Mid-Infrared Single-Photon Detection with Tungsten Silicide Superconducting Nanowires

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Working principle
Superconducting Nanowire Single-Photon Detector (SNSPD)

Superconducting WSi:
- Temperature $< T_C$ (~ 4.5 K)
- Current density $< J_C$

Gol’tsman et al., APL 79, 705 (2001)
Superconducting Nanowire Single-Photon Detector (SNSPD)

Superconducting WSi:
- Temperature $< T_C$ (~ 4.5 K)
- Current density $< J_C$

$R = 0$

Gol'tsman et al., APL 79, 705 (2001)
Superconducting Nanowire Single-Photon Detector (SNSPD)

- **Bias Current**
- **Current density above critical**

Superconducting WSi:
- Temperature $< T_C$ (~ 4.5 K)
- Current density $< J_C$

$R > 0$

Gol’tsman et al., APL 79, 705 (2001)
Superconducting Nanowire Single-Photon Detector (SNSPD)

Superconducting WSi:
- Temperature $< T_C \ (\sim 4.5 \text{ K})$
- Current density $< J_C$

$R > 0$

Gol’tsman et al., APL 79, 705 (2001)
Superconducting Nanowire Single-Photon Detector (SNSPD)

Superconducting WSi:
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Gol’tsman et al., APL 79, 705 (2001)
Superconducting Nanowire Single-Photon Detector (SNSPD)

Bias Current

Si

WSi

160 nm

5 nm

Superconducting WSi:

• Temperature $< T_C$ ($\sim 4.5$ K)
• Current density $< J_C$

$R = 0$

Voltage (mV)

Time (ns)

Gol’tsman et al., APL 79, 705 (2001)
93% System Detection Efficiency

\[ SDE_{\text{max}} = 93.2 \pm 0.4\% \]
\[ SDE_{\text{min}} = 80.5 \pm 0.4\% \]

\( \lambda = 1550 \text{ nm} \)

\( T = 120 \text{ mK} \)

Marsili et al., Nature Photonics 7, 210 (2013)
93% System Detection Efficiency

Thursday 11:30 am – 1:30 pm
POSTER SESSION III: Light-Matter Interactions, ultrafast & Quantum Optics

Marsili et al., Nature Photonics 7, 210 (2013)

λ = 1550 nm
T = 120 mK

SDE_{max} = 93.2 ± 0.4%
SDE_{min} = 80.5 ± 0.4%

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Can we achieve high SDE in the mid-IR?
How to never miss a photon

Coupling Efficiency × Absorption × Internal Efficiency
How to never miss a photon

- Coupling Efficiency
- Absorption
- Internal Efficiency

Optical Alignment
Detector Active Area

Resonant absorption

Device Design

Marsili CLEO 2013
How to never miss a photon

1. Coupling Efficiency
2. Absorption
3. Internal Efficiency

- Optical Alignment
- Detector Active Area
- Resonant absorption
- Device Design

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Characterization set up

mid-IR LED

mid-IR fiber

Cryostat

SNSPDs

to Readout Electronics

8 mm

$T = 300 \text{ K}$

$T = 250 \text{ mK}$
Detector Detection Efficiency (DDE)

![Graph showing detector detection efficiency (DDE) against bias current (I_B) for different wavelengths (λ): 2.1 μm, 3 μm, 3.8 μm, and 4.2 μm.]

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Wavelength Dependence of Absorption

Absorption (simulation)

DDE (experiment)

Wavelength, $\lambda$ (nm)

DDE, $A$ (%)
Dependence on Nanowire Width

$w = 180 \text{ nm}$

$w = 140 \text{ nm}$

$w = 100 \text{ nm}$
How to never miss a photon

- Coupling Efficiency
- Absorption
- Internal Efficiency
- Optical Alignment
- Detector Active Area
- Resonant absorption
- Device Design
Absorption: Optical Stack

- TiO₂
- Au (pads)
- WSi SNSPD
- SiO₂ (sputtered)
- Au (mirror)
- SiO₂ (thermal)
- Si (substrate)
Absorption: Optical Stack

Absorption (\%) vs Wavelength, $\lambda$ (nm)

- Parallel
- Perpendicular
Absorption of cavity devices
How to never miss a photon

Coupling Efficiency

Optical Alignment
Detector Active Area

Absorption

Resonant absorption

Internal Efficiency

Device Design
Coupling efficiency: Optical Alignment

Room temperature deposition of WSi on 3 in Si wafers

107 dies
Coupling efficiency: Optical Alignment

- Optical fiber
- Fiber ferrule
- Zirconia sleeve
- Device chip
- Sapphire rod
- Coaxial connector pin

Miller et al., Opt. Express 19 (10), 9102 (2011)
Experimental Results
Characterization set up

mid-IR LED

Cryostat

mid-IR fiber

SNSPDs
to Readout Electronics

$T = 300 \text{ K}$

$T = 250 \text{ mK}$
Characterization set up

- Cryostat
- mid-IR LED
- mid-IR fiber
- SNSPDs

Detector cannot be operated

$T = 300 \text{ K}$

$T = 250 \text{ mK}$
Characterization setup

- Mid-IR LED
- Cryostat
- Mid-IR fiber
- Blackbody radiation
- Small-IR fiber to SNSPDs

$T = 250 \text{ mK}$

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Characterization set up

- **SNSPDs**
- **Cryostat**
- **mid-IR LED**
- **mid-IR fiber**
- **BP filter** $T = 250$ mK
- **Blackbody radiation**
- **Blackbody** $T = 300$ K
- **SNSPDs**

To Readout Electronics

- $T = 250$ mK
- $\sim 1$ mm
System detection efficiency at $\lambda = 3$ $\mu$m

$\lambda = 3$ $\mu$m
$T = 250$ mK
Mismatch between the mode field diameter and the active area of the detector

Cavity not optimized for the mid-IR

Saturated internal efficiency up to 5 μm wavelength
End of Presentation
Backup slides
Dependence on Nanowire Width

Dependence on Nanowire Width

Bias current, $I_B$ (μA)

$\lambda$
Temperature Dependence

![Graph showing temperature dependence](image)

- 0.25 K
- 0.5 K
- 1 K
- 1.5 K
- 2 K

System detection efficiency, $SDE$ (ppm) vs. Bias current, $I_B$ (µA)
Coupling efficiency: Optical Alignment