Low Temperature Single photon detectors for Quantum Information Applications

Sae Woo Nam, Aaron Miller, Danna Rosenberg, Arto Salminen, Erich Grossman, John M. Martinis, Robert Schwall

Quantum Information and Terahertz Technology
National Institute of Standards and Technology
325 Broadway, Boulder, CO 80305, USA

7/24/2003
Additional Collaborators

- Quantum Sensors Project at NIST

- Quantum Imaging Lab at Boston Univ.
  - A. Sergienko, M. Teisch, B. Saleh

- Quantum Cryptography Group at Los Alamos National Lab
  - R. Hughes, J. Nordholt, G. Peterson

- Stanford University
  - Blas Cabrera, R. Romani
Basics of Quantum Information Science

- Use of information encoded in quantum mechanical states
- Manipulation and measurement of quantum states

Easy to generate quantum states with photons
Quantum Information Examples

- Quantum Cryptography
  - Quantum Key Distribution
  - Quantum Coin Tossing
- Quantum Measurement and Optics
  - Single Photon Sources, SPDC, SPT
  - Bell State Analysis, Quantum Teleportation
- Quantum Computing
  - Efficient linear optical quantum computing
Optical photon detector needs in Quantum Information

- High Quantum Efficiency
  - As high as possible
- Low Dark Count rate
  - No false counts
- Speed
- Energy Resolving / Photon Number Resolving
Transition-edge sensor performance

- Photon Number Resolution
- Low Noise
  - NEP < 10^{-19} \text{ W}/\sqrt{\text{Hz}} (limited by stray light)
  - No Dark Counts
- High QE at telecommunication wavelengths
  - \sim 20\% end-to-end measured
  - AR coatings give no limit, in principle
  - Target of >80\% at 1550 nm
Tungsten TES

"E_\gamma = 0.8 eV (\lambda = 1.55 \mu m)"

7/24/2003 LTD10, Genova, Italy
# TES compared to APD

<table>
<thead>
<tr>
<th></th>
<th>TES</th>
<th>APD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantum Efficiency</td>
<td>~20% (-&gt;100%) AR coatings</td>
<td>~15% - 70% intrinsic limit</td>
</tr>
<tr>
<td>Wavelengths</td>
<td>10 μm – 100 nm</td>
<td>Gap dependent</td>
</tr>
<tr>
<td>Count Rate</td>
<td>&lt;50 kHz thermal recovery</td>
<td>~100 kHz afterpulsing</td>
</tr>
<tr>
<td>Dark Count Rate</td>
<td>None, Stray light</td>
<td>~10-30 kHz Bias Gating</td>
</tr>
<tr>
<td># Resolving</td>
<td>YES</td>
<td>Difficult</td>
</tr>
</tbody>
</table>
Example in Quantum Optics

Laser (351 nm) → Non-linear Crystal
β-BBO Type II (H, V) Collinear
Spontaneous Parametric Down Converter

Pump Beam Filter → Beamsplitter

Detector

θ_{signal} \rightarrow θ_{idler}
Counting *ALL* the photons

- What is the rate of “coincident” events?
- What is the rate of “doubles” events?
Calculations

\[ | H_0 V_0 > \rightarrow i | H_3 V_2 > - i | V_3 H_2 > + | H_2 V_2 > - | H_3 V_3 > \]

\[ \rightarrow (\cos(\theta_3)\sin(\theta_2) - \sin(\theta_3)\cos(\theta_2)) \mid D1\ D2 > \]
\[ +\sin(\theta_2)\cos(\theta_2) \mid D1\ D1 > \]
\[ +\sin(\theta_3)\cos(\theta_3) \mid D2\ D2 > \]

Probability : \( \sin^2(\theta_3 - \theta_2) \quad \text{Coincident} \)
\[ \sin^2(2\theta_2), \sin^2(2\theta_3) \quad \text{Doubles} \]
Data with a TES

Coincident Doubles

Counts

Relative Angle ($\theta_{\text{signal}} - \theta_{\text{idler}}$)

Rate of double photons

$\theta_{\text{signal}}$

7/24/2003 LTD10, Genova, Italy
Conclusions

• Many opportunities in quantum information
  o Basic tests of quantum mechanics
  o First applications using W-TES
• LTDs are advantageous to use
  o PNR, Dark count rate, QE
• Room for improvement
  o Light leaks, QE