Progress in Few-Photon Metrology at NRC

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Outline

1. Few-photon metrology for single-photon detectors and sources
2. Single-photon detection efficiency calibration system
3. Single-photon detectors
4. Single-photon sources
Few-photon metrology laboratory

Single-Photon Detector Calibration System
Quantum Dot Nanowire Single-Photon Source
Superconducting Nanowire Single-Photon Detector
Few-photon metrology for quantum photonics

ETSI GS QKD 011 V1.1.1 (2016-05)

Quantum Key Distribution (QKD);
Component characterization: characterizing optical components for QKD systems

C. J. Chunnilall et al., Optical Engineering 53, 081910 (2014)
SI-traceable detection-efficiency calibration

NRC Absolute Cryogenic Radiometer

Transfer Standard Radiometer

Single-Photon Detector
Detection efficiency characterization

\[ \eta_{eff} = \frac{E_{det}}{E_{in}} = \frac{hc}{\lambda} \times \frac{N_{SPAD}}{E_0 \times \prod_{i=1}^{2} T_i} = \frac{hc}{\lambda} \times As \times \frac{Q_0 \times Q_{SPAD}}{Q_1 \times Q_2} \]

h: Planck constant
\( \lambda \): wavelength
\( N_{SPAD} \): number of photons detected by SPAD
\( T_i(i = 1,2) \): filter transmission
s: TSD spectral responsivity
A: amplification
\( Q_i(i = 0,1,2) \): ratio \( V_i/V_{i,mon} \)
\( Q_{SPAD} \): ratio \( N_{SPAD}/V_{SPAD,mon} \)


NATIONAL RESEARCH COUNCIL CANADA
Measurement apparatus

Active area of SPAD
Measurement results

![Graph showing detection efficiency vs. counts per second]

- **TSD**
- **SPAD**
- **F1**
- **F2**
- **BS**
- **LENS (f=75 mm)**
- **LASER**
- **AMP**
- **3D SCAN**
- **NRC**
- **Meters & Counters**
- **NIST**

**Graph Details**
- x-axis: Counts per second
- y-axis: Detection efficiency
- Data points for NRC and NIST
Single-photon detector at NRC in collaboration with NIST

**Type:** superconducting nanowire  
**Material:** Tungsten silicide  
**Operating temperature:** 0.7 K  
**Wavelengths:** 800, 1064, and 1550 nm  
**Efficiencies:** > 90 %  
**Timing resolution:** 80 ps  
**Dark counts:** < 1 Hz  
**Recovery time:** 30 ns
Single-photon source towards quantum candela

PTB: NV-centered diamond

NPL: artificial atom

INRIM: PP-lithium niobate crystal

Single-photon source at NRC
in collaboration with NRC Advanced Electronics and Photonics & Security and Disruptive Technology

**Type**: semiconductor quantum dot nanowire

**Material**: InAs-InP

**Operating temperature**: <10 K

**Wavelength**: 930 nm

**Lifetime**\(^1\): 1.6 ns

**Bandwidth**\(^1\): 4 \(\mu\)eV

**Efficiency**\(^1\): 43 % (di-directional -> total 86 %)

**Single-photon purity**\(^1\): 0.002 (0 for a true single photon)

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Towards single-photon metrology

- single-photon detection efficiency measurement
- quantum candela development
- single-photon detection technique development