Optically probing the detection mechanism in amorphous MoSi SNSPDs

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Introduction

(a) Superconducting nanowire

(b) Single photon excites an electron

(c) With $I_b \sim I_c$
Superconductivity broken $\rightarrow$ signal

Performances:
• High efficiency: $\sim 93\%$ at 1550 nm
• High repetition rate: $> 20$ MHz
• Low jitter: $< 20$ ps
• Low DCR: $< 10$ Hz
• No after pulsing effect

Motivation:
• Detection mechanism is still not completely understood
• Understand fundamental limits
• Reach better performances
• No extensive studies on amorphous MoSi

still a challenge to combine all of them!

Some research themes in the group
• High-speed, long-distance QKD experiments
• Long-distance quantum communication in optical fibres
• High-performance single-photon detection
  ‣ direct integration in the group experiments

SNSPD development in 3 years
• Developed a high-yield fabrication process based on amorphous MoSi
• Complete system:
  ‣ electronics
  ‣ packaging
  ‣ cryostat

We now achieve
• System detection efficiency: > 80%
• Jitter < 30 ps
• Counting rate > 10 MHz
• DCR < 10 Hz

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Detection mechanism in MoSi SNSPDs
Detection models

How to probe the detection mechanism:

- **Energy-current relation**, $I_{\text{bias}} = f(E)$
- **Vortex** assisted mechanism

\[ I_{\text{bias}} = f(E) \]

non-linear

linear

Nanofabrication

Molybdenum silicide:
- Mo$_{0.8}$Si$_{0.2}$: **5-7 nm** thick film by co-sputtering deposition
- **Different design**:
  ‣ nanowire widths
  ‣ fill factor
  ‣ SNAP, spiral, etc…
- **Single layer** optical cavity (no TiO$_2$)
- 16x16 um$^2$ area
- Self aligned package technique
Probing the detection mechanism

**Photon count rate**
- Unpolarized CW light from halogen lamp
- Calibrated monochromator: \( \lambda : 550 \rightarrow 2050 \) nm

\[
f(I_{\text{bias}}) = \text{PCR} - \text{DCR}
\]

**Jitter**
- Constant fraction discriminator (CFD)
- 6 ps laser pulses, 1550 nm
**Photon count rate**

- **First study** with a **plateau** over the full range of energies (unique to MoSi and WSi)
- **All information** on the detector behavior
- If the photon deposits more energy when absorbed → less bias current needed
- Discriminator settings limits to 750 nm

Photon count rate

- **Non-linear** over the full energy range
- Other temperature measurement

![Graph showing energy vs. count rate normalized for different wavelengths and bias currents. The graph indicates non-linearity and the necessity of diffusion, as well as other temperature measurements.]


Photon count rate

Transition width

\[ \Delta I_b = I_b^{80\%} - I_b^{20\%} \]

• possible thanks to the **large plateau** region

\[ \Delta I_b (\mu A) \]

\[ \text{Energy (eV)} \]

\[ \text{Wavelength (nm)} \]

\[ \text{Normalized bias current} \left( I_b / I_b^{50\%} \right) \]

\[ \text{Count rate normalized} \]

\[ \text{Bias current} I_b (\mu A) \]

\[ \text{Count rate normalized} \]

→ **50% reference value**

→ Error function fits
  ‣ Fano fluctuations: number of quasiparticle fluctuates
  ‣ position dependent effect?

→ **New intrinsic** parameter to give input to the theory

M. Caloz et al. *APL* 110, 083106 (2017)

Probing the detection mechanism with jitter measurement

- Intrinsic jitter is directly related to the hotspot dynamics

\[ j_{\text{system}} = \sqrt{j_{\text{noise}}^2 + j_{\text{setup}}^2 + j_{\text{intr}}^2} \]
\[ j_{\text{intr}} = \sqrt{j_{\text{hotspot}}^2 + j_{\text{geometric}}^2} \]

- possible thanks to 7 nm thick MoSi
  - high bias current operation → better SNR → jitter is not dominated by the noise

MoSi meandered devices can have very low jitter: 26 ps!

Same behavior for different designs

This evolution is due to the intrinsic jitter.
Detection mechanism in MoSi SNSPDs

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Non-gaussian tail
• current dependent

\[ j_{\text{system}} = \sqrt{j_{\text{noise}}^2 + j_{\text{setup}}^2 + j_{\text{intr}}^2} \]

• All other contributions are gaussian
→ non gaussian tail due to intrinsic behavior
Residues maximum $\sim I_{\text{sat}}$

Even in the deterministic region (plateau), the jitter (3 and 20 dB) **decrease a lot**

**intrinsic limitations**?

Measurement at lower wavelengths would be very interesting: probing far in the plateau

Nice measurement to study the detection mechanism

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Main points:

- PCR with a **large plateau**
  - All detector information
  - Non-linear energy-current relation
  - QP diffusion only is not sufficient to explain our data
  - opportunity to reveal new intrinsic parameter
- Jitter measurement
  - great improvement for amorphous material
  - studying the intrinsic jitter behavior
- Experimental data with MoSi
  - give inputs to theorists
The team

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