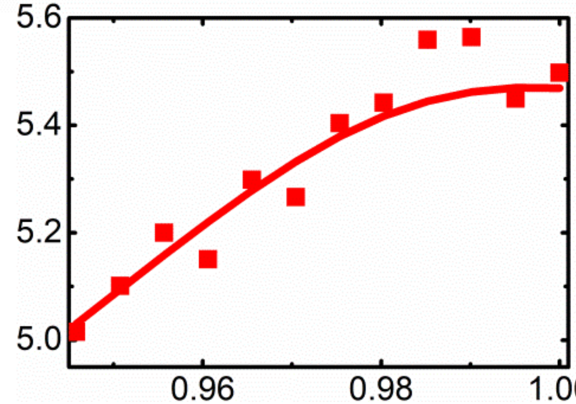
Results

80nm-width SNSPDs



60nm-width SNSPDs





Conclusion

- We developed a novel alignment method
- We fabricated NbN SNSPD on to of 3C SiC substrate
- Approaching $\eta_{Int} \backsimeq 1$ for 60nm-width SNSPD

What's next?

- Integration on top of SiC Waveguides
- More complex architectures

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Thank you for the attention!

ShaMROCk
795923

PoC: 3D count

Progetto premiale
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