IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), April 2016.
Invited presentation FD-1-1 given at ISS 2015 in Funabori, Tokyo, Japan, November 16 to 18th, 2015.

ISS 2015
28th International Symposium on Superconductivity
November 16 - 18, 2015

Superconducting Nanowire Single Photon Detector for Quantum Information

SNSPD for QI

Lixing You

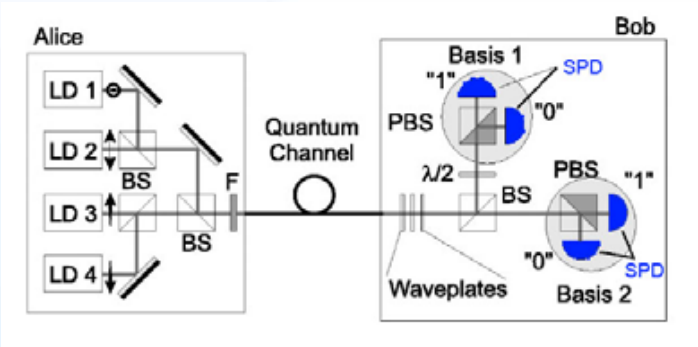
[1]Shanghai Center for SuperConductivity (SC[2]), SIMIT, CAS
[2]Dept of Phys., UC Berkeley
lxyou@mail.sim.ac.cn

Nov. 17, 2015

Content

- Quantum Information and SPD
- Introduction to SNSPD
- SNSPD for 1550 nm
- SNSPD for NIR to VIS
- Applications

SNSPD for Quan Commun



Schematics of QKD

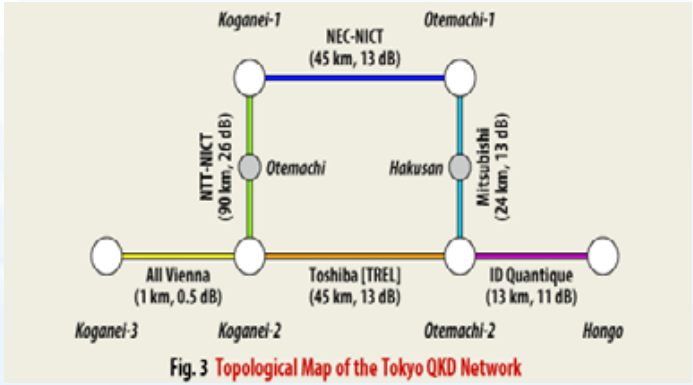
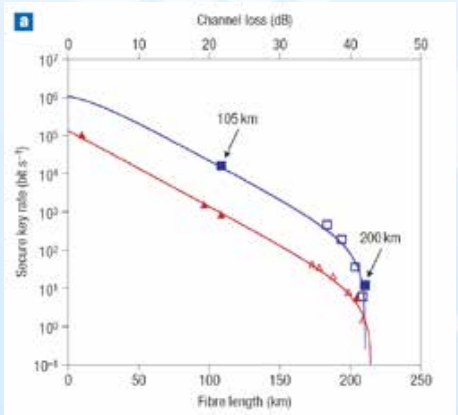
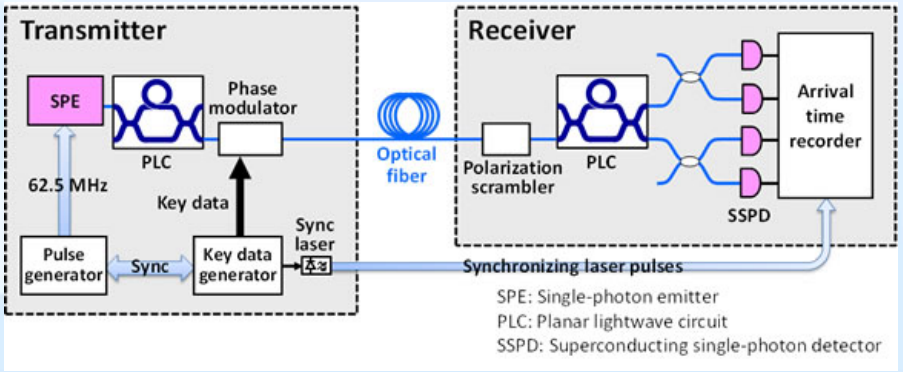


Fig. 3 Topological Map of the Tokyo QKD Network

Tokyo QKD network since 2010

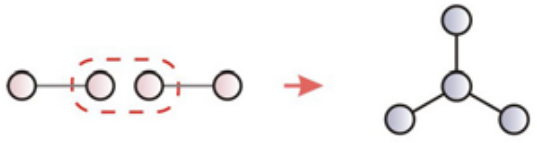




Demonstration of 200 km QKD
(NTT & NIST) Nat Photon, 1: 343(2007)

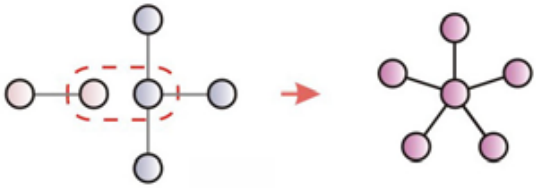
Demonstration of QKD using QD and SNSPD
（東大、富士通、NEC）**Sci Rep** 5: 14383. (2015)

SNSPD for Quantum Simulation



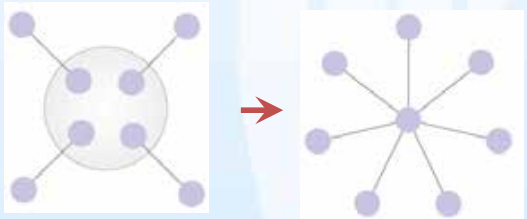
4-qubit
GHZ state

Pan *et al.*, PRL 86, 4435 (2001)



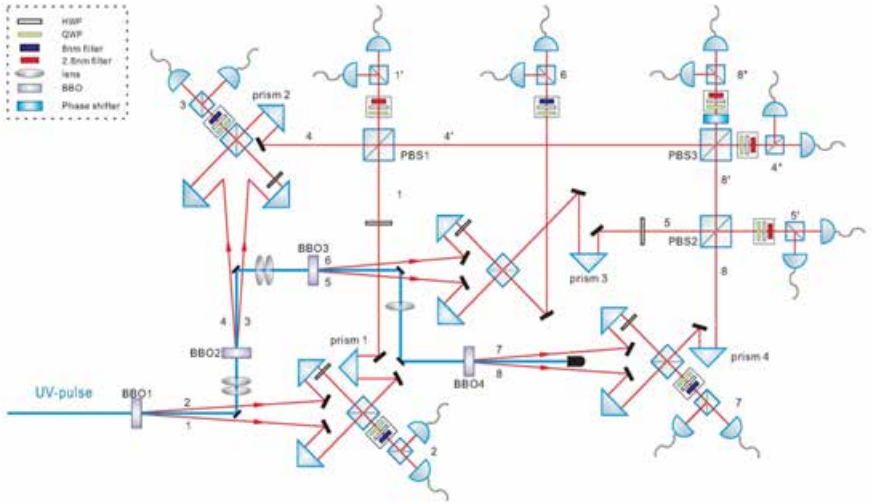
6-qubit
GHZ state

Lu *et al.*, Nature Physics 3, 91 (2007)



8-qubit
GHZ state

Yao *et al.*, Nature Photonics 6, 225 (2012)



a ***n***-photon coincidence count rate

$$R \sim h^n$$

Current Si SPD : h~ 20% @940 nm
Gives 1 Hz for f=10MHz for ***n***=10

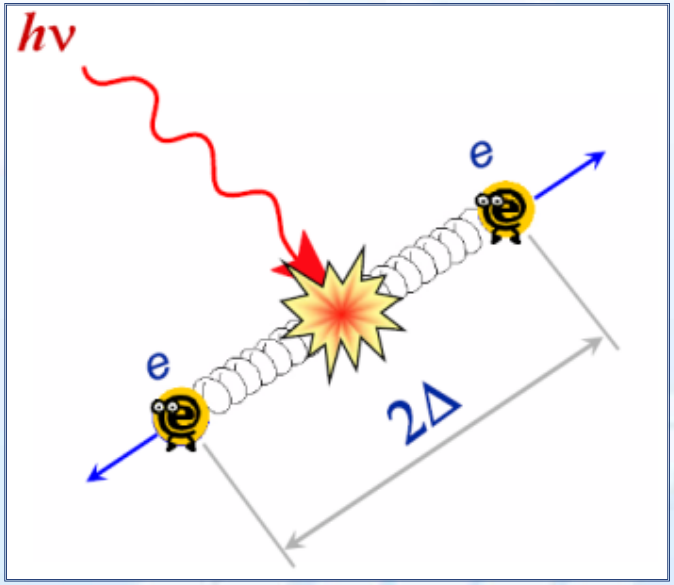
If we could improve h to 60%,
the coincidence count rate can improved by 4-5 orders of magnitude.
Measurement Time can be suppressed from 1 year to 10 min.

Content

- Quantum Information and SPD
- Introduction to SNSPD
- SNSPD for 1550 nm
- SNSPD for NIR to VIS
- Applications

Detection Mechanism

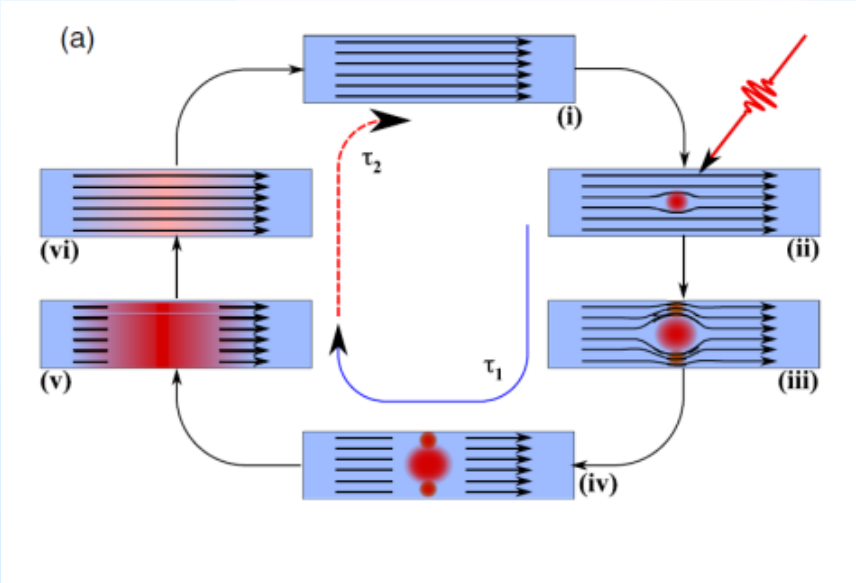
Cooper pair breaking by single photon



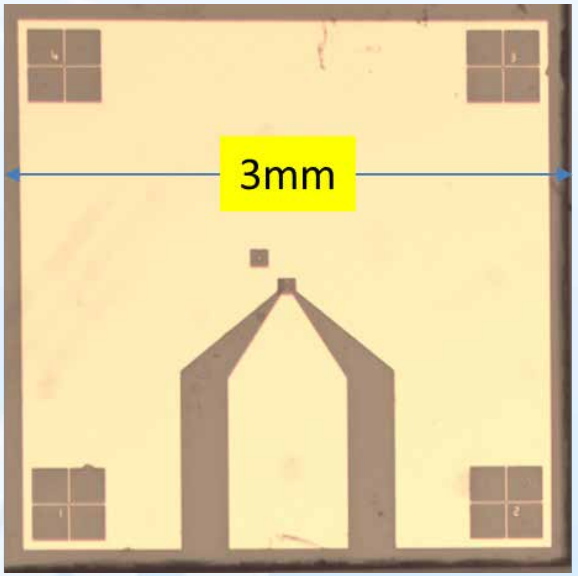
Photon energy	vs	Superconducting gap/Cooper Pair energy
hn (1eV)	vs	2D (6.4 meV)

Detection Mechanism

- Material: Ultra thin NbN film（~ 5 nm）
- Structure: nanowire (linewidth <= 100nm)



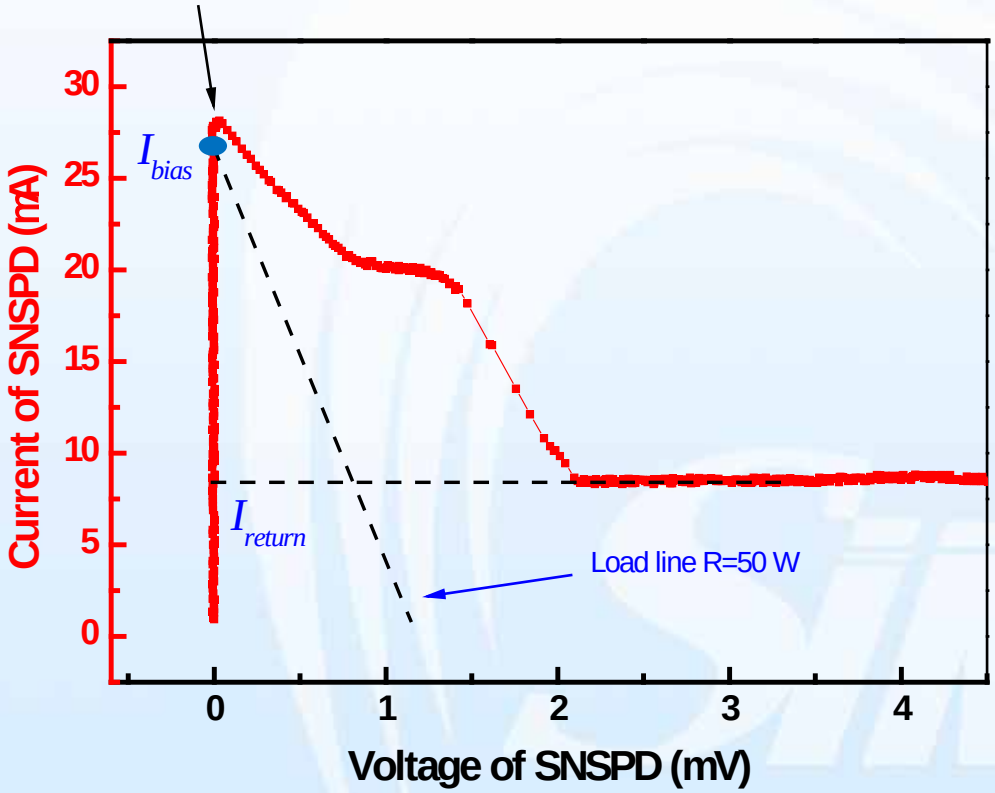
Dynamics

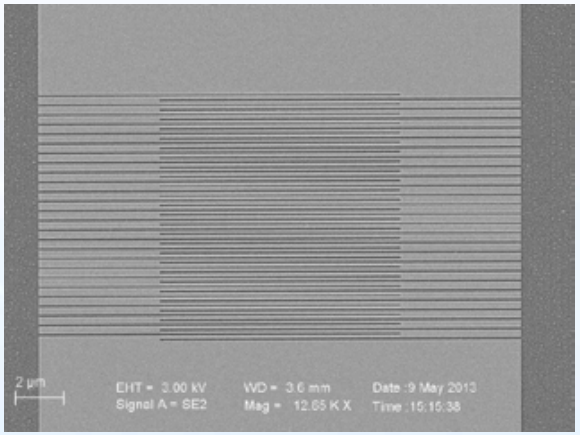


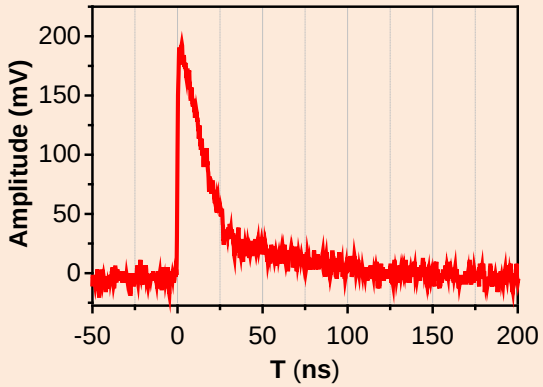
Planar Structure

- Thermal relaxation time : tens of ps ——》 high speed detection

Detection Mechanism

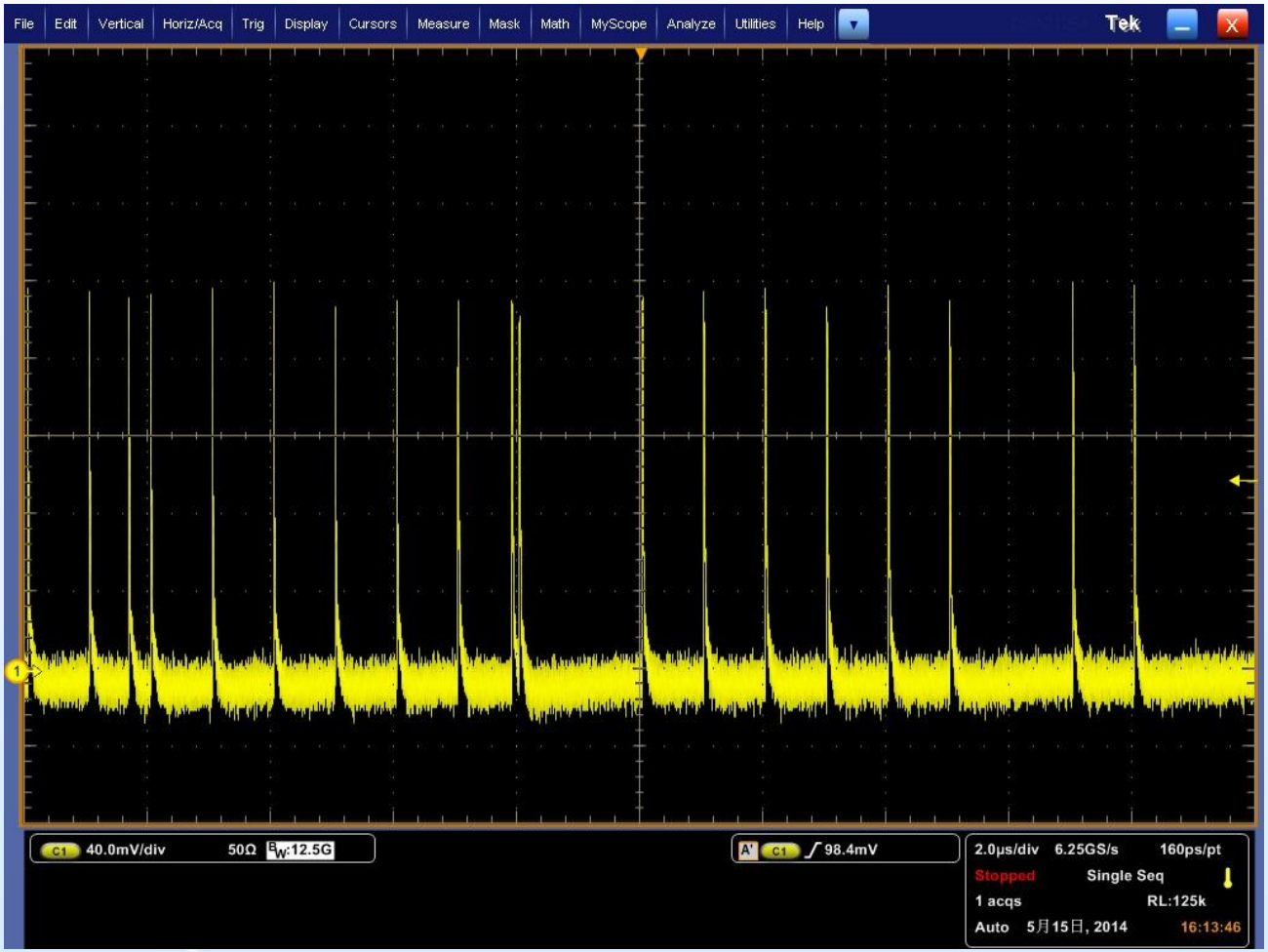






v **Thermal relaxation time : tens of ps ——》 high speed detection**

Detection Mechanism



SPD performances @ 1550 nm

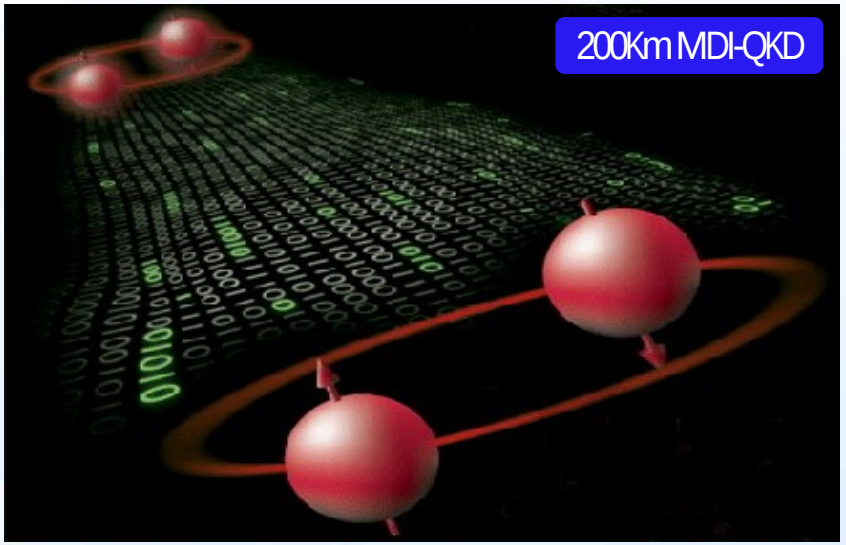
SPD	Count Rate (Hz)	DE (%)	Dark Counts (s^{-1})	Jitter (ps)	Temp.
SNSPD (NbN)	>100 M	> 80	<1	<20	~ 2.2 K
STJ (Al)	5 K	60	N/A	N/A	< 1K
TES (W)	100 K	95	~ 0	100 ns	0.1 K
InGaAs APD	100 M	20	16K	55	200 K
IR PMT	10 M	2	200 K	300	室温

SNSPD is a very competitive

Applications

u **Deep Space Laser communication**

u **QKD**



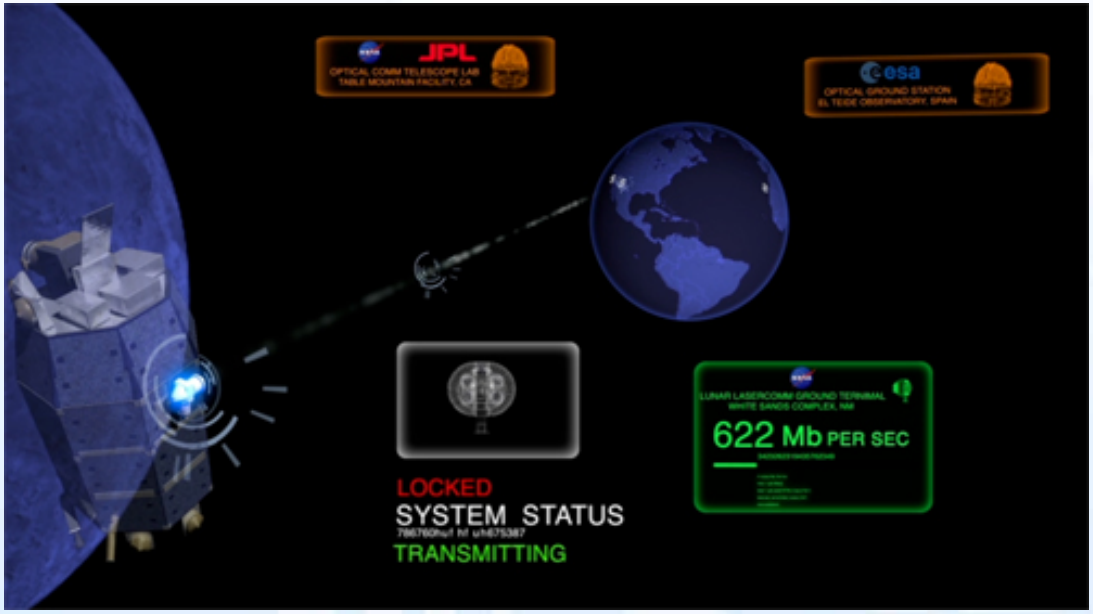
u **Single photon imaging**

u **Laser ranging**

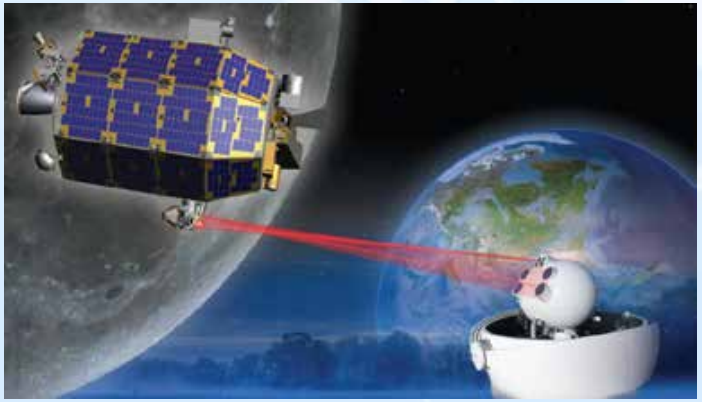
Alternative to APD/PMT

- u **Fiber Sensing**
- u **IC testing**
- u **Biological fluorescence**
- u …

Deep space laser communication



- ü 2013/9/6 LADEE launched，
- ü 2013/10/18，moon satellite-earth communication demonstrated



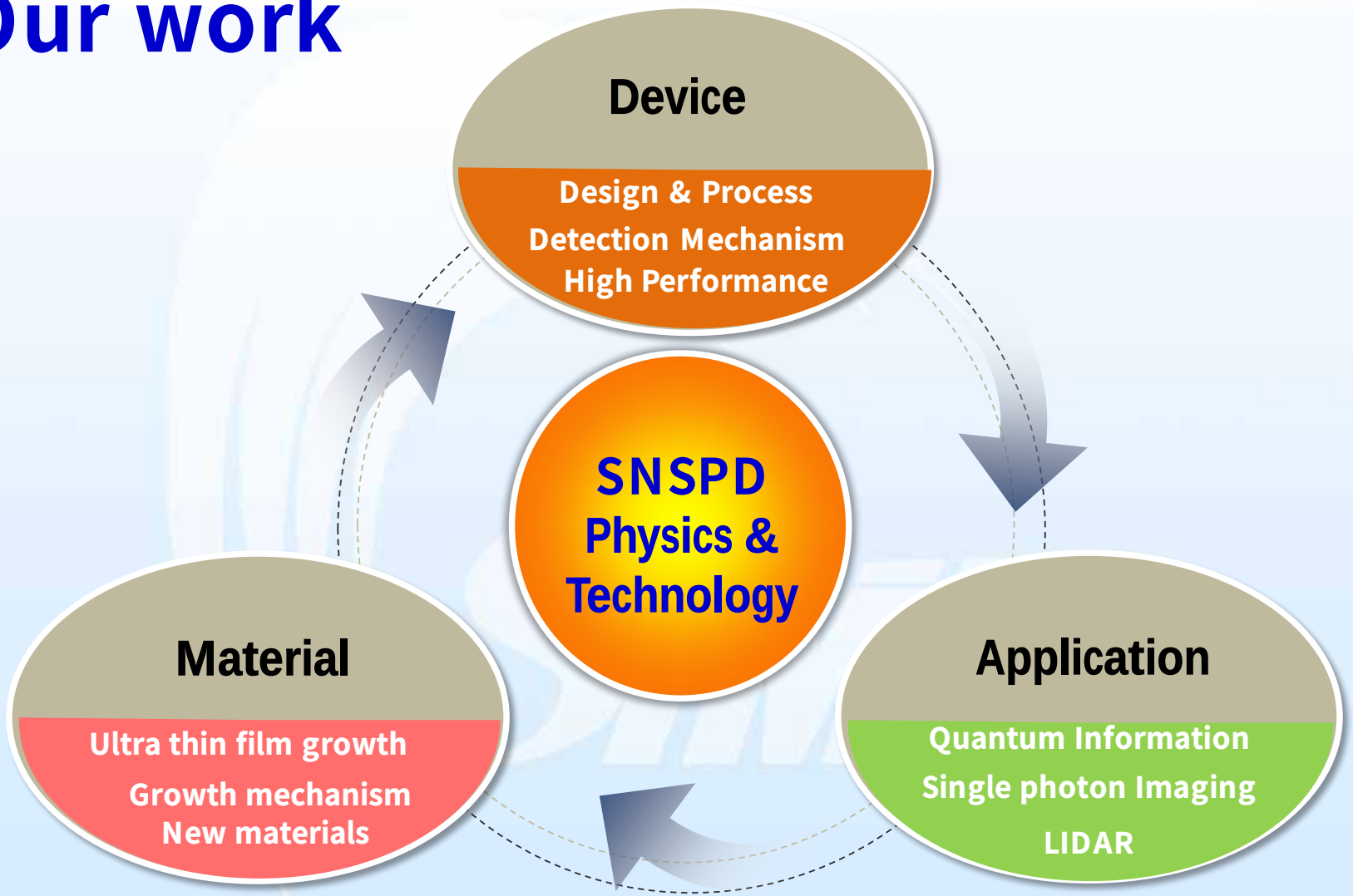
Record-breaking distance of 380K KM

- Download vs Upload：622 Mbps vs 20 Mbps

Content

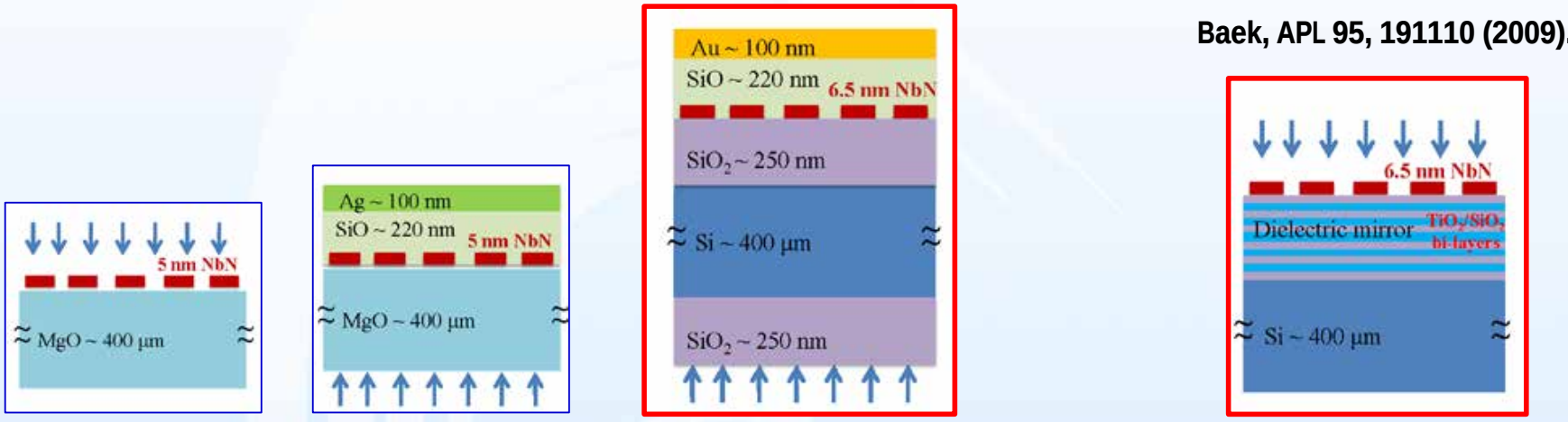
- Quantum Information and SPD
- Introduction to SNSPD
- SNSPD for 1550 nm
- SNSPD for NIR to VIS
- Applications

Our work


Device
Design & Process
Detection Mechanism
High Performance
SNSPD
Physics &
Technology
Material
Ultra thin film growth
Growth mechanism
New materials
Application
Quantum Information
Single photon Imaging
LIDAR

Structure Development

Baek, APL 95, 191110 (2009).



w/o cavity | Single Cavity | Double Cavity | SDE ~ 80% | Di-electric Mirror

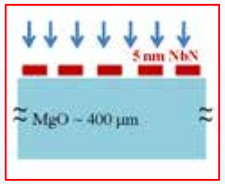
SDE > 5% | SDE > 17% | SDE > 35% | SDE > 50% | SDE > 70% | SDE ~ 80%

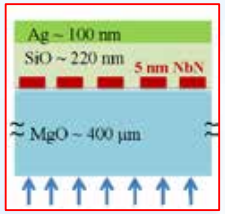
2012.09 10 2012.12 2013.01 05 07 11 2014.04 06 2014.11 2015.06

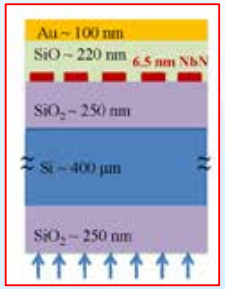
Since 2012.08

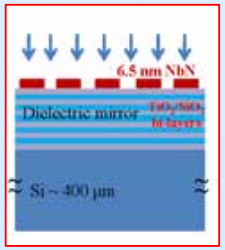
The key is to improve the photon absorption of the superconducting nanowire

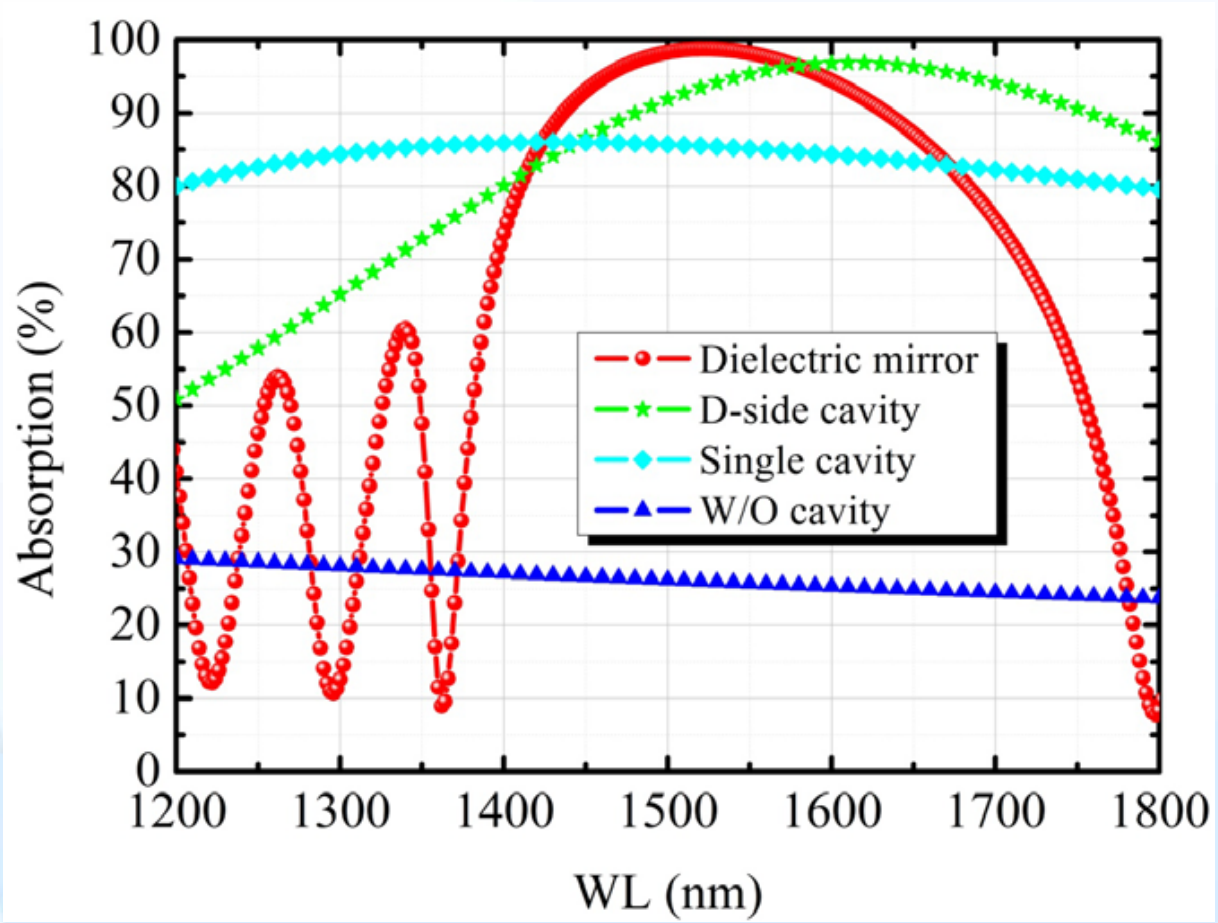
Improvement on absorption







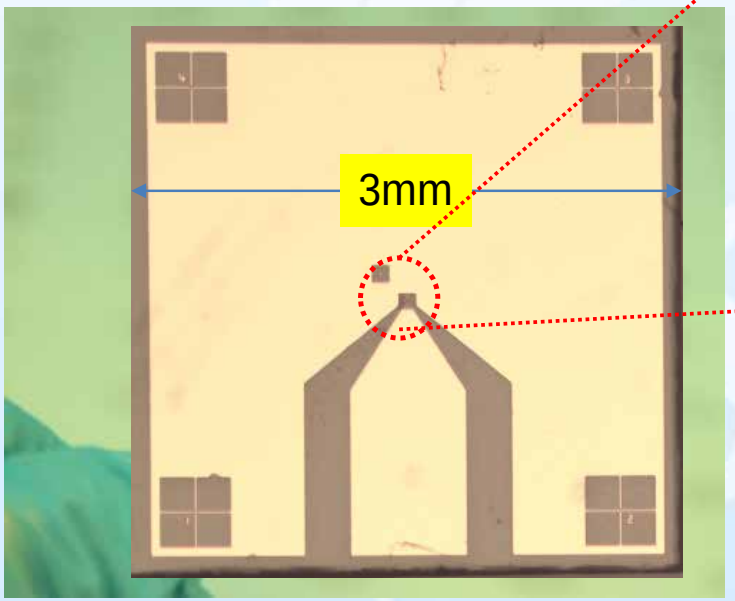


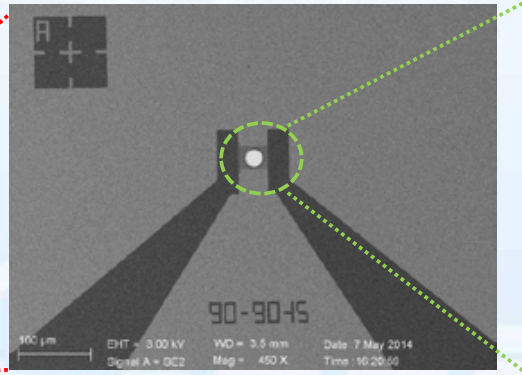


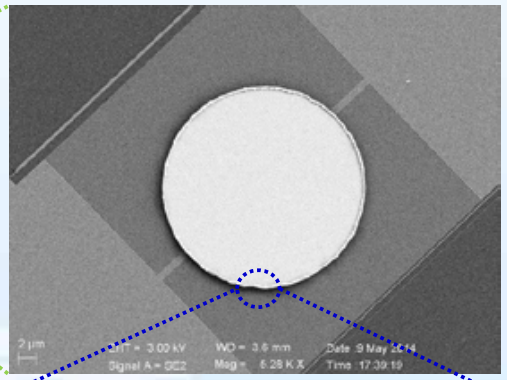
Simulation of absorption for different structures

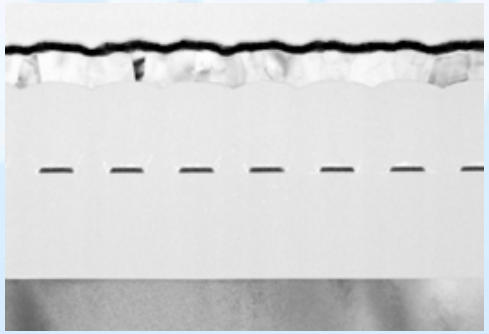
Fabrication Process

Electrode and mark → Nanowire pattern → Define Active area → Optical cavity → Dicing

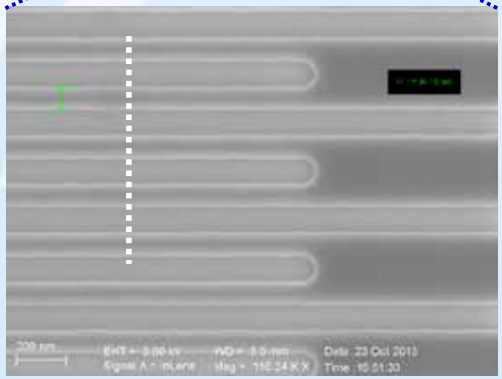




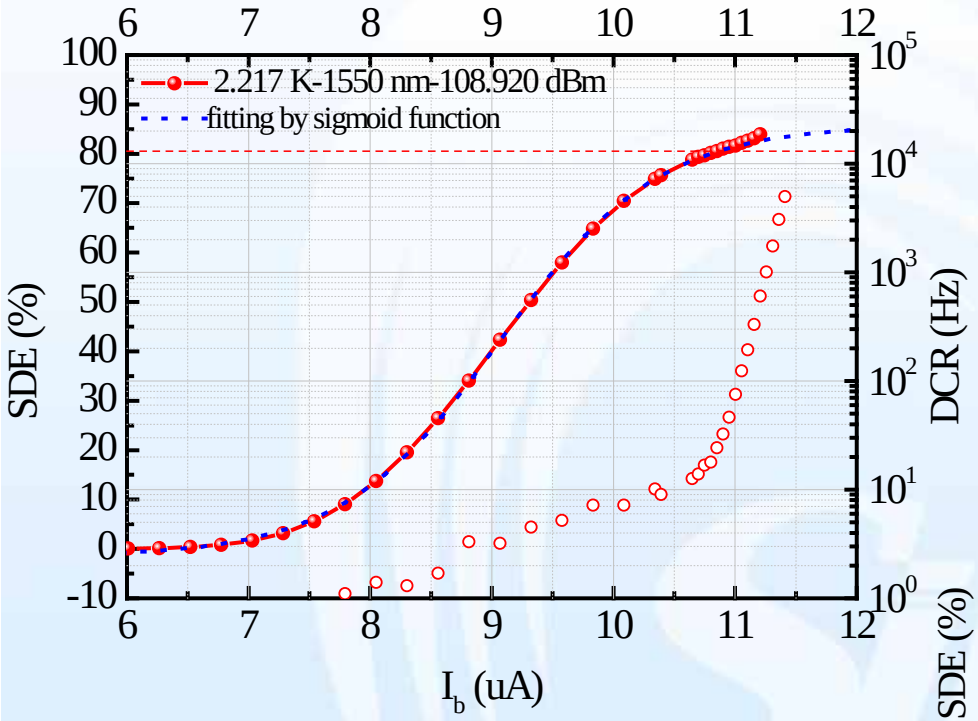




Cross section view

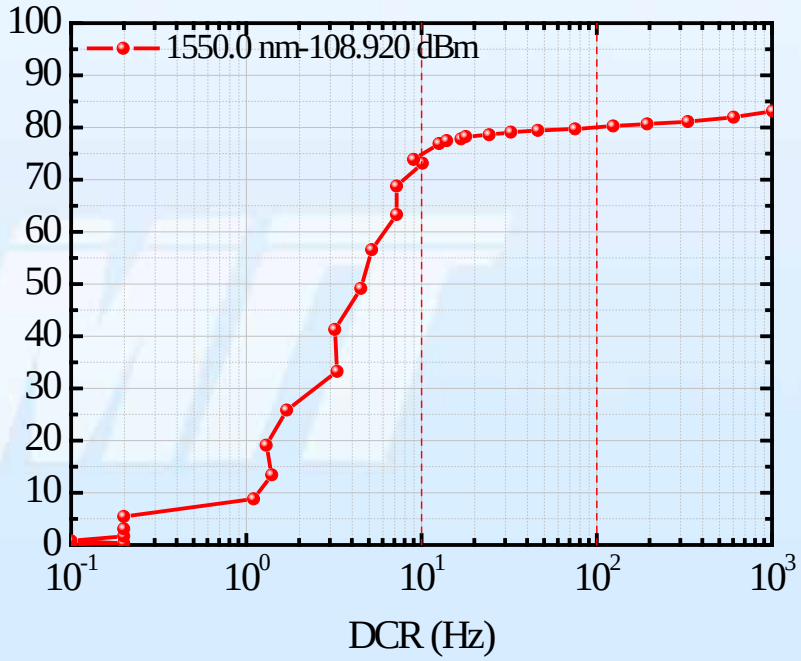


High DE SNSPD @1550 nm



SDE & DCR vs I_b

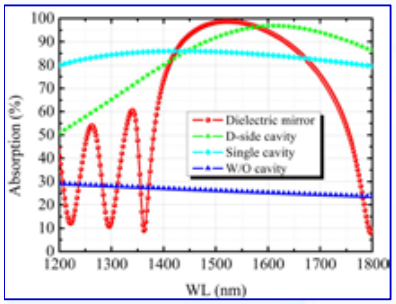
SDE vs DCR

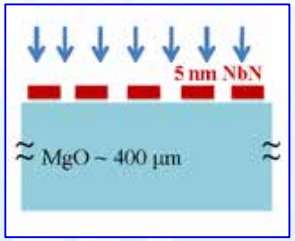


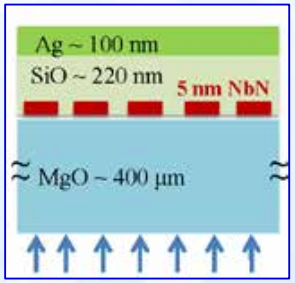
Content

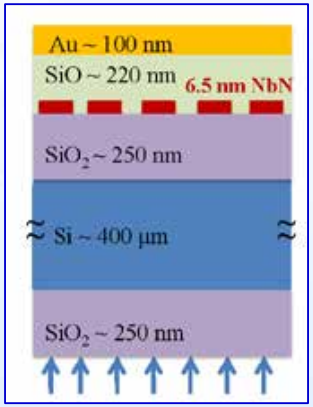
- Quantum Information and SPD
- Introduction to SNSPD
- SNSPD for 1550 nm
- SNSPD for NIR to VIS
- Applications

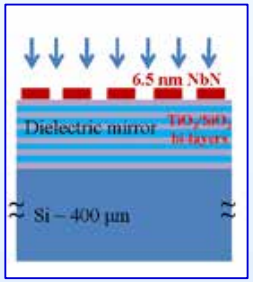
Wavelength Compatibility of optical structures











	w/o cavity	Single Cavity	Double Cavity	Dielectric Mirror
NIR	J	J	J	J
VIS	J	J	L	J
Absorption	L	K	J	J

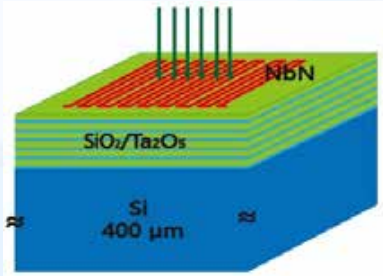
SNSPD at 1064nm

Why 1064nm?

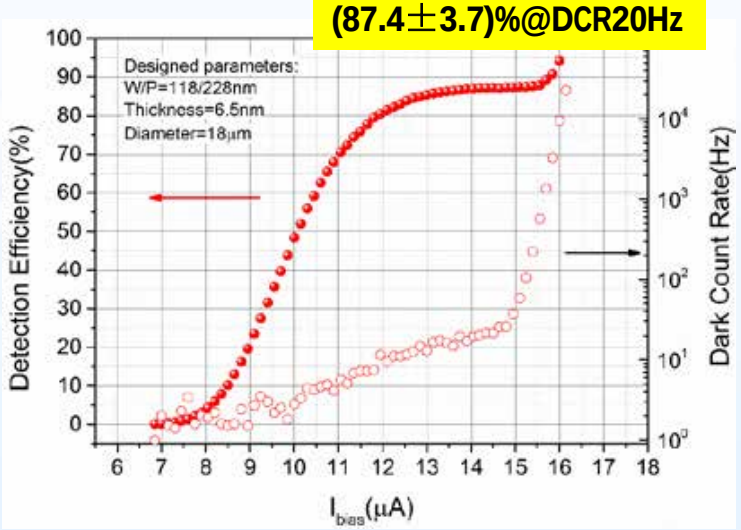
1. **Potential applications for *quantum optics, satellite laser ranging, ghost imaging* and so on.**
2. **Semiconductor APDs have a limited DE < 30%.**

Design of SNSPD

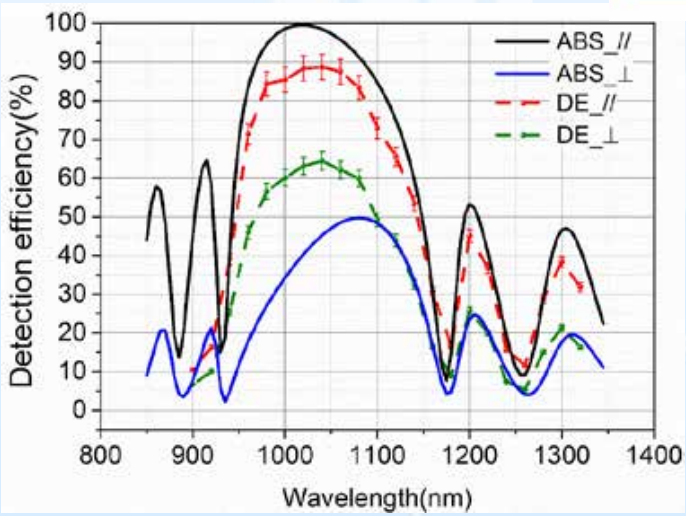
1. 13 bilayers with reflectivity>99%.
2. HI 1060 Flex (f =6mm) SMF coupled.
3. Abs~1 with polarized photons.



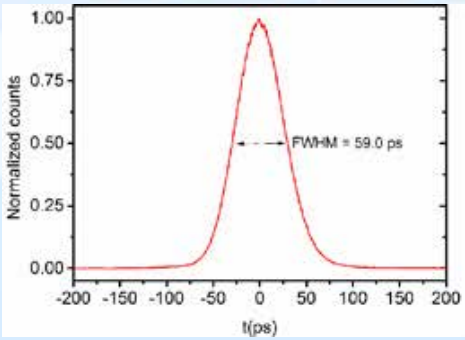
(87.4±3.7)%@DCR20Hz



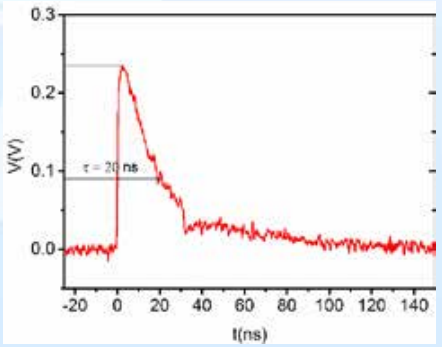
SDE & DCR vs I_b



SDE & Abs vs l



Timing jitter

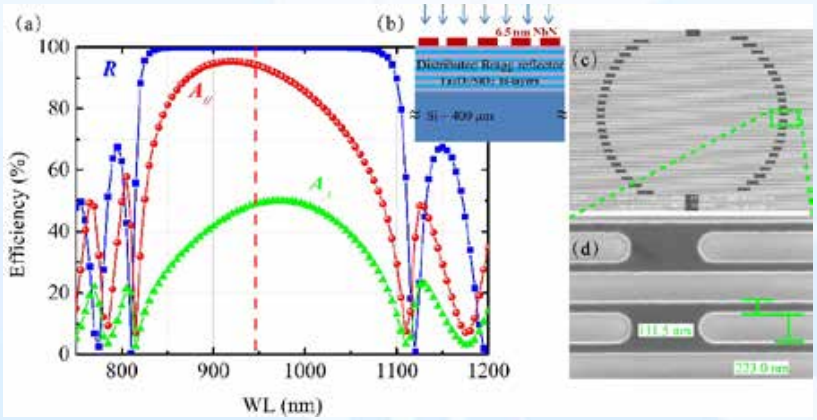


Response waveform

SNSPD for 945 nm

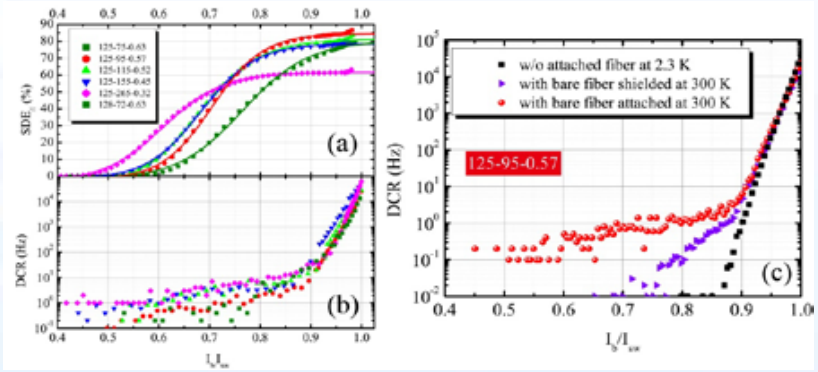
Why 945 nm?

- Best available QD at this wavelength
- Important platform for quantum information process

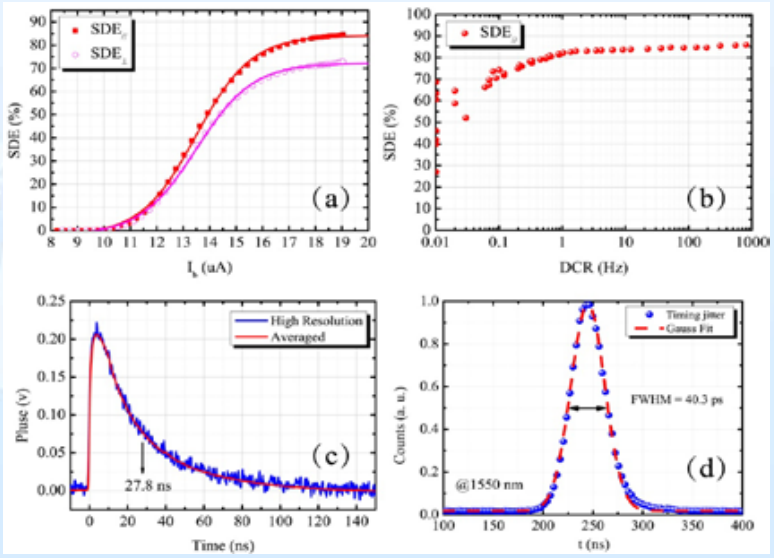


Detector	DE	Dead Time
Si APD	20-30%	45 ns
SNSPD	>80%	28 ns

Ten-fold count rate will be improved by $10^{5\text{-}6}$



SDE and DCR vs Bias current

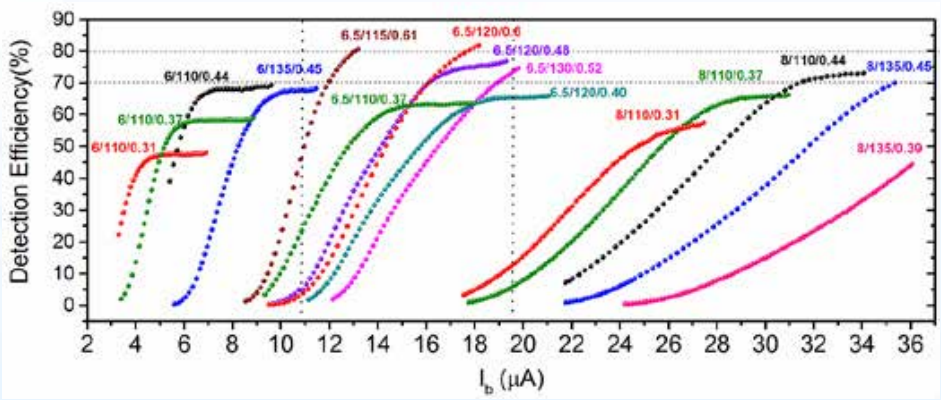


W. J. Zhang **AIP Advances** 5(6): 067129. (2015)

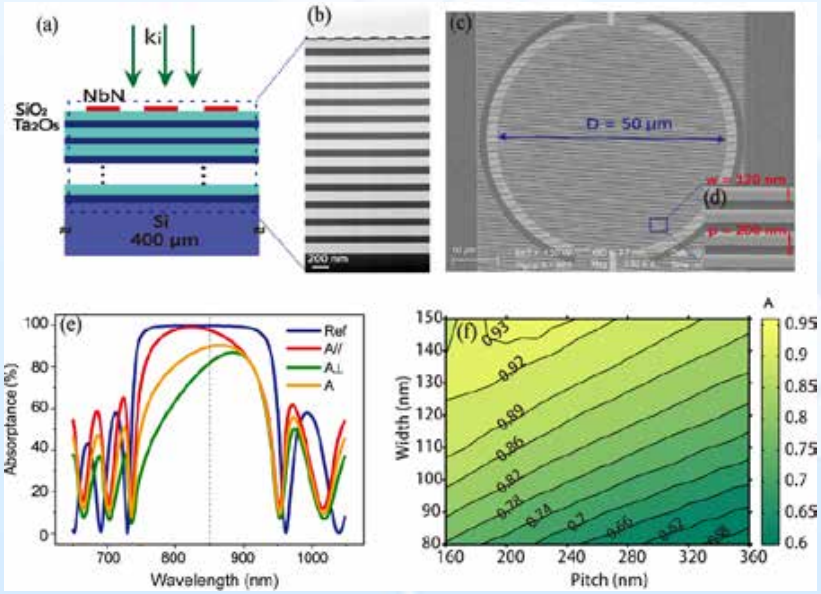
SNSPD for 850 nm

Why 850 nm?

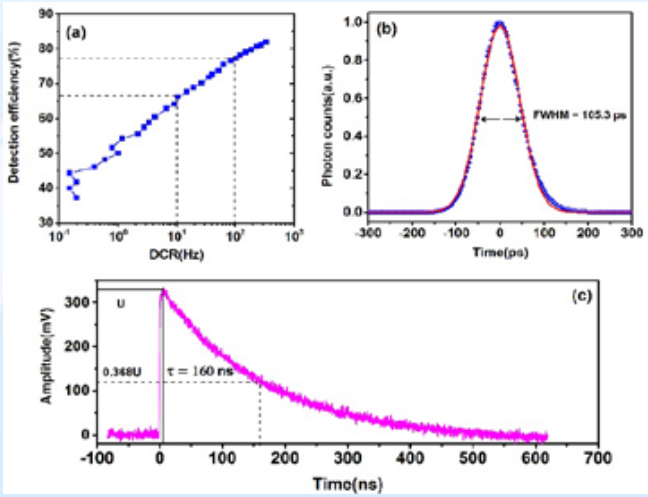
Detector	DE
Si APD	50%
SNSPD	80%



SDE (> 80%) vs Bias current



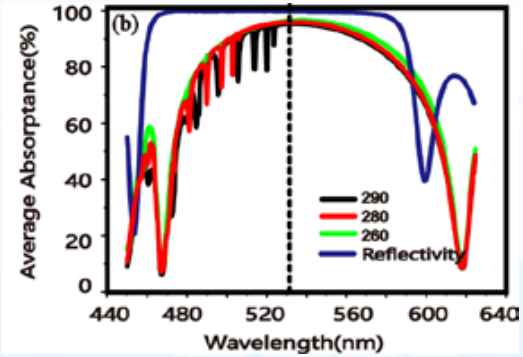
Hao Li, et al OE 23(13): 17301 (2015)



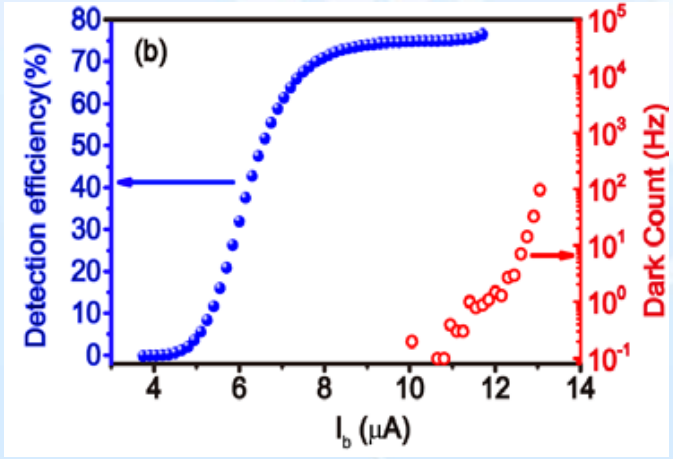
Key perforamance

SNSPD at 532nm aiming to SLR

Device design and performance

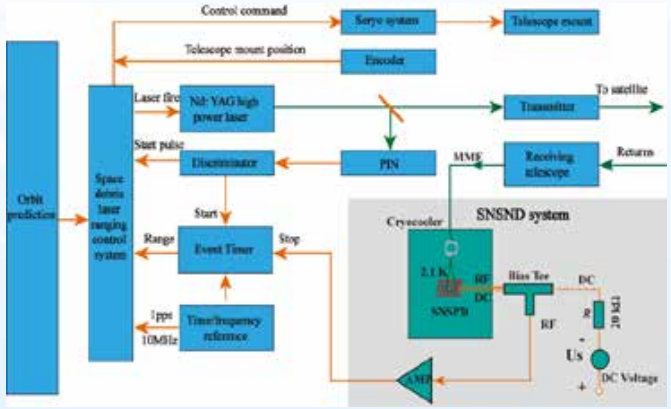


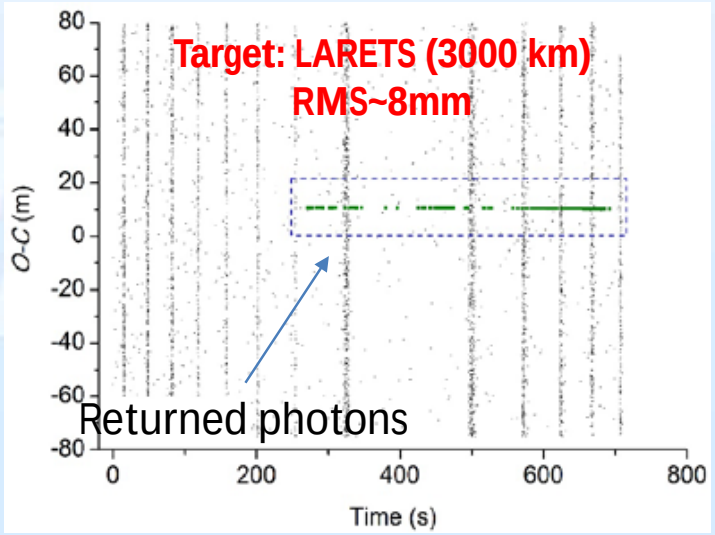
1. HR based.
2. MMF(f =50mm)
3. W/p=140/280 (nm)
4. f =42 mm



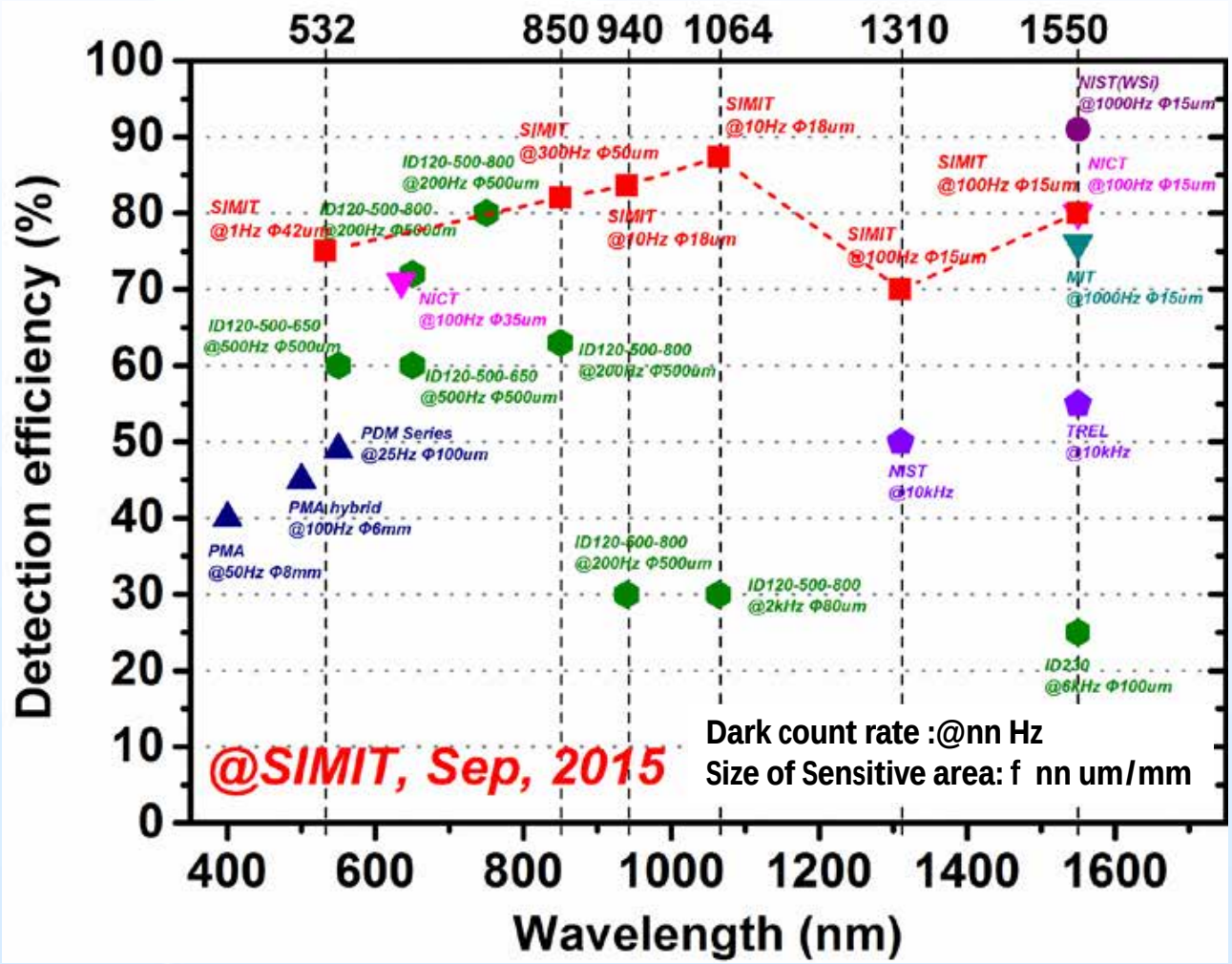
SDE=75%@DCR<1

SLR measurement setup





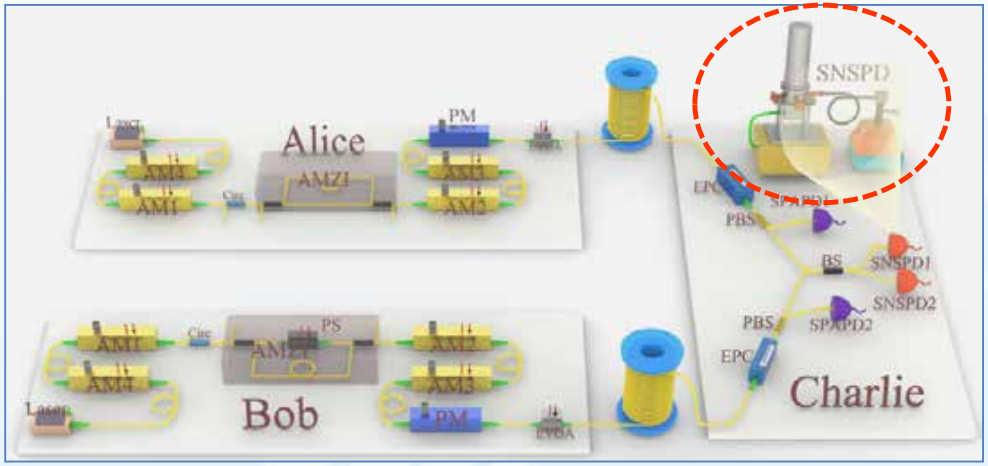
High DE SNSPD@ VIS&NIR

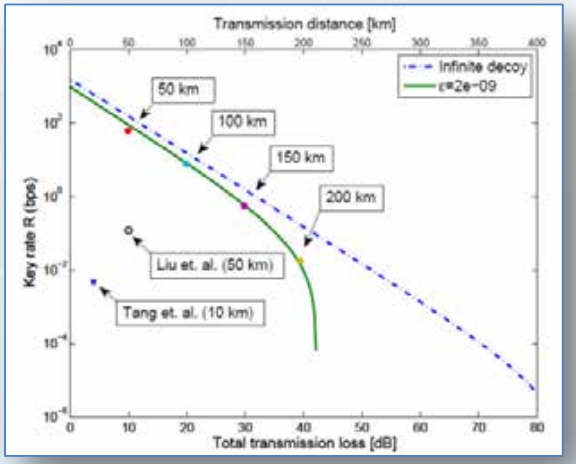


Content

- Quantum Information and SPD
- Introduction to SNSPD
- SNSPD for 1550 nm
- SNSPD for NIR to VIS
- Applications

Demo---- MDI-QKD





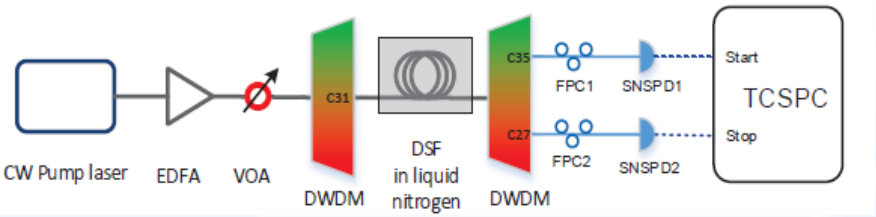
SNSPD SDE > 40% @10 Hz DCR

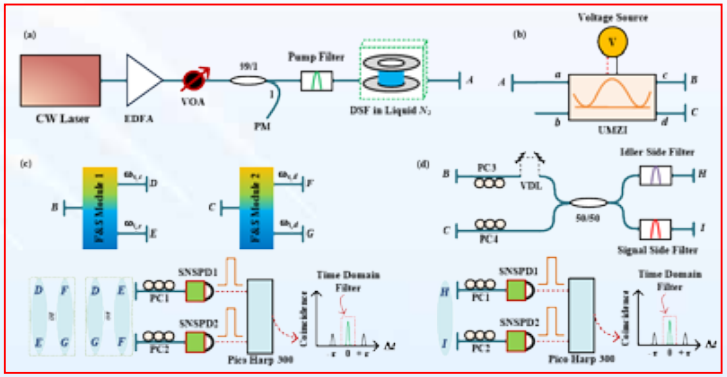
First Demonstration of 200 km MDI-QKD in lab & 30 km MDI-QKD field test

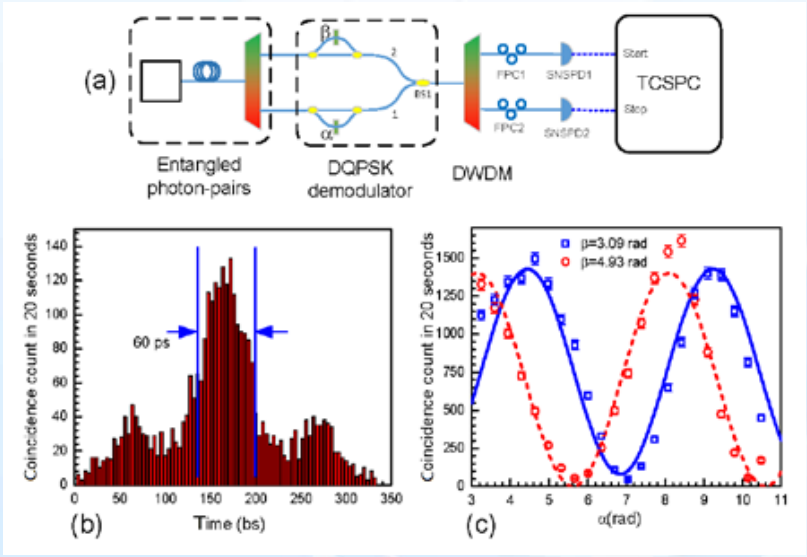
Collaborated with JW Pan's Group in USTC
Y. L. Tang et al. PRL 113(19): 190501. (2014)
Y. L. Tang et al. IEEE STQE 21(3): 1 (2015)

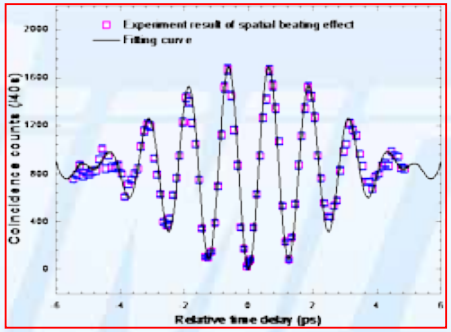
Demo ---- Quan Source characteriz.

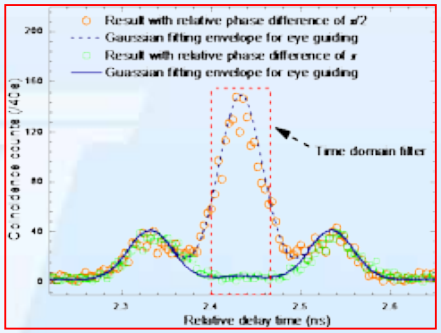
Collaborated with W Zhang in Tsinghua Univ.











Energy-time entanglement using low jitter SNSPD

- Optics Express 22 000359 (2014)
- J. Opt. Soc. Am. B **31** (8), 1801-1806 (2014)

- Sci Rep 5: 9195. (2015)

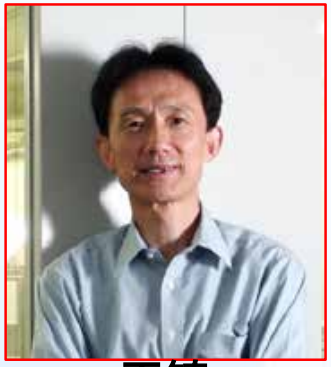
Conclusion

- **SNSPD matches the requirements of QI and .....**
  - **High SDE from VIS to NIR**
  - **Low DCR**
  - **Low jitter .....**
- **Niche market available for SNSPD**

Other Companies:

- Ø SconTel (Russia)
- Ø Single Quantum (Netherlands)
- Ø Quantum Opus (USA)
- Ø Photon Spot (USA)

团队成员 Group Member



王镇
Chief Scientist

尤立星
Project Leader

研究生/Graduate Students

何宇昊
Yuhao HE

巫君杰
Junjie WU

郭琦
Qi GUO

吕超林
Chaolin LV

研究人员 / Research staff

张伟君 博士
WJ ZHANG, PhD

李浩 博士
H LI, PhD

陈思井 博士
SJ CHEN, PhD

周慧 博士
H ZHOU PhD

杨晓燕 博士
XY YANG, PhD

张露 硕士
L ZHANG, MS