Microfiber-coupled Superconducting Nanowire Single Photon Detector

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Content

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

Cooper pair breaking by single photon

Photon energy vs gap/Cooper Pair energy

$\nu \ (1\text{eV}) \ vs \ 2\Delta \ (6.4 \text{ meV})$

Dynamics

SEM Image

Photon Response
Progress on Devices @SIMIT

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

**SDE > 80% at DCR=1Hz**

**NbN SNSPD from VIS to NIR**

**System jitter <15 ps**

Accepted by SUST

AO 56 2195 (2017)
Progress on Applications @SIMIT

- **Record MDI-QKD of 404 km in fiber**
- **Satellite laser ranging over 3000 km**
- **Quantum Teleportation over 30 km**
- **Time-bin Boson Sampling**

Collaborators: JW Pan from USTC et al

- **OE 24, 3535 (2016)**
- **Nat. Photonics 10: 671 (2016)**
- **PRL 118 190501 (2017)**

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Double Cavity SNSPD with Backside optical coupling

SNSPD on DBR with Top optical Coupling
Li et al, OE 23,017301 (2015)

- High SDE over 90%
- Spectrum limited by cavity
Optical Coupling via waveguide

- **SNSPD on AlGaAs substrate**
  - Sprengers et al, APL 99, 181110 (2011)
  - Good for Photonics on Chip

- **SNSPD on SiO$_2$/Si substrate**
  - 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

Optical absorption to NbN nanowire in evanescent field of MNF

Schematics of MNF coupled SNSPD
3D schematics of MNF coupled SNSPD

<table>
<thead>
<tr>
<th>Material Parameters</th>
<th>SNSPD Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>Linewidth</td>
</tr>
<tr>
<td>1550 nm</td>
<td>100 nm</td>
</tr>
<tr>
<td>( n ) (fiber)</td>
<td>Space</td>
</tr>
<tr>
<td>1.444</td>
<td>100 nm</td>
</tr>
<tr>
<td>( n ) (MgF(_2))</td>
<td>Thickness</td>
</tr>
<tr>
<td>1.38</td>
<td>6 nm</td>
</tr>
<tr>
<td>( n ) (NbN)</td>
<td>Wire No.</td>
</tr>
<tr>
<td>5.23-5.82i</td>
<td>TBD</td>
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</table>
Parameters Optimization

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

Schematics of the coupling system

Optical image of coupling
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Conventional SNSPD on MgF₂

Conventional SNSPD on MgF₂ substrate shows similar performance of SNSPDs on MgO substrates [SUST, 2016, 29. 065011]
## Absorption

### Transmittance

<table>
<thead>
<tr>
<th>MNF No.</th>
<th>$P_0$ (mW)</th>
<th>$P_{max}$ (mW)</th>
<th>$P_{min}$ (mW)</th>
<th>PER</th>
<th>$T_{max}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>6.0</td>
<td>4.6</td>
<td>2.4</td>
<td>1.9</td>
<td>77%</td>
</tr>
<tr>
<td>11</td>
<td>5.4</td>
<td>4.6</td>
<td>4.16</td>
<td>1.1</td>
<td>85%</td>
</tr>
<tr>
<td>new</td>
<td>5.4</td>
<td>4.8</td>
<td>4.1</td>
<td>1.2</td>
<td>89%</td>
</tr>
</tbody>
</table>

### Absorption

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

When $T \sim 90\%$, the Abs of nanowire can exceed 90%
SDE at 2 K

The electric performance and DCR is normal, however, the SDE is very low, < 0.1%
Loss of MNF vs Temp

n of adhesive $\sim$1.41 @2.2 K, with using MNF with $D$=2 $\mu$m, The loss is 3.3 dB
$n$ of Adhesive changes at LT

Calculated Temp dependence of $n$ for adhesive

Temp dependence of $n$ of PMMA
J of Macromolecular Sci-Phy, 1986, B25(4)
SDE >20% !!! with MNF of 2 um

- 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%

SDE&DCR vs Ib for 1550 nm
SDE vs wavelength

- 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

- $\tau = 12\ \text{ns}$
- $U/e$

Timing jitter

- 54.0 ps FWHM

- Similar jitter and shorter pulse width of $\sim 50\%$
Conclusion

- MNF coupled SNSPD is demonstrated
  - With SDE 20% @ 1550 nm and 50% @ 850 nm;
  - Further improvement possible

SNSPDers @ SIMIT, CAS