中国科学院超导电子学卓越创新中心
Center for Excellence in Superconducting Electronics (CENSE)

ISEC 2017

Microfiber-coupled Superconducting Nanowire Single Photon Detector

Lixing You

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YX Xu, W Fang, LM Tong

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浙江大學
ZHEJIANG UNIVERSITY

Jun. 2017

Content

- Introduction to SNSPD
- Optical Coupling of SNSPD
- Micro/Nano-fiber coupled SNSPD
- Results
- Summary

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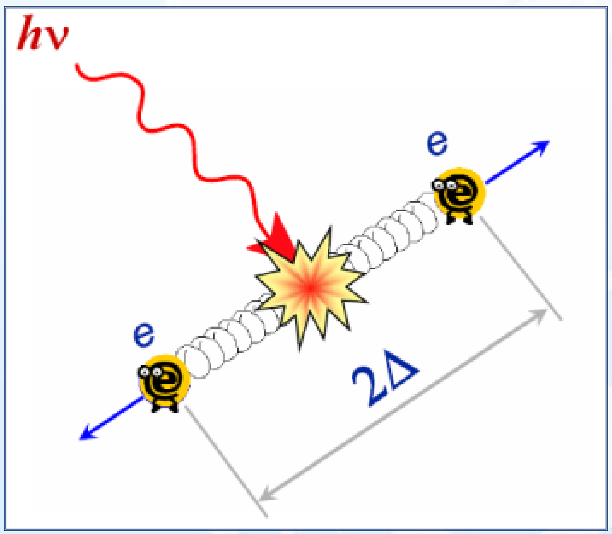
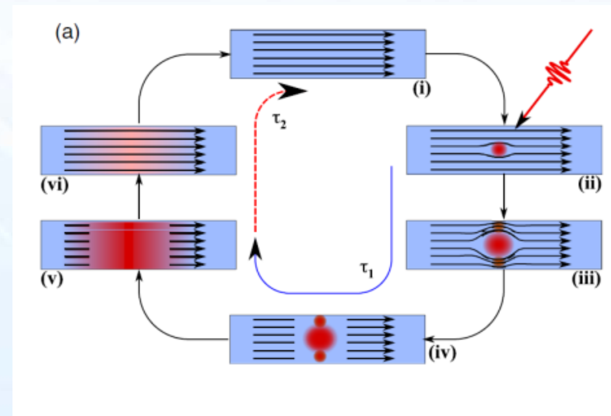
Detection Mechanism

Cooper pair breaking by single photon

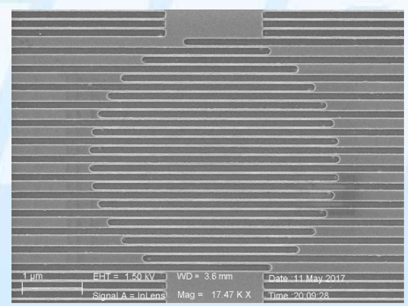




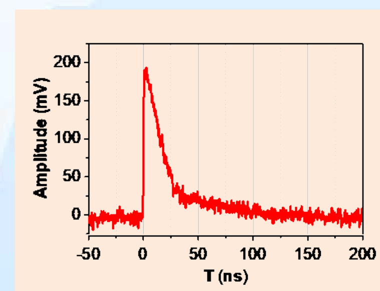
Dynamics

Photon energy vs gap/Cooper Pair energy

hν (1eV) vs 2Δ (6.4 meV)



SEM Image



Photon Response

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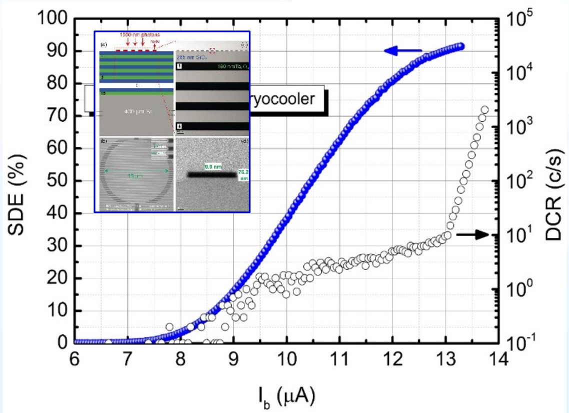
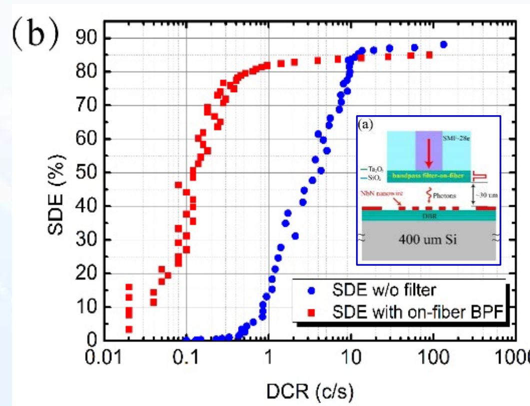
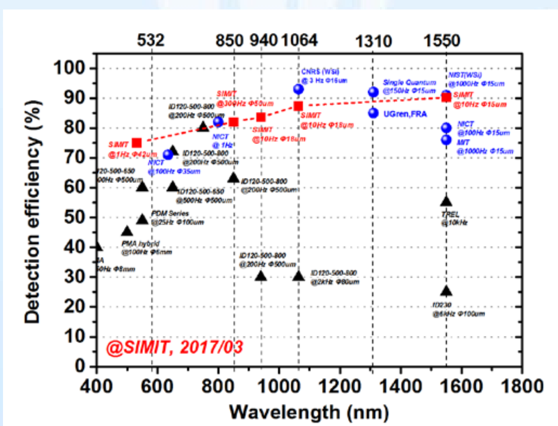
Progress on Devices @SIMIT



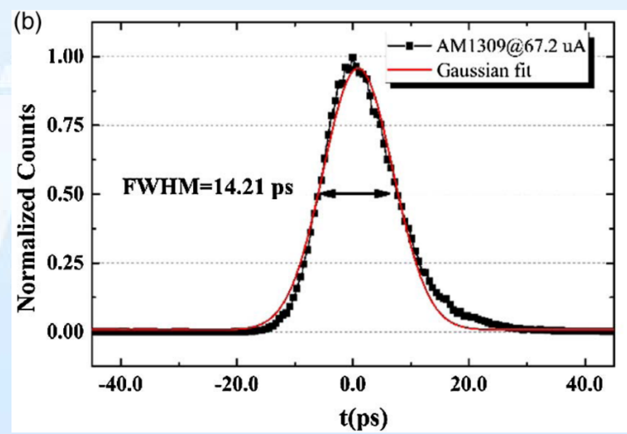
NbN SNSPD with SDE>90% @ 2.1 K, DCR10Hz



SDE > 80% at DCR=1Hz



NbN SNSPD from VIS to NIR **Accepted by SUST**



System jitter <15 ps **AO 56 2195 (2017)**

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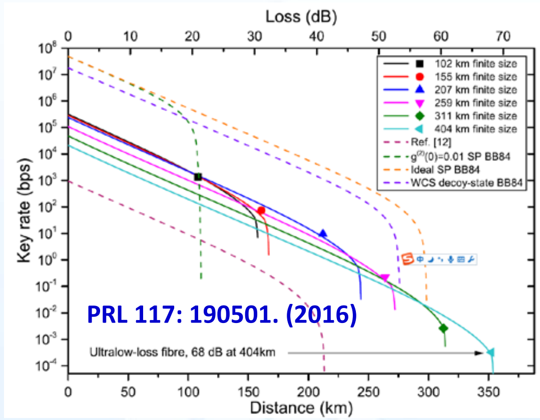
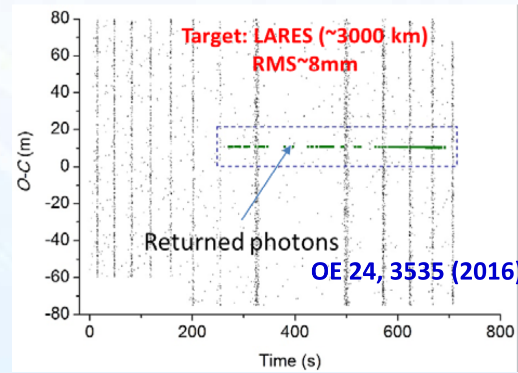
Progress on Applications @SIMIT

Collaborators： JW Pan from USTC et al

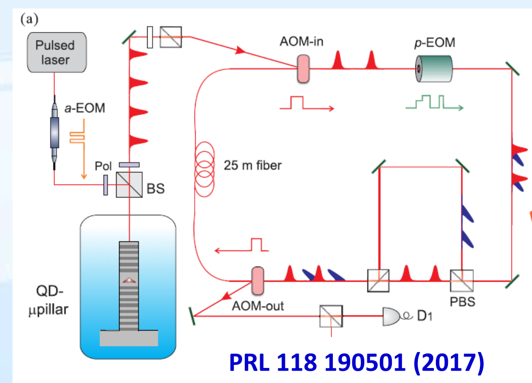


Record MDI-QKD of 404 km in fiber



Satellite laser ranging over 3000 km

Quantum Teleportation over 30 km



Time-bin Boson Sampling

IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), July 2017.
This invited oral presentation We-I-DET-01 was given at ISEC 2017.

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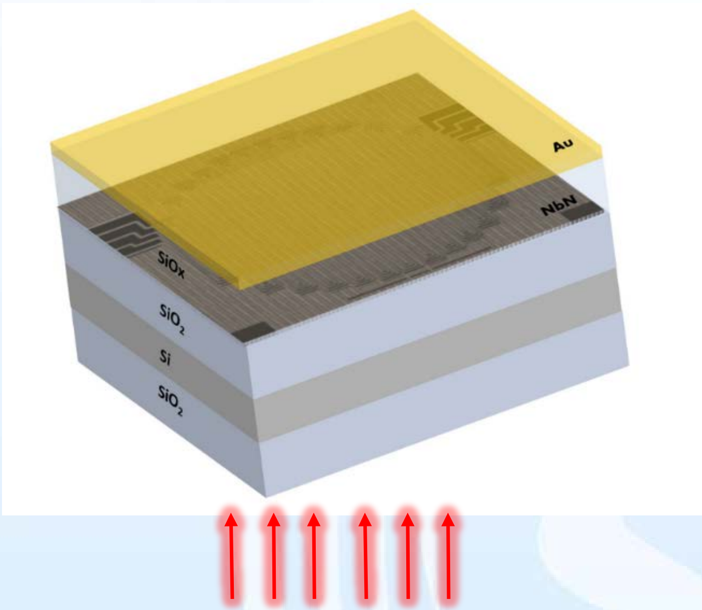
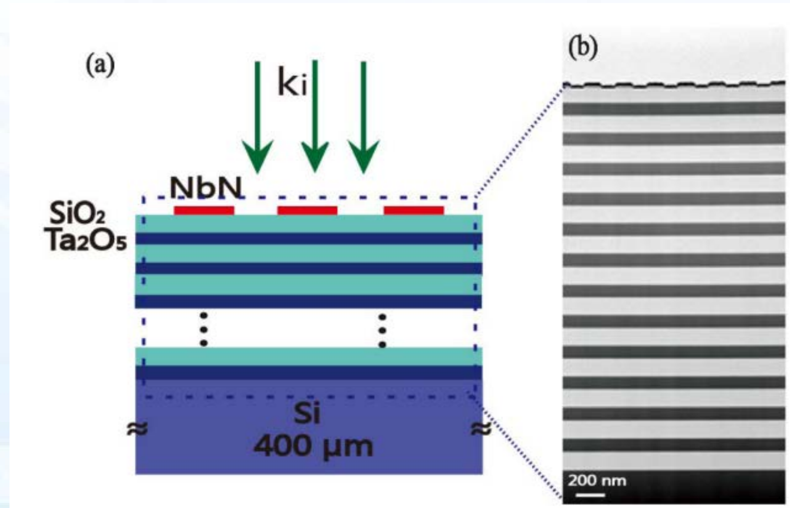
Vertical Optical Coupling





Double Cavity SNSPD with Backside optical coupling

Dauler et al, Opt Eng 53,081907 (2014)

SNSPD on DBR with Top optical Coupling

Li et al, OE 23,017301 (2015)

- High SDE over 90%
- Spectrum limited by cavity

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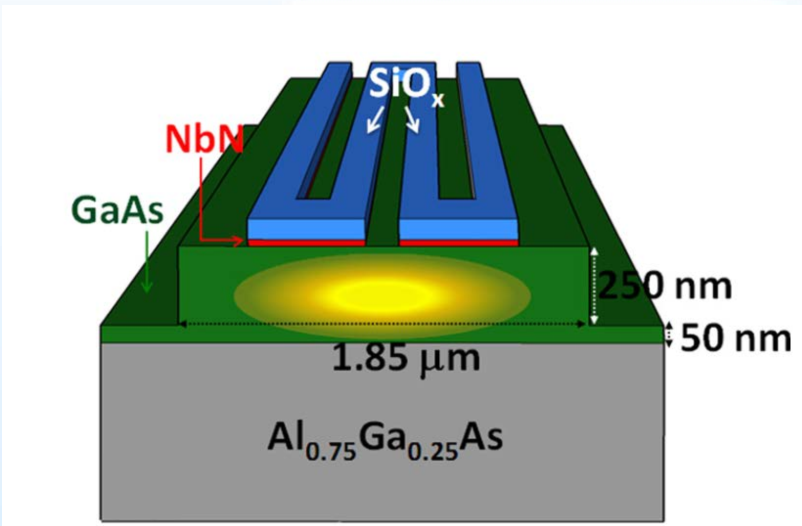
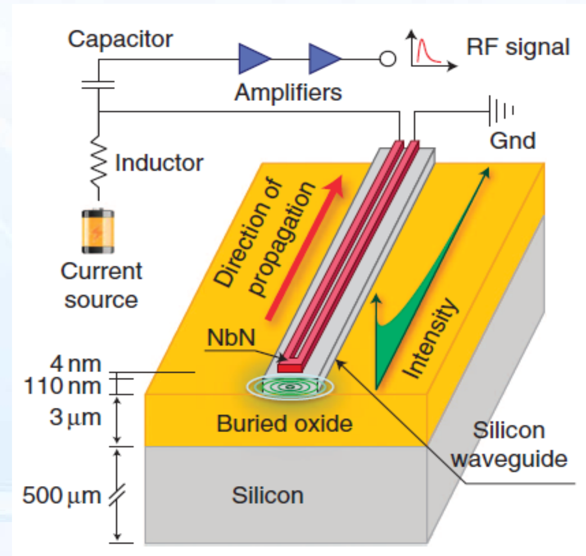
Optical Coupling via waveguide





SNSPD on AlGaAs substrate
Sprengers et al, APL 99, 181110 (2011)

SNSPD on SiO_2/Si substrate
Pernice et al, Nat Comm 3, 1325 (2012)

- Good for Photonics on Chip
- Limited system coupling

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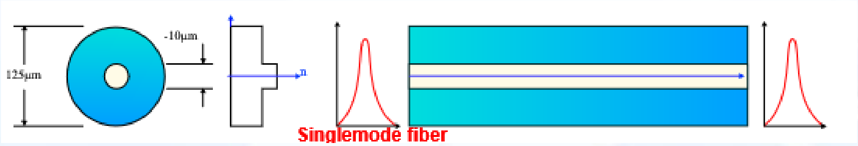
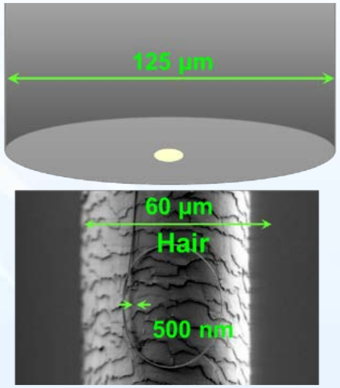
What is Micro/nano-Fiber?

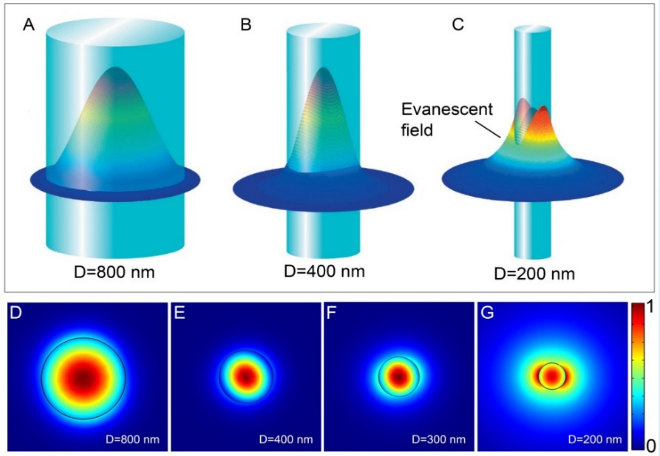
Conventional SM Fiber





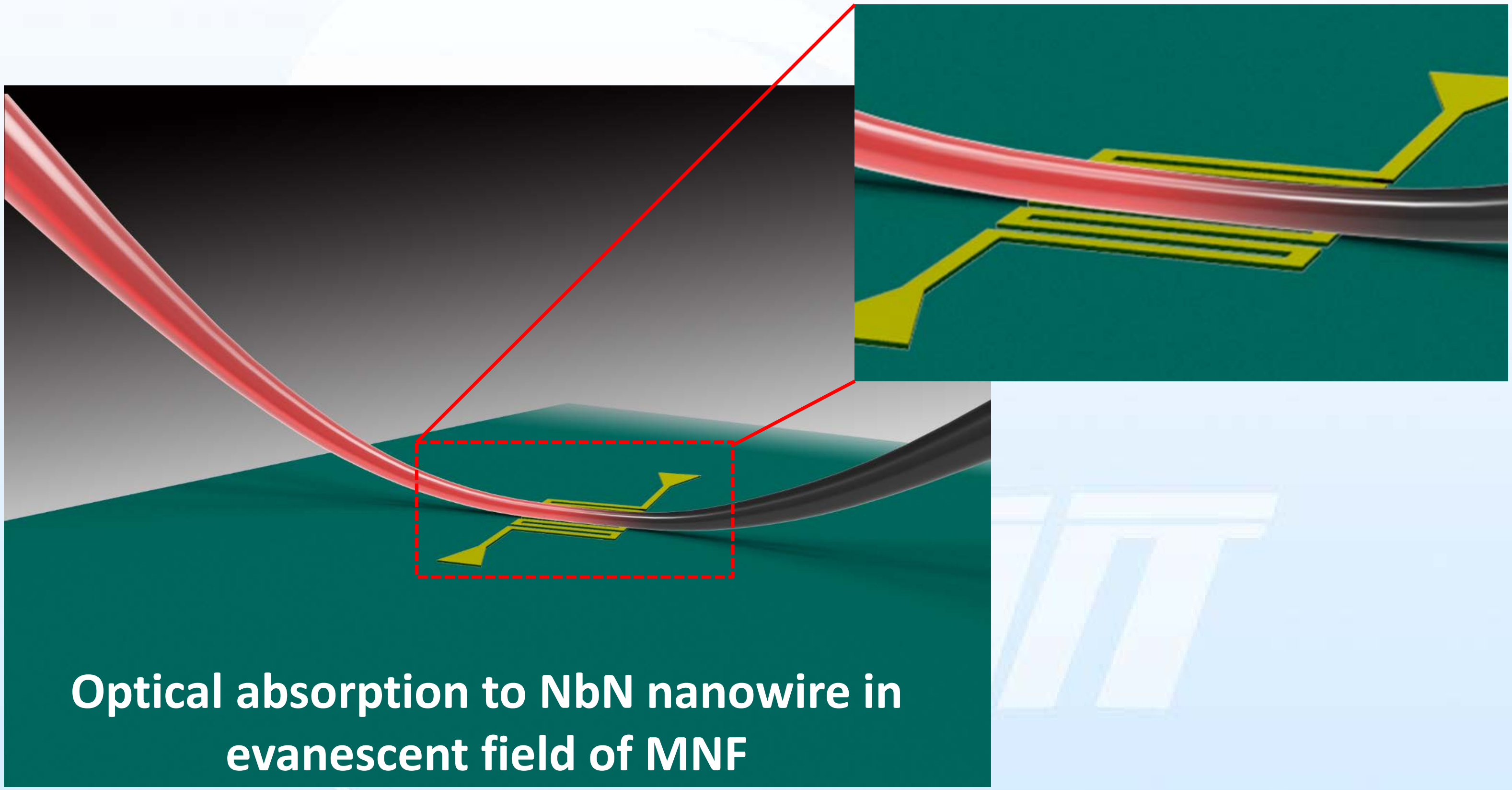
Size Comparison of SMF and MNF

From SMF to MNF using flame
（*Nanophotonics* 2, 407 (2013)）



Energy distribution of MNF @ 633 nm
Nanophotonics 2, 407 (2013)

MNF Coupled SNSPD



Schematics of MNF coupled SNSPD

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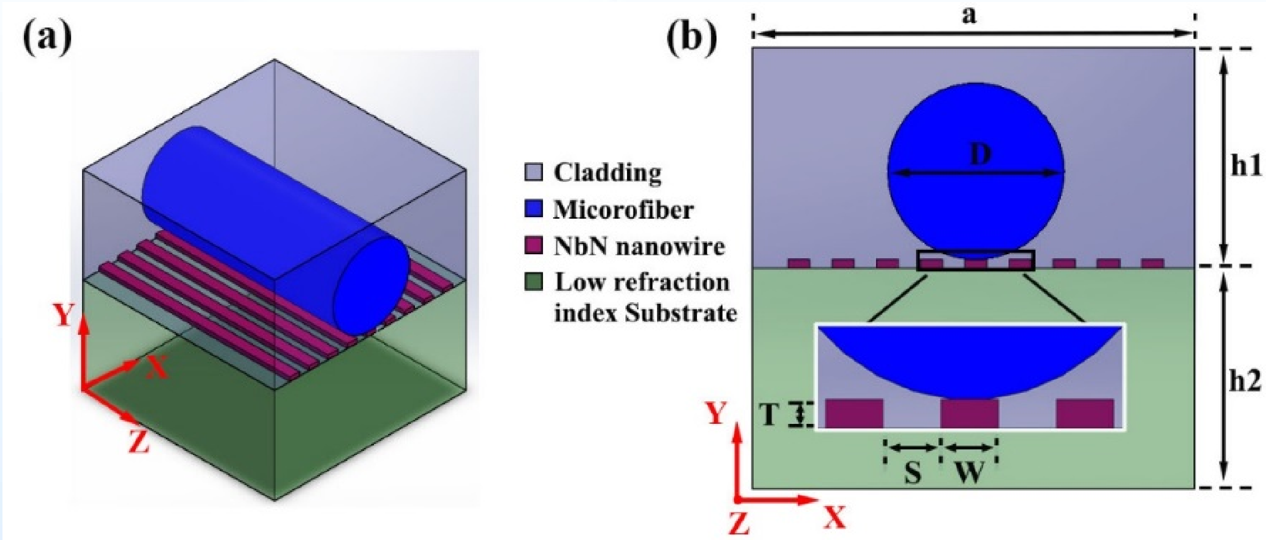
Model



3D schematics of MNF coupled SNSPD

Cross-section of MNF coupled SNSPD

Material Parameters	
Wavelength	1550 nm
n (fiber)	1.444
n (MgF_2)	1.38
n (NbN)	5.23-5.82i

SNSPD Parameters	
Linewidth	100 nm
Space	100 nm
Thickness	6 nm
Wire No.	TBD

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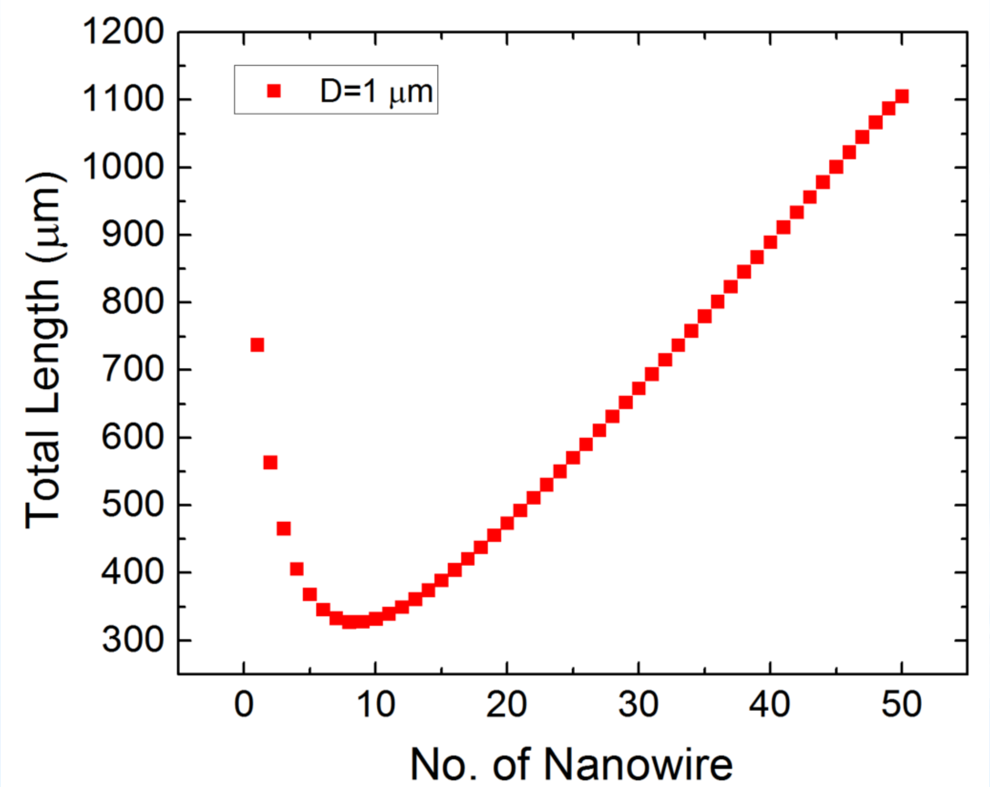
Parameters Optimization



- Absorption: 90%
- Dia of MNF: 1 μ m
- LRIA Cladding *with n* of 1.38
- Length: 30 μm/each
- No. of wires: 9

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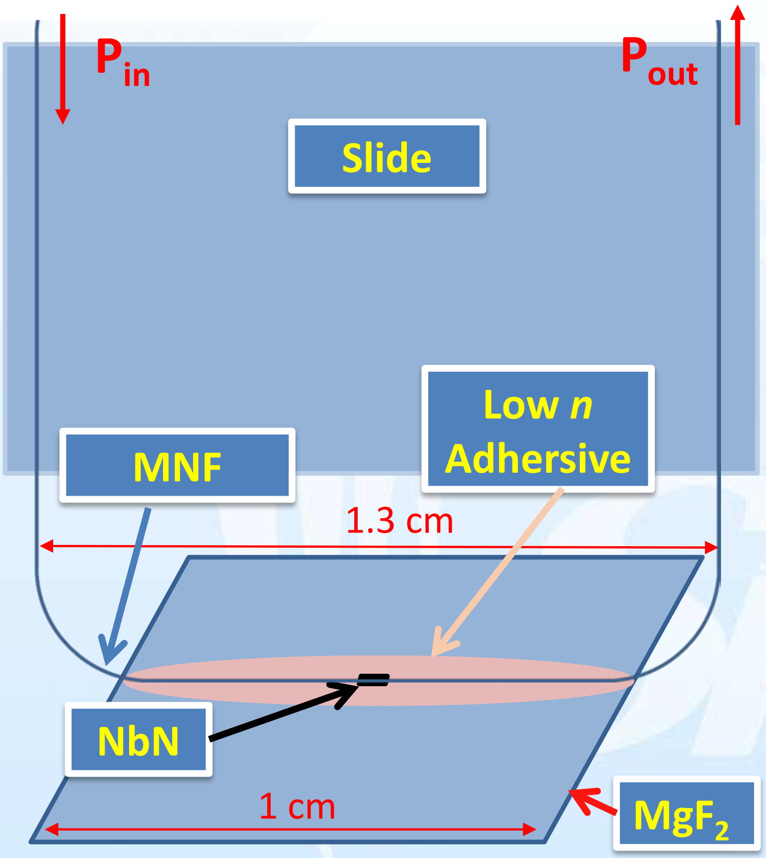
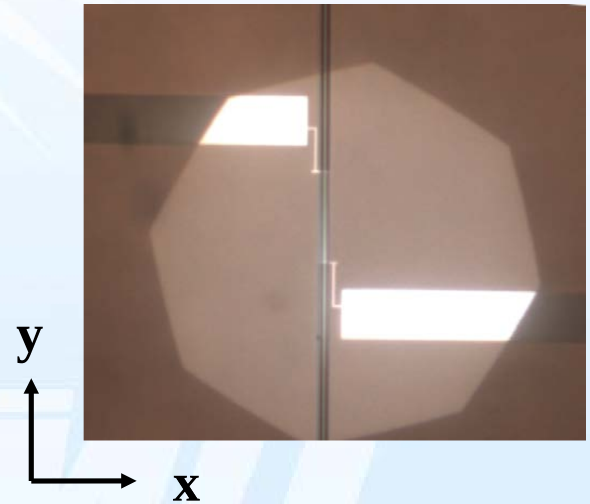
MNF coupled SNSPD



Schematics of the coupling system



Optical image of coupling

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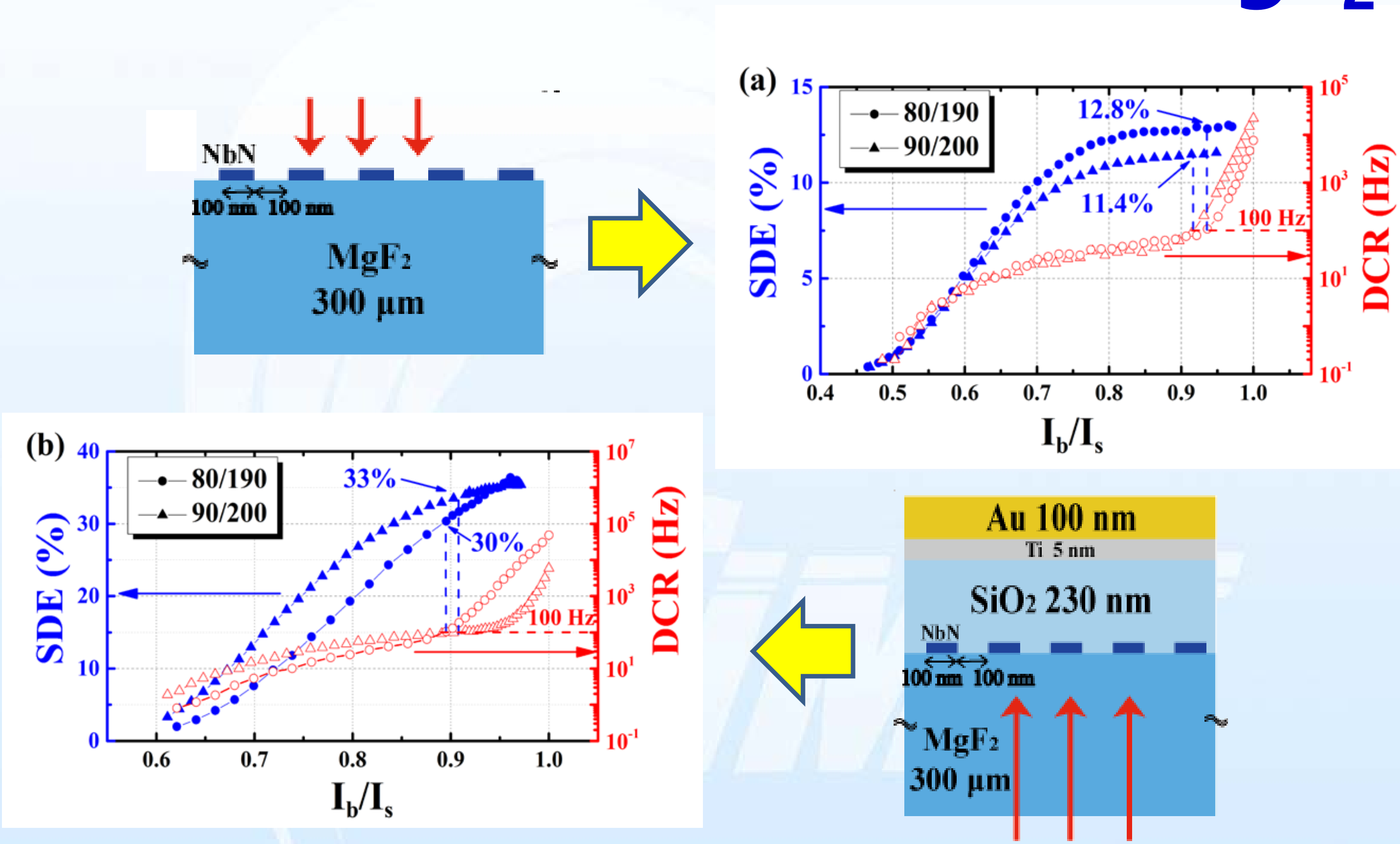
Conventional SNSPD on MgF_2



Conventional SNSPD on MgF_2 substrate shows similar performance of SNSPDs on MgO substrates [SUST, 2016, 29. 065011]

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Absorption

MNF D=1.3 μm

Transmittance

MNF No.	P_0（mW）	P_{max}（mW） TE	P_{min}（mW） TM	PER	T_{max}
9	6.0	4.6	2.4	1.9	77%
11	5.4	4.6	4.16	1.1	85%
new	5.4	4.8	4.1	1.2	89%

Absorption

DUT No.	P_0(mW)	Geo Para	P_{TM} - P_{TE}	Calculated Abs_{TE}
160707A5	6.2	11*50 um	3.7—0.50 mW	92%
160707A6	6.2	11*50 um	3.9—0.52 mW	92%
160707A7	5.6	11*50 um	3.6—0.48 mW	91%
160707A8	5.3	11*50 um	3.4—0.35 mW	93%
160711A3	5.4	11*20 um	4.2—1.7 mW	68%
160712A3	6.4	11*20 um	4.4—2.2 mW	66%

When T~90%， the Abs of nanowire can exceed 90%

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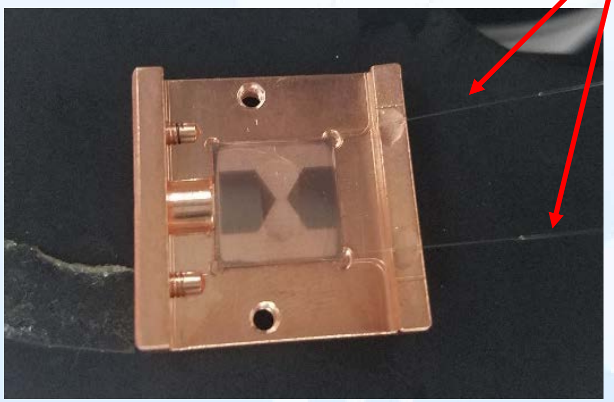
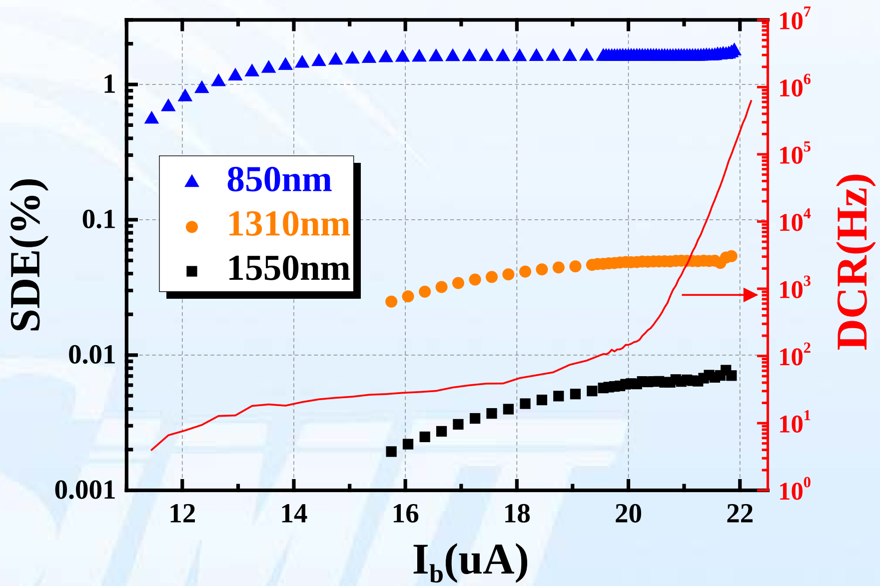
SDE at 2 K



Fiber

Package for LT measurement



SDE and DCR vs bias current

The electric performance and DCR is normal,
However, the SDE is very low, < 0.1%

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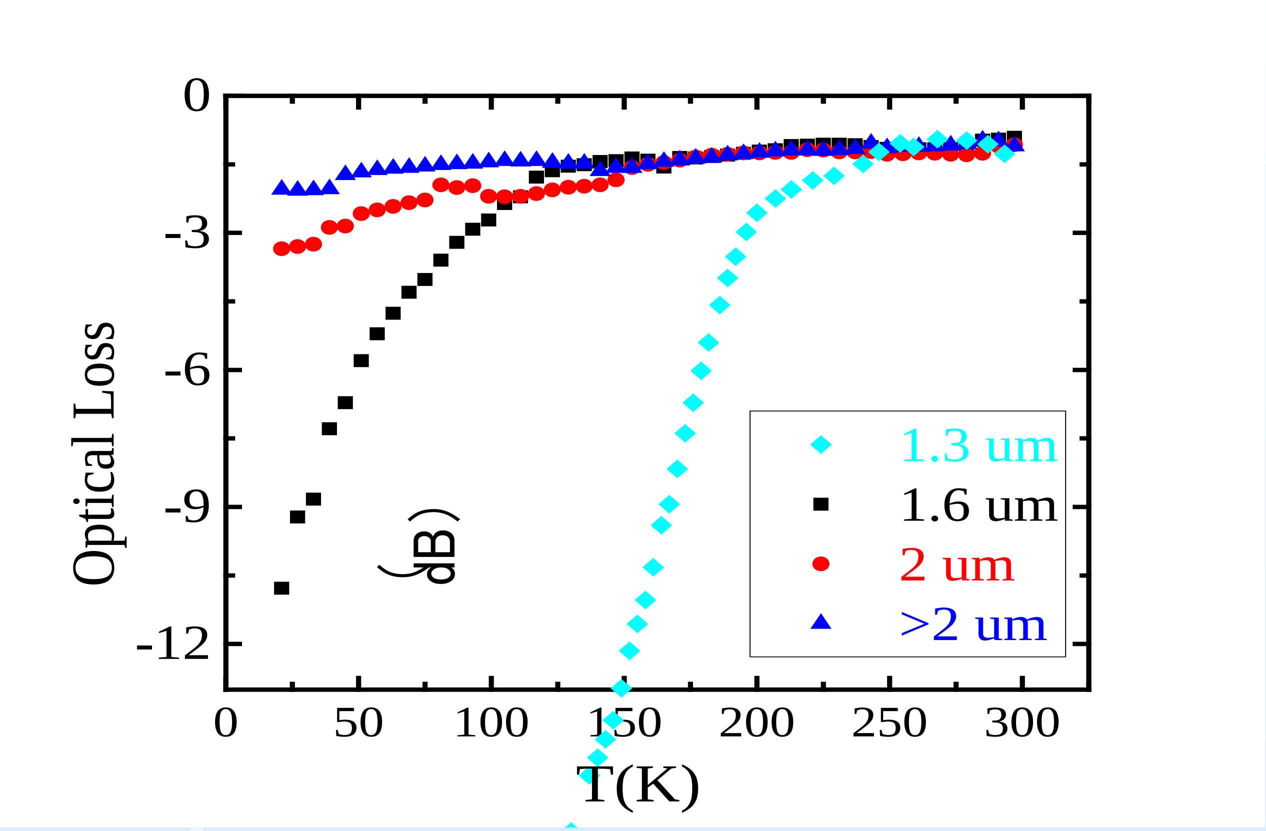
Loss of MNF vs Temp



n of adhesive ~1.41 @2.2 K，with using MNF with *D*=2 μm，The loss is 3.3 dB

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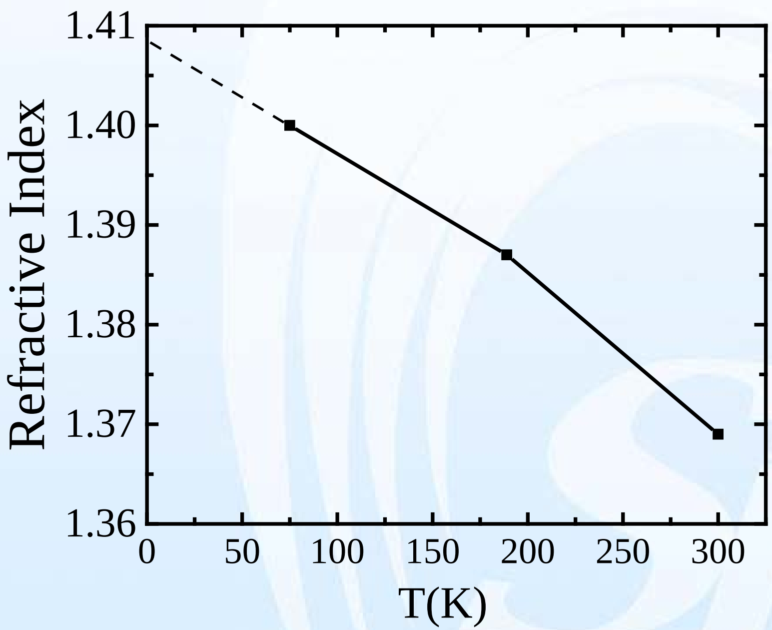
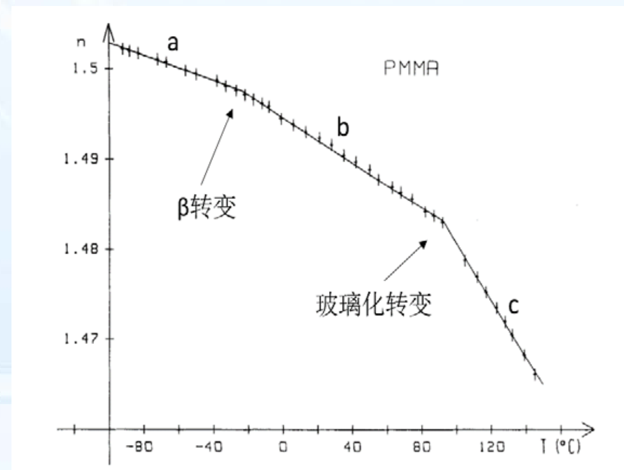
n of Adhersive changes at LT





Temp dependence of n of PMMA
J of Macromolecular Sci-Phy, 1986, B25(4)

Calculated Temp dependence of n for adhesive

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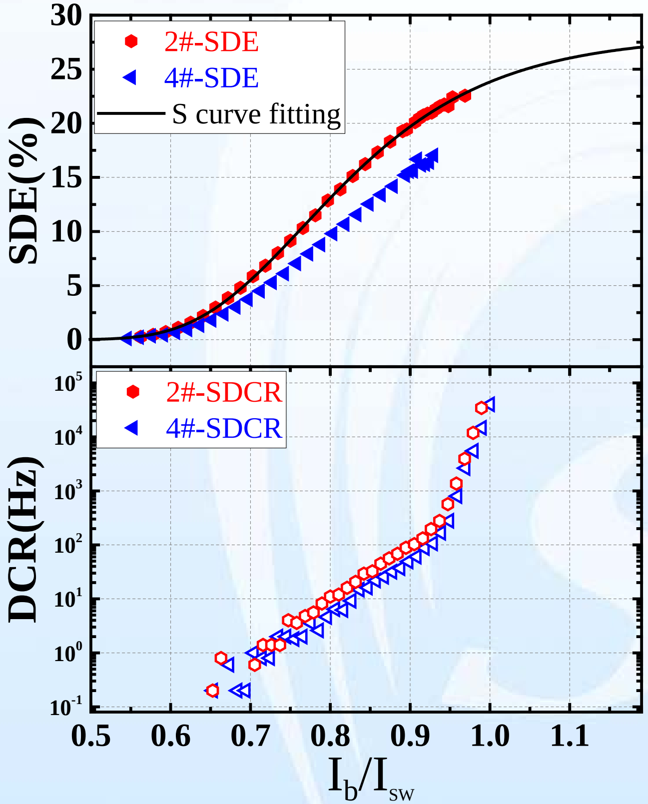
SDE >20% !!! with MNF of 2 um



SDE&DCR vs Ib for 1550 nm

Non-saturated SDE curve

Non-perfect fabrication process

Optical loss at Low Temp

Roughly 3 dB

纳米线吸收效率

With n_{adh}=1.41, the calculated Abs is 68%

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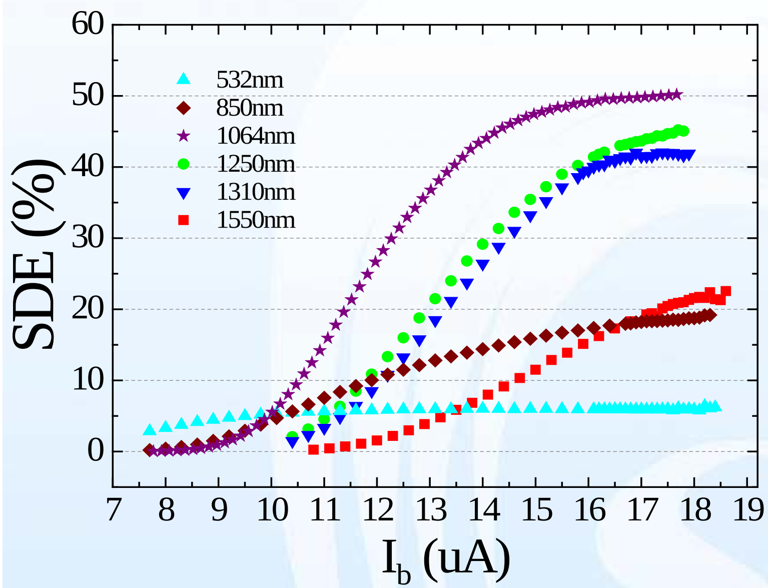
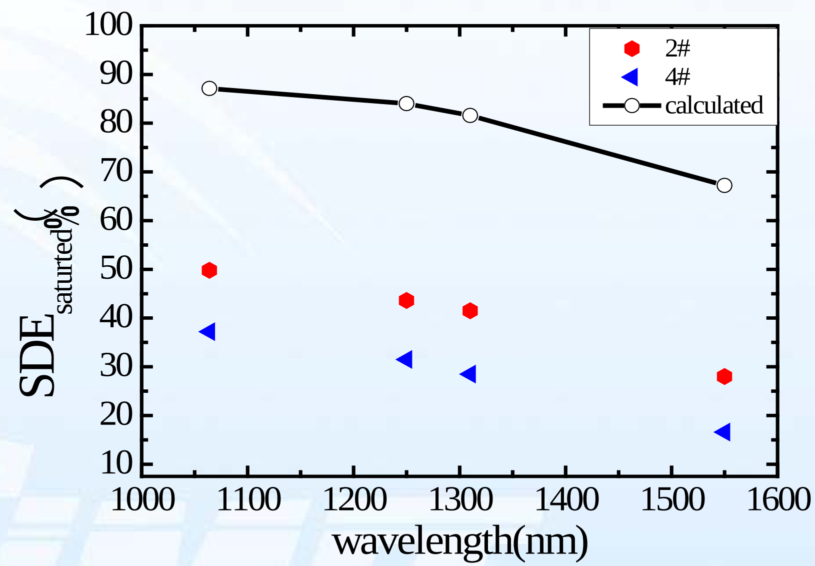
SDE vs wavelength



SDE vs Ib for various wavelength



SDE_{max} vs theoretical absorptance

- SDE increase with the decrease of the wavelength, consistent with theory;
- The difference between the measurement and calculation is about 3dB, consistent with the estimated loss, which can be minimized with MNF with 1.3 μm diameter.

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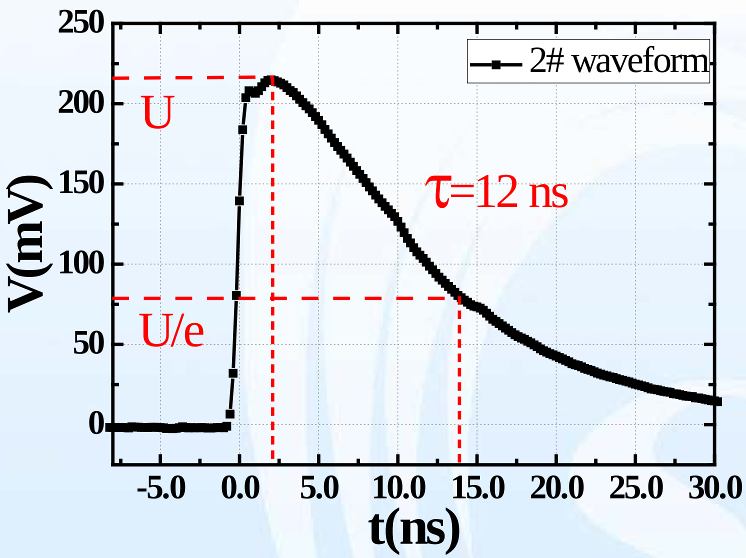
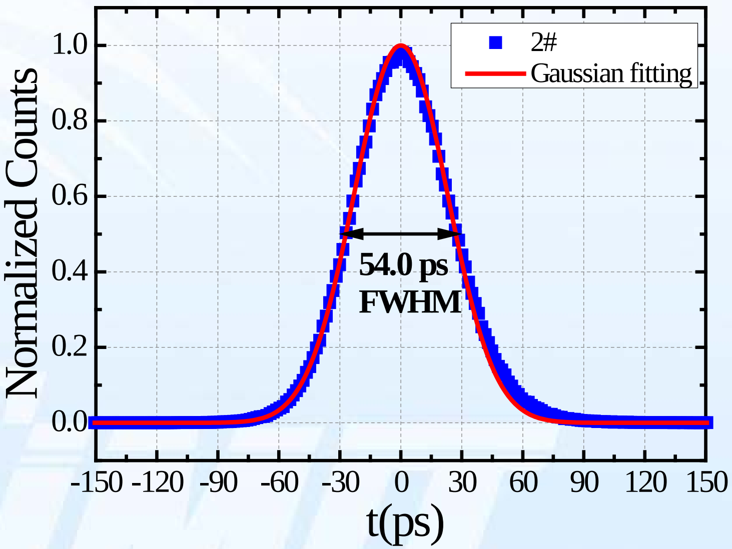
Other parameters



Response pulse waveform



Timing jitter

■ Similar jitter and shorter pulse width of ~50%

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Conclusion

MNF coupled SNSPD is demonstrated

- ✓ With SDE 20% @ 1550 nm and 50% @ 850 nm;
- ✓ Further improvement possible

SNSPDers @ SIMIT, CAS