Сверхпроводниковый однофотонный детектор (SSPD – Superconducting Single-Photon Detector) ближнего ИК диапазона на основе NbN наноструктур.

Михаил Тархов

Учебно Научный Радиофизический Центр

при Московском Педагогическом Университете.

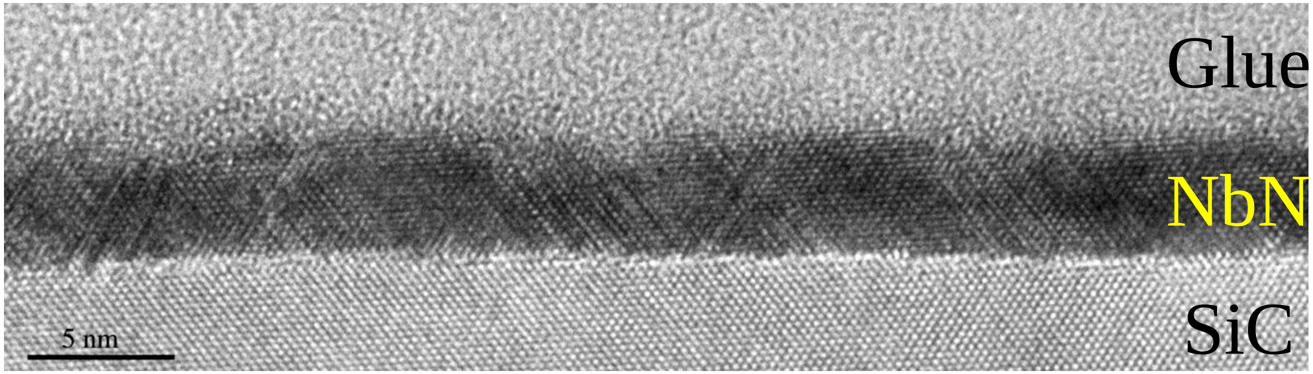
Содержание

Сравнение оптических однофотонных детекторов

	SEMICONDUCTING APDs		SUPERCONDUCTING SPDs	
Detectors	**Si**	**InGaAs**	**SSPD (NbN)**	**TES (W)**
Temperature (K)	300	200	2	0.1
Wavelength (μm)	0.25-1.1	1.1-1.8	0.4-5.6	0.1-5
Time resolution (ps)	**50**	~300	**20**	$3\text{x}10^5$
Quantum efficiency	25%@0.7μm	14%@1.54μm	**20%@1.55μm**	>80%@1.5μm
Apertures (μm)	200	30-80	SM fiber	SM fiber
Dark count rates (cps)	$<10^4$	$>3\text{x}10^4$	$<10^{-4}$	<0.001
Data rate	**< 10 MHz**	<15MHz	>2 GHz	20 kHz
Dynamic range(# *h*)	1-3000	NA	$>10^8$	50
Electrical quenching	Yes (0.3 ns)	Yes (0.3 ns)	No	No
Photon number resolution	Limited	No	No	Yes
Ruggedness	Very high	High	High	Low
Availability	Yes	Limited	Limited	Very limited

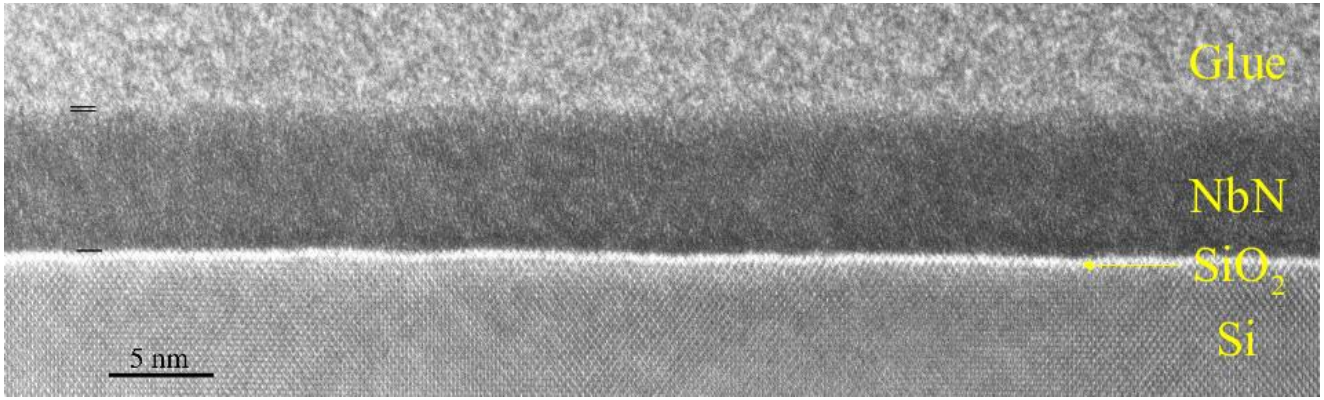
Структура пленок NbN

NbN on 3C-SiC buffer layer on Si substrate (HREM)



NbN is monocrystalline
a_0 (3C-SiC) = 4.36Å
a_0 (NbN) = 4.39Å
Thickness is 3.5 – 4.1 nm
Not really flat surface

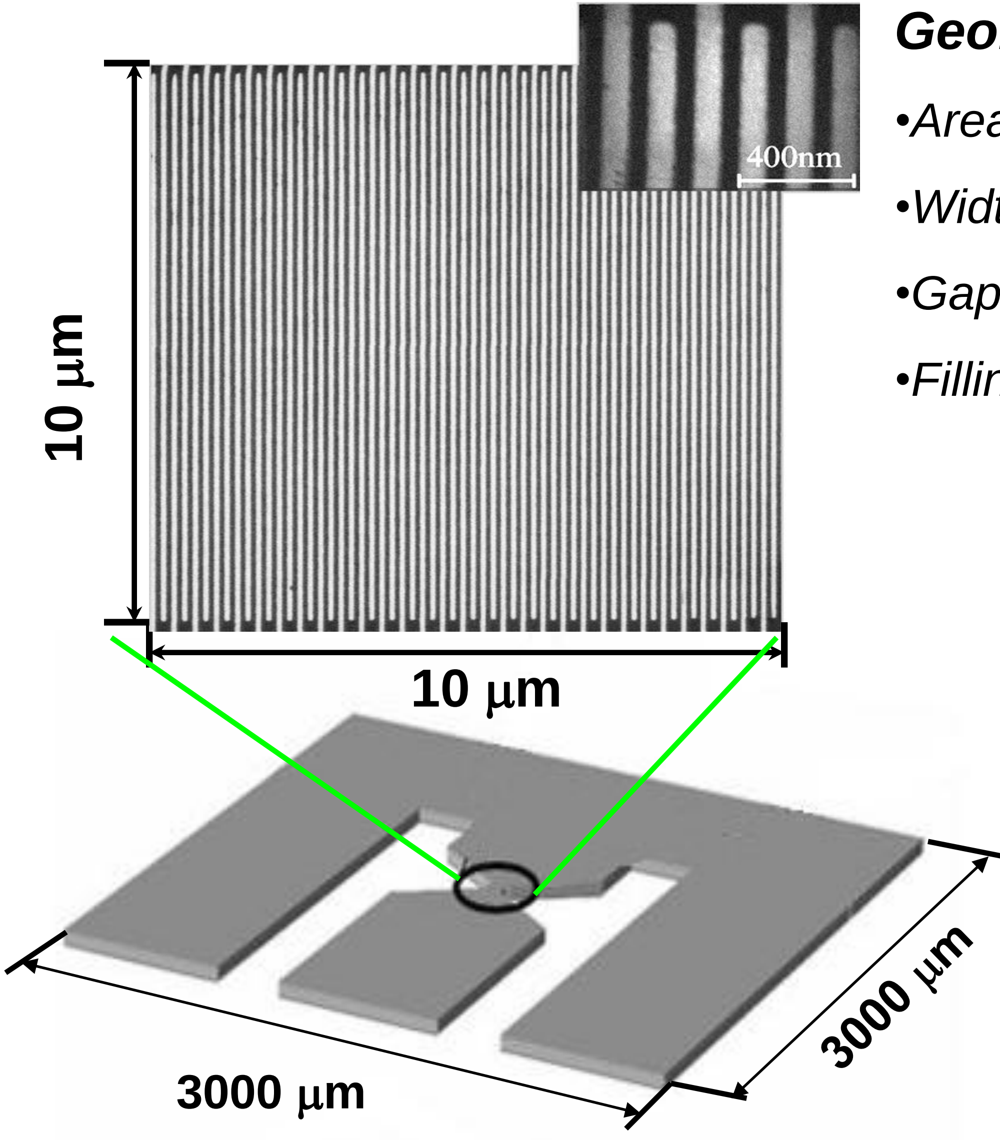
NbN on Si substrate



The NbN on Si is polycrystalline.

J.-R. Gao, G. Gol'tsman, B.Voronov, *et al* "Can NbN films on 3C-SiC/Si change the IF badwidth of hot electron bolometer mixers?" presented at the 17th International Symposium on Space Terahertz Technology, 10-12 May 2006, Paris

Топология чипа и чувствительного элемента SSPD.



Geometry sensitive element of SSPD:

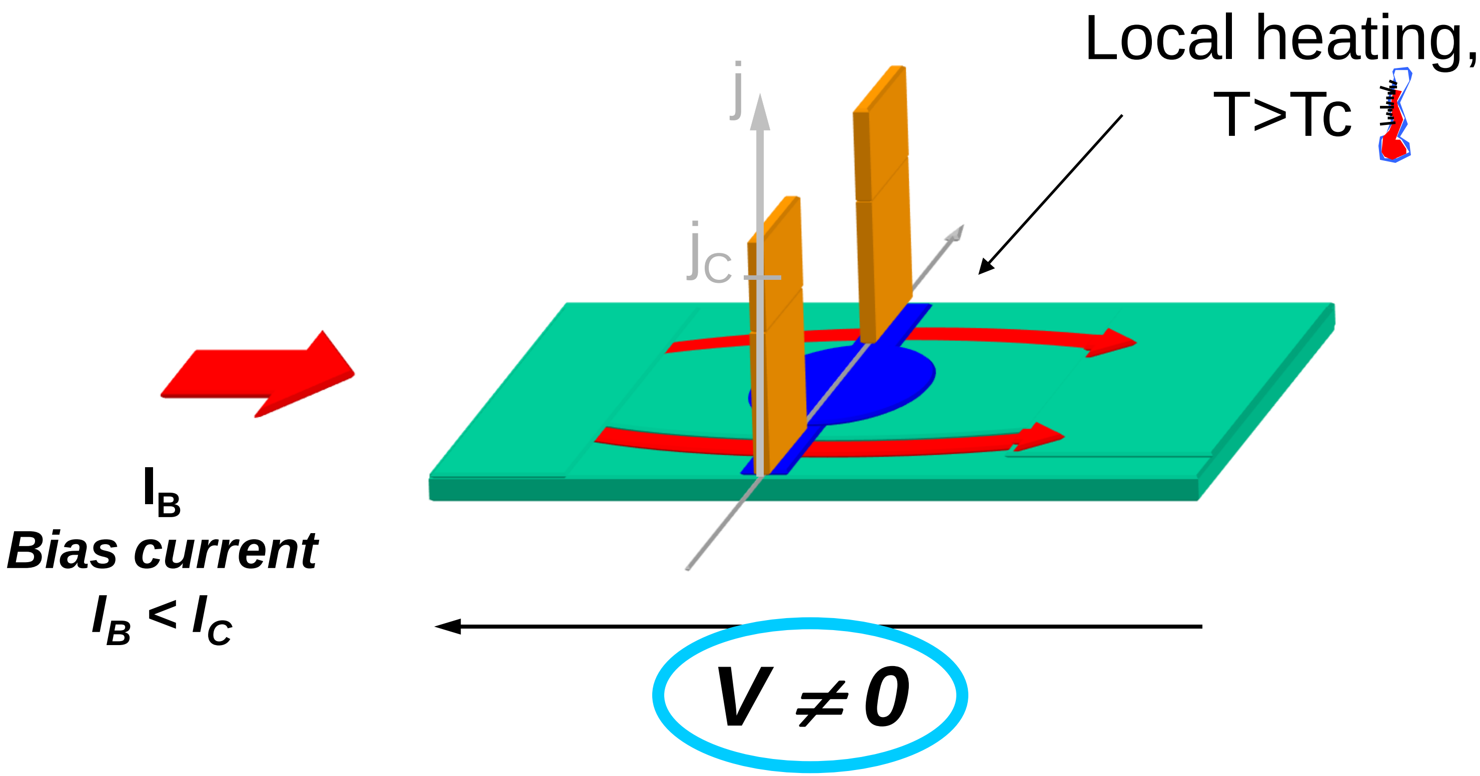
- *Area 10x10 μm² (optimisation for SM fiber)*
- *Width strip is 120 nm.*
- *Gap is 80 nm.*
- *Filling factor is 0.6*

Fabrication:

1) DC reactive magnetron sputtering of 4-nm-thick NbN film.
2) Patterning of meander-shaped structure by direct e-beam lithography.
3) Formation of Au contacts with optical lithography.

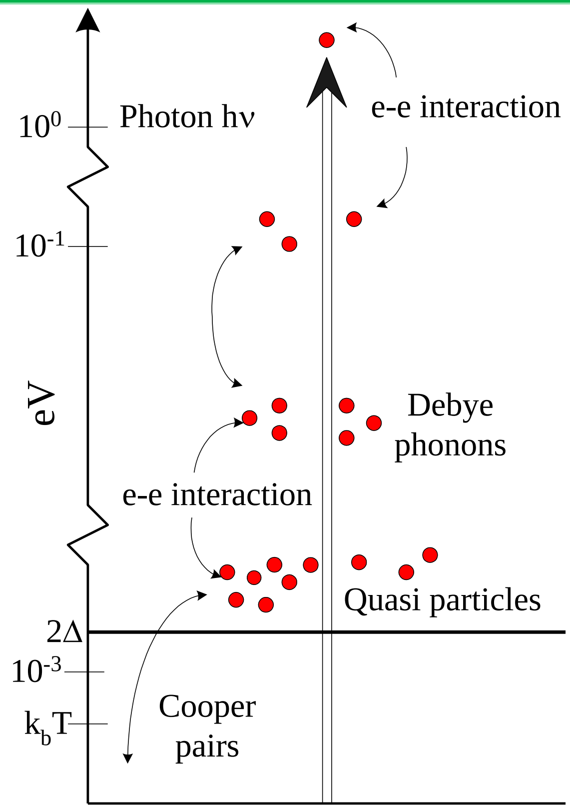
Korneev A. *et al*, *Appl. Phys. Lett.* 84 (2004) 5338

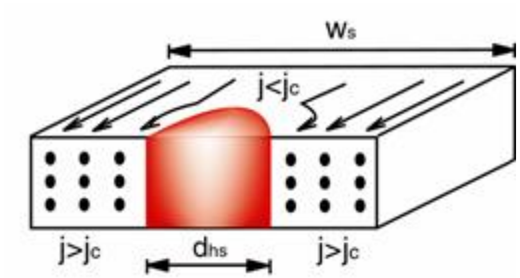
Механизм детектирования одиночных фотонов сверхпроводниковой узкой полоской.

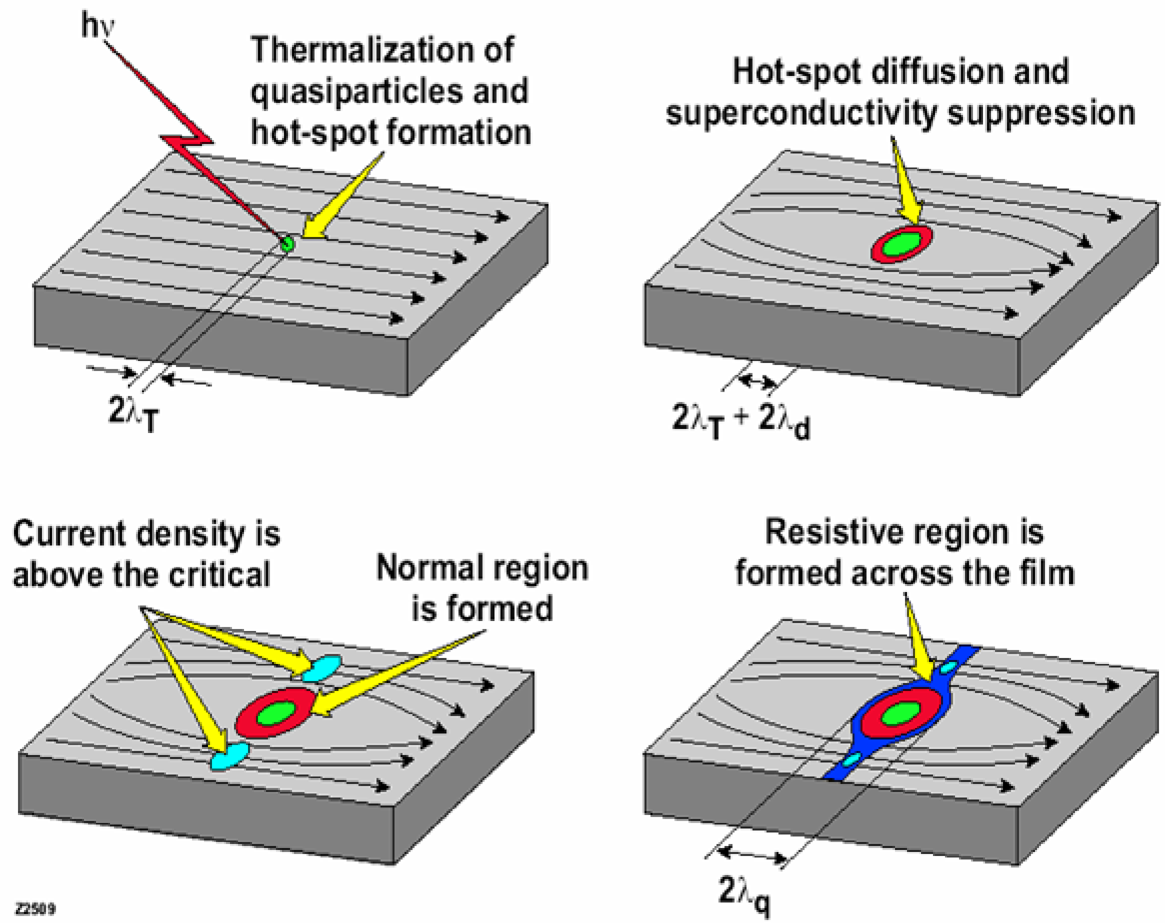


G. Gol'tsman *et al*, Applied Physics Letters 79 (2001): 705-707
A. Semenov *et al*, Physica C, 352 (2001) pp. 349-356

Схема энергетической релаксации.





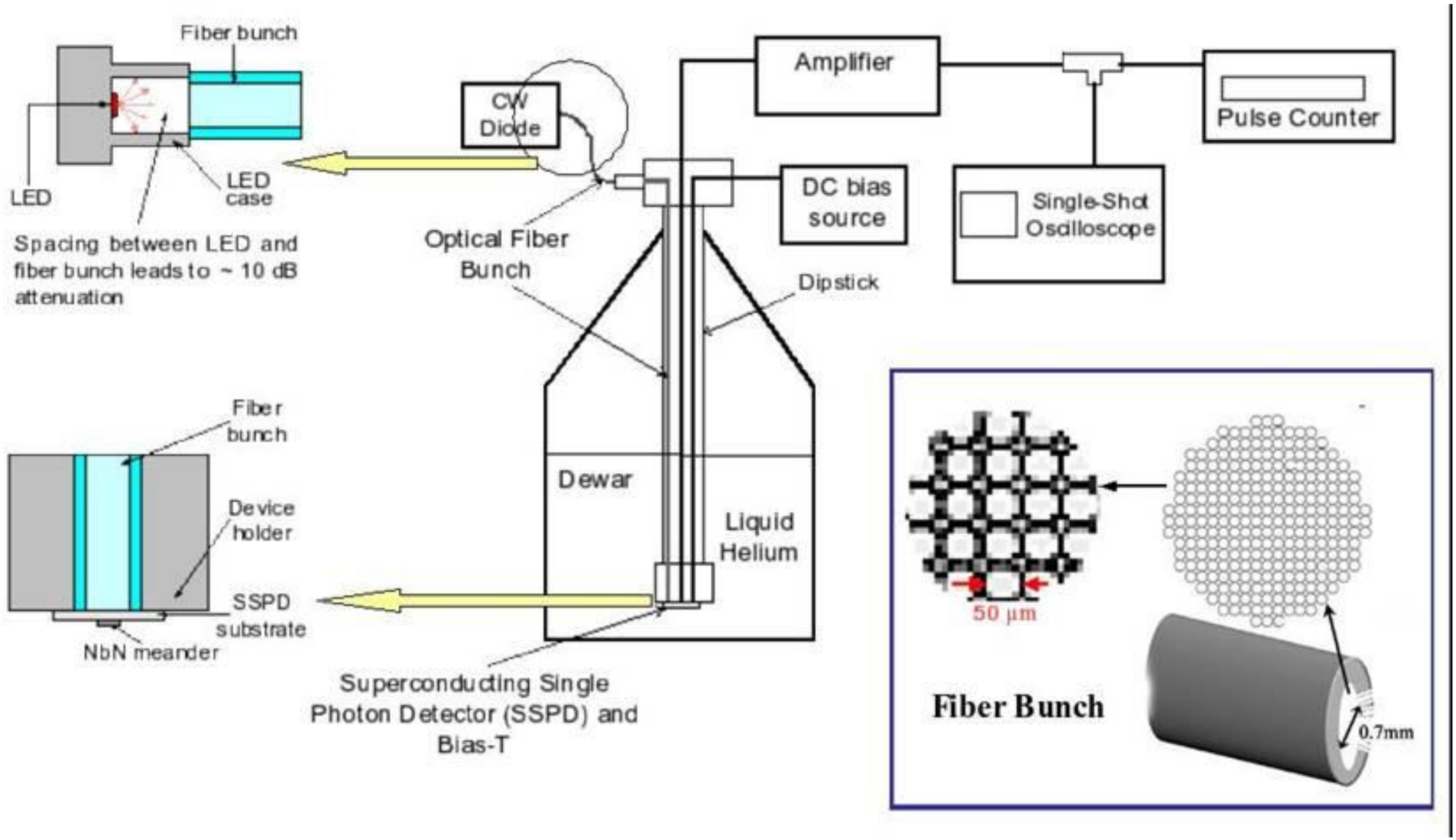


G. Gol'tsman *et al*, Applied Physics Letters 79 (2001): 705-70

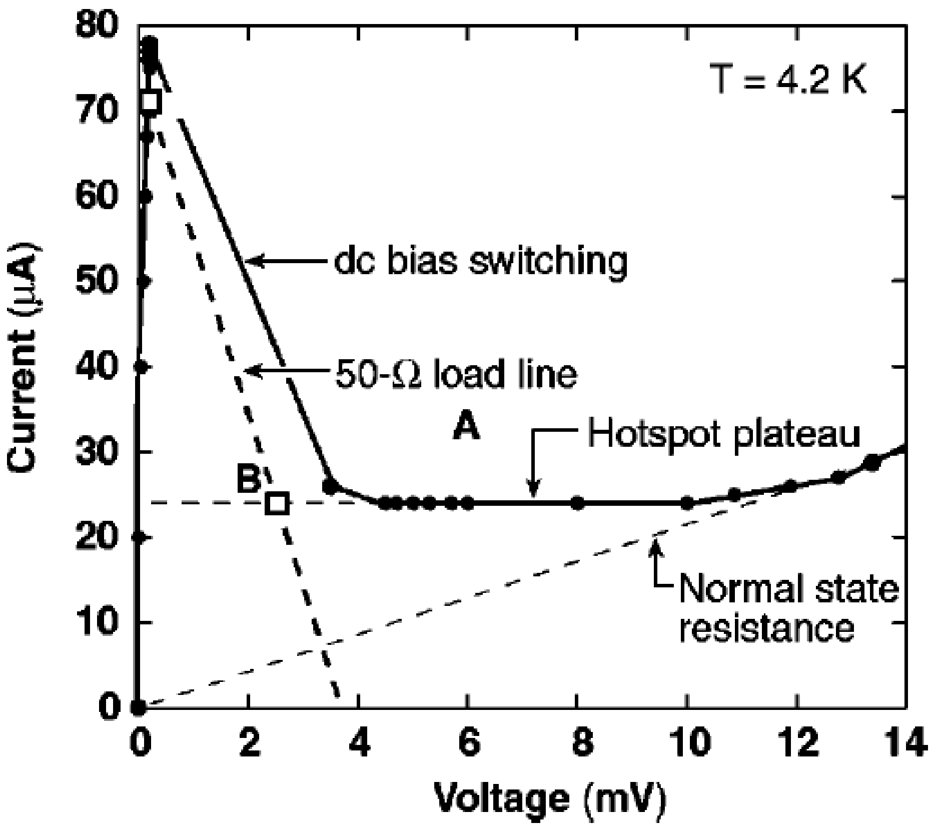
A. Semenov *et al*, Physica C, 352 (2001) pp. 349-356

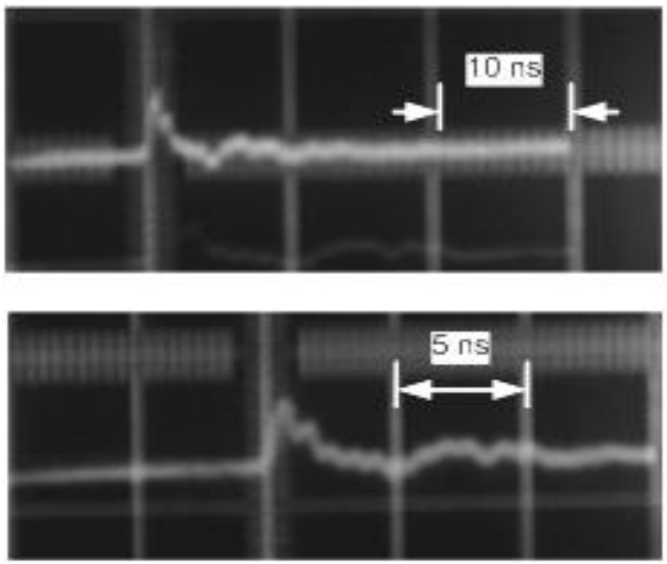
Choice of standard parameters, test and characterisation vehicles among partners

Experimental setup for quantum efficiency and dark counts rate measurement



Вольт-амперная характеристика SSPD и принципиальная схема контроля и считывания.





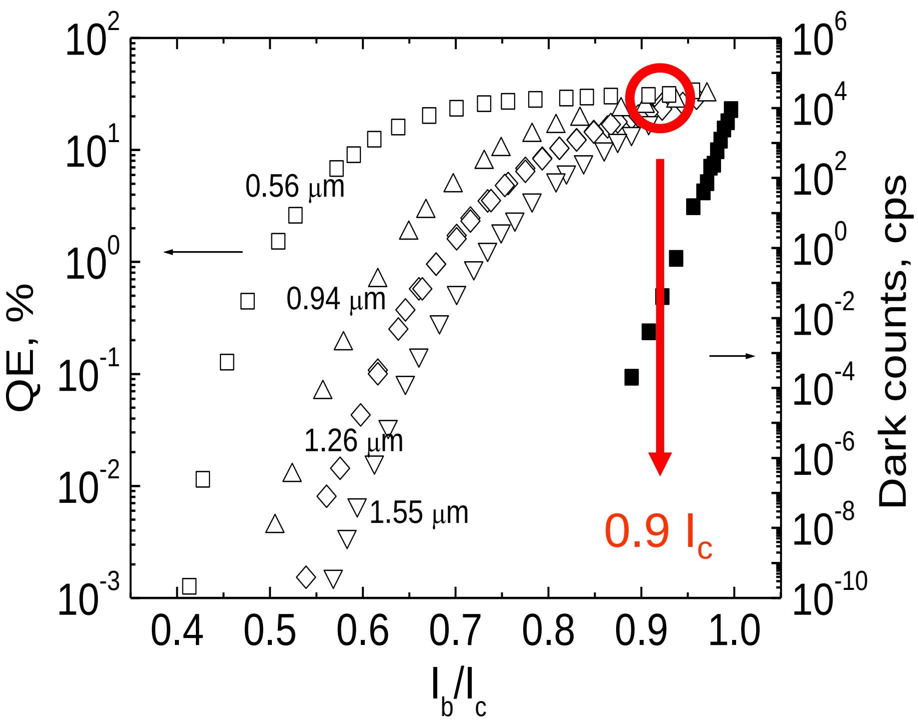
Квантовая эффективность.

$$QE = \frac{N_{det}}{N_{photons}}$$

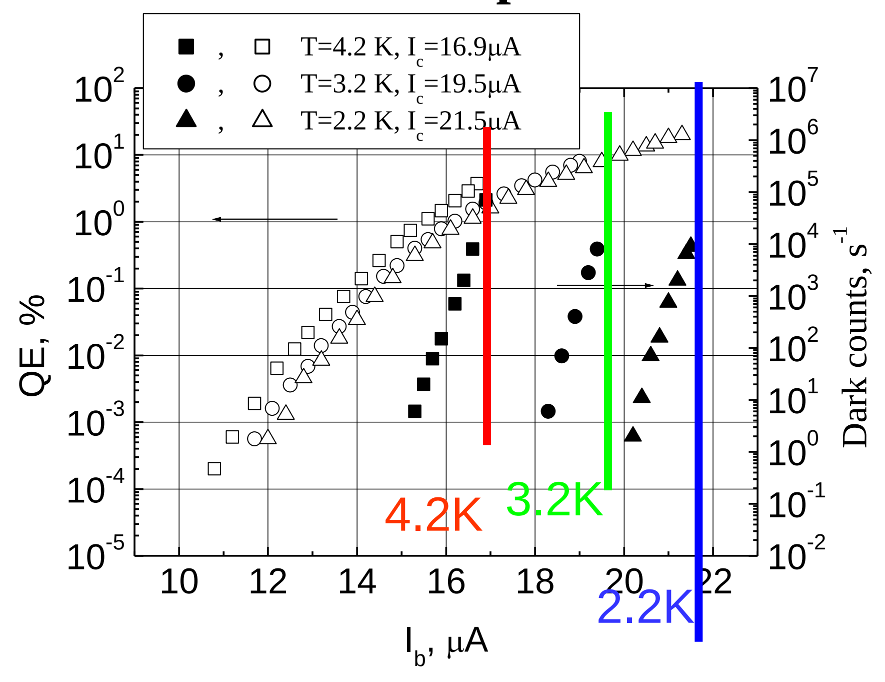
where N_{det} - Quantity of pulses from SSPD.

$N_{photons}$ - Quantity of photons.

Experimental quantum efficiency and dark counts rate vs. normalized bias current at 2 K.

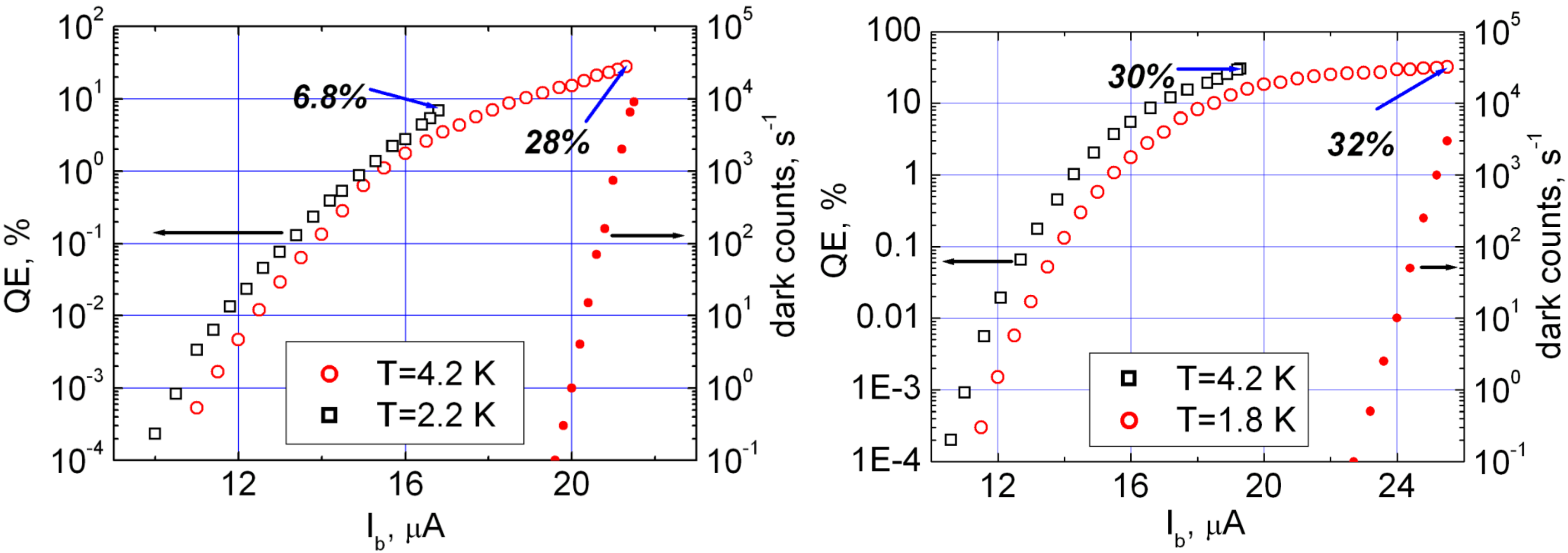


Experimental data for QE (open symbols) and the dark count rate (closed symbols) vs. the bias current measured for 1.55-μm photons and different temperatures.



Demonstration of SSPD with performance exceeding state-of-the-art (efficiency >20% at 1300 nm and dark count rate <0.1 s-1)

At present: single SSPDs exhibit QE up to 32%



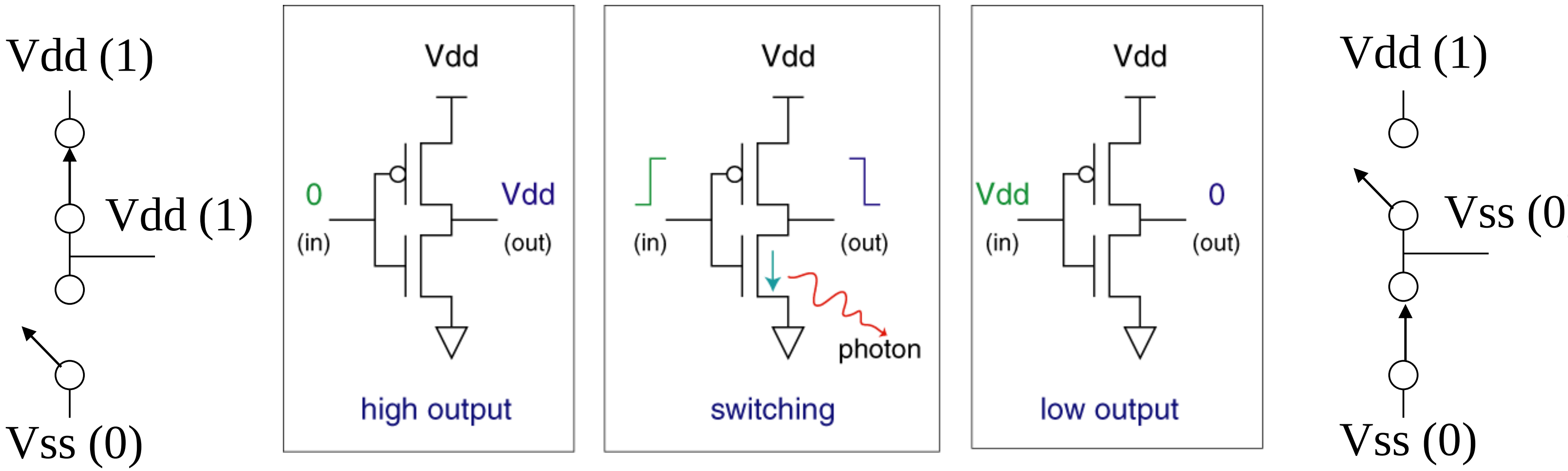
For best SSPDs the reduction of temperature does not lead to a significant improvement of QE. Maximum QE is limited by the optical coupling.

Области применения SSPD

- волоконно-оптические линии дальней связи без промежуточного усиления
- квантовая криптография
- исследование однофотонных источников корреляционными методами
- неразрушающая диагностика интегральных микросхем методом PICA
- оптическая рефлектометрия с временным разрешением (OTDR)
- флуоресцентная спектроскопия с временной корреляцией (TCFS)
- связь с космическими аппаратами на больших расстояниях

Применение SSPD для отладки Si интегральных микросхем

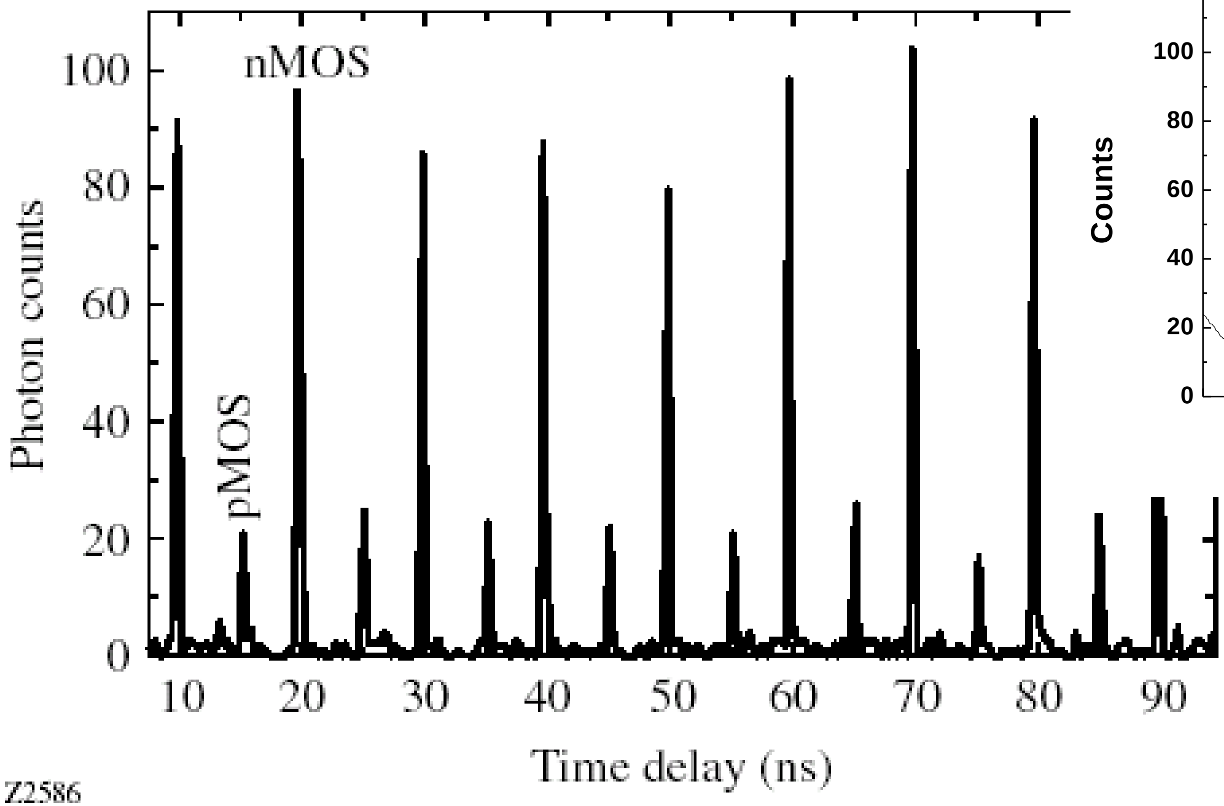
- Normally operating nMOS transistor emits near IR photons (0.9-1.4um) when current passes through the channel
- Time-correlated photon emission detection measures transistor switching time

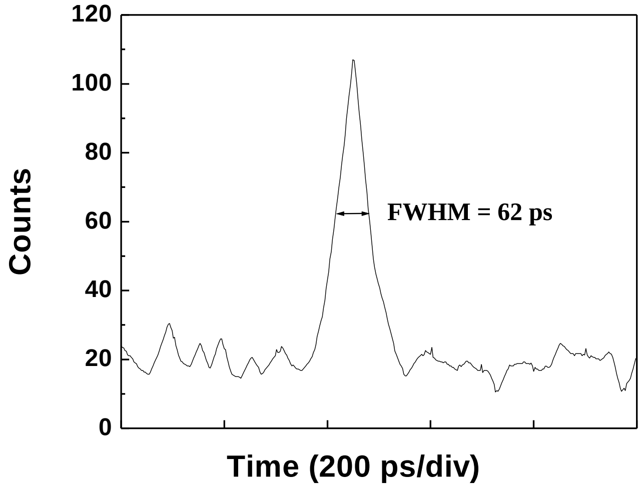


Kash, J. A. and J. C.-H. Tsang (1999). Noninvasive optical method for measuring internal switching and other dynamic parameters of CMOS circuits. USA, International Business Machines Corporation. US Patent # 5,940,545

Регистрация излучения
*n*MOS и *p*MOS транзисторов

0.13-μm linewidth, 1.3-V bias CMOS circuit running at 100 MHz

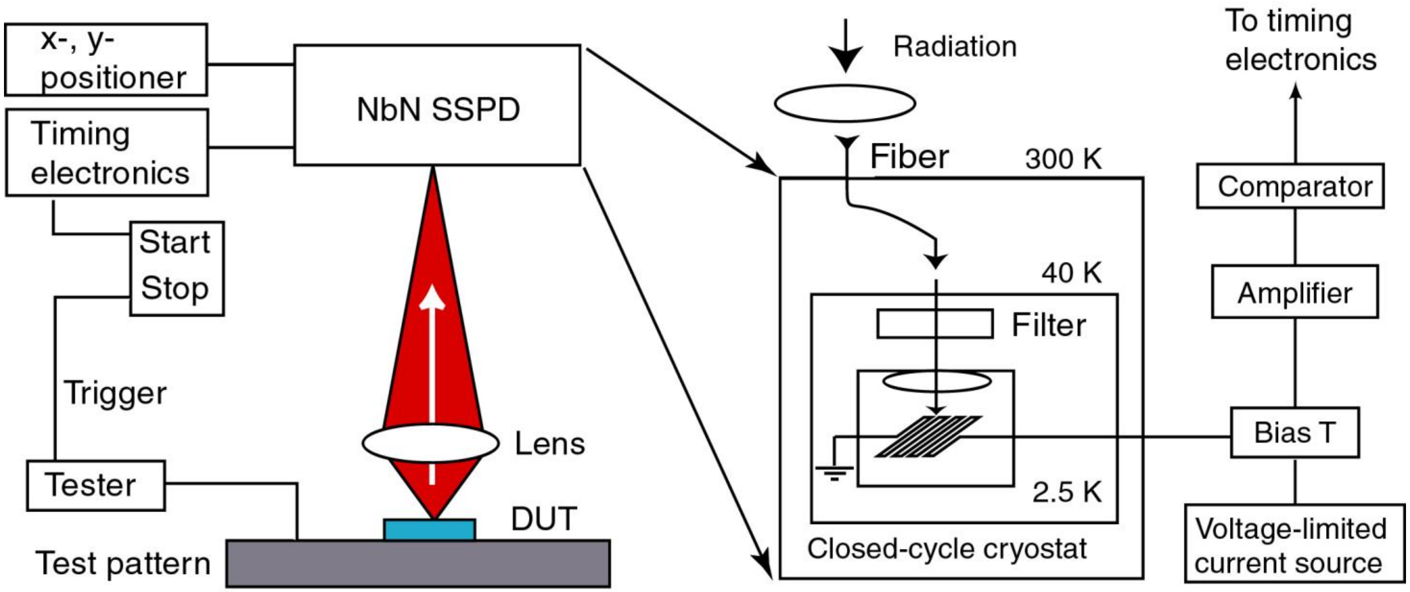




Zhang *et al.*, El. Lett, 39, 1086 (2003)

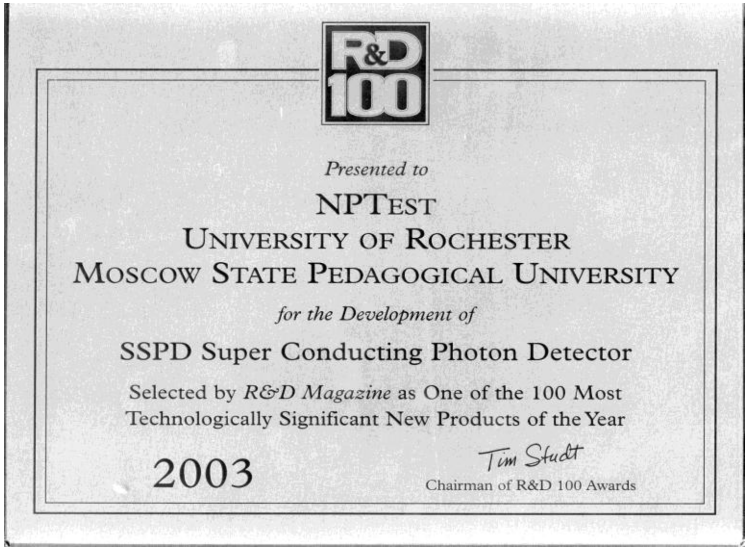
Схема тестера микросхем

TRPE: Time-Resolved Photon Emission



Commercially available TRPE system has been developed by NPTest, Inc. San Jose, CA, in cooperation with UR and MSPU.

Коммерческий тестер микросхем OptiCA®
на основе SSPD



R&D 100

Presented to

NPTest
University of Rochester
Moscow State Pedagogical University

for the Development of

SSPD Super Conducting Photon Detector

Selected by *R&D Magazine* as One of the 100 Most Technologically Significant New Products of the Year

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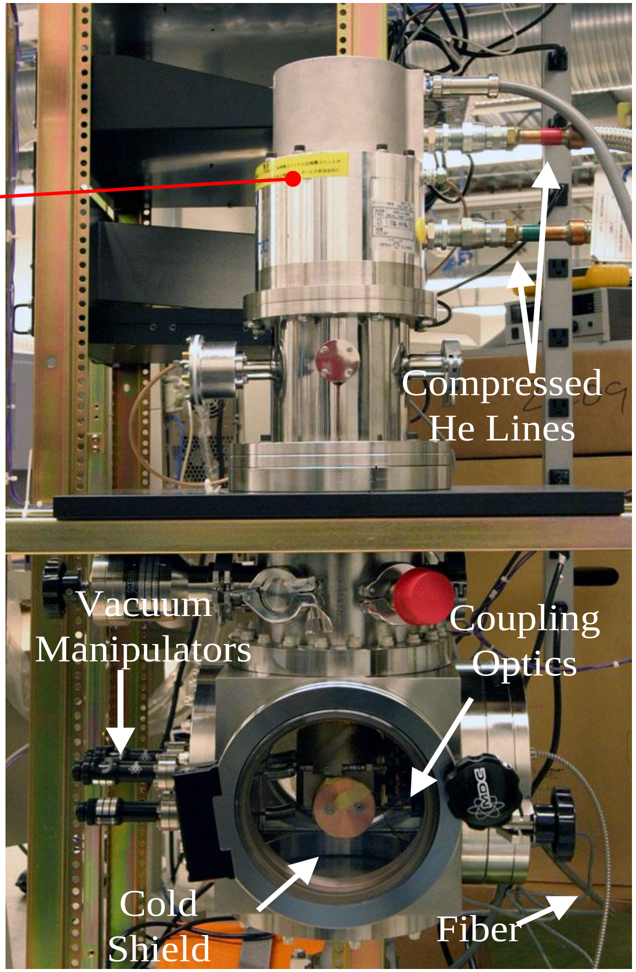
Tim Studt
Chairman of R&D 100 Awards

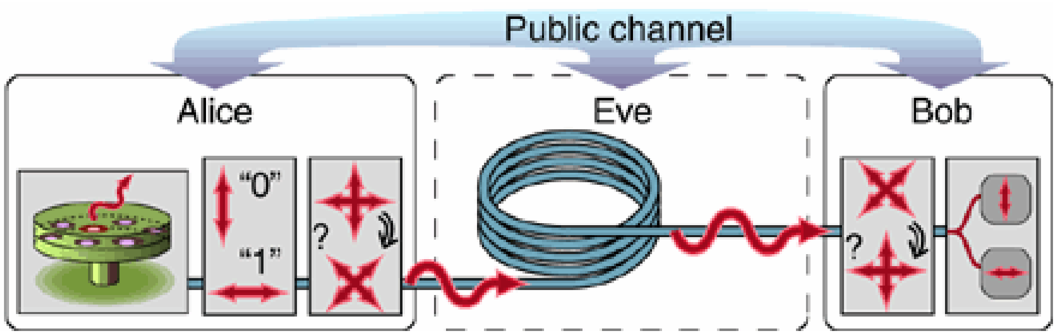


For more information:

http://www.nptest.com/products/probe/idsOptica.htm

Применение SSPD в квантовой криптографии

Alice
(Sender)



Bob
(Receiver)

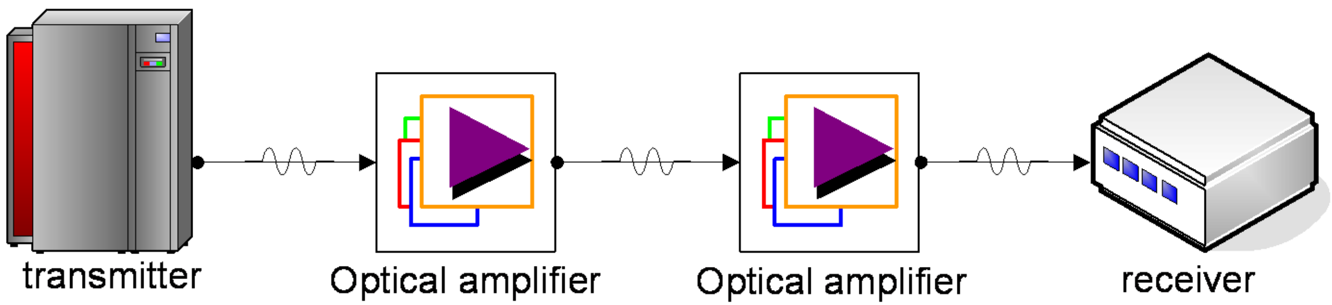
[from Simon Benjamin, Science 290, 2273 (2000)]

- **Unconditionally secret, quantum key distribution is possible in actual physical environments due to Heisenberg Indeterminacy Principle:**
  It is impossible to measure the state of a quantum bit without altering it.

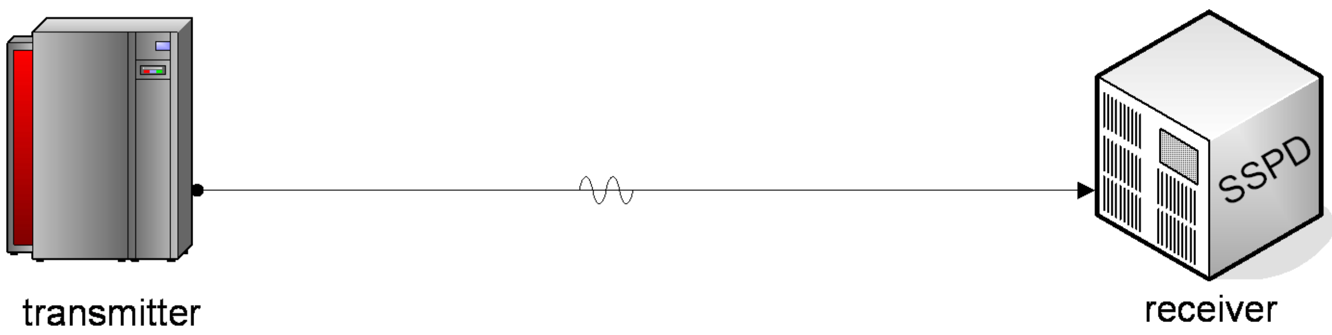
- **Alice (Sender) - single-photon source.**
- **Bob (Receiver) - single-photon detector.**

Применение SSPD: волоконно-оптические линии далней связи без промежуточного усиления

традиционная линия волоконно-оптической связи:



линия связи с SSPD не содержит оптических усилителей:



В рамках SINPHONIA Pirelli Labs продемонстрирует использование SSPD в линии связи Рим - Помезия