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Summer Internship Report

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Over the summer, I worked with a group that designed and built Superconducting Nanowire Single Photon Detectors (SNSPD). Applications for SNSPDs include high-data rate interplanetary optical communications, spectroscopy of ultrafast quantum phenomena in biological and solid-state physics, quantum key distribution, and noninvasive, high-speed digital circuit testing to name a few.[2]

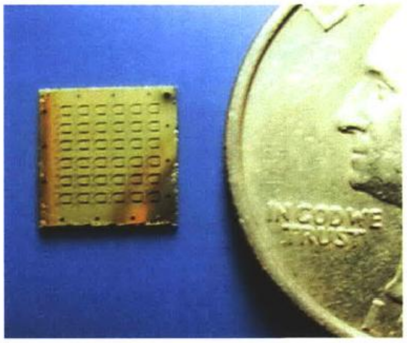

Figure 1 Photograph of the chip of superconducting-nanowire single-photon detectors (36 in total) after the processing was completed. The size of the chip is 10mm by 10 mm.

The heart of a typical SNSPD system is the photon detector, which consists of a nanowire few nanometers thick and approximately hundred nanometers wide. The detector's active area is approximately 10μm x 10μm and consists of a NbN nanowire mesh (See Figure 1 and 2)[3]. For single photon detection, one needs to couple the light from a 1.55μm infrared laser source to a detector. A fiber focuser attached to a single mode fiber produces a light beam with a beam waist of approximately 5 microns. It is very crucial to couple the beam onto a detector surface such that axis of the beam is perpendicular to the detector surface and the beam waist is aligned at the center of the detector in XYZ direction. Efficiently coupling the light can optimize detection efficiency of the device.

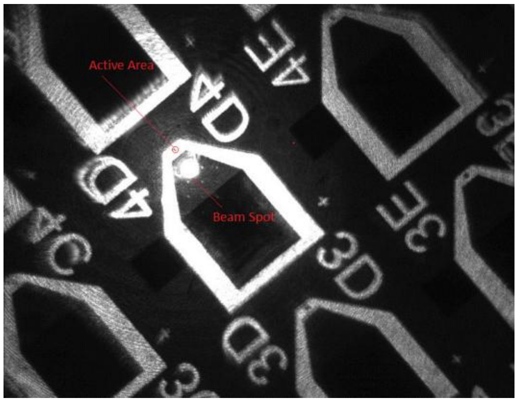

Figure 2 CCD image of detector using a 10x microscope objective. The figure also shows the coupling of a red laser with the detector.

I worked with the optical subgroup that was designing Superconducting Nanowire Avalanche Photodector (SNAPPY). The goals of my optical setup were to use back-reflection of the light from the detector to

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[1] I am greatly thankful to the donor, Dr. Randolph S. Peterson, and Sewanee for providing me with the necessary funds required to conduct this internship.

[2] Andrew J. Kerman, *Constriction-limited detection efficiency of superconducting nanowire single-photon detectors*, Applied Physics Letters 90, 10110, 2007

[3] Photo Courtesy of Xiaolong Hu, *Efficient Superconducting-Nanowire Single-Photon Detectors and Their applications in Quantum Optics*, 2011

1. Perform vibration interferometry to test robustness of the mechanical design of the system
2. Align the beam waist to the detector surface in X, Y and Z direction
3. Correct for the angular misalignments to within fractions of a degree
4. Observe change in the resonant frequencies as the SNAPPY system is cooled down to cryogenic temperatures

During the summer, I was able to accomplish most the goals of our optical setup and designed the following system of vibration interferometry and alignment:

Vibration interferometry to test the robustness of the mechanical design

A Michelson interferometer setup using DFB laser source with a relatively longer coherence length, 50/50 fiber coupler, fast-photo diode, and fiber collimator is used to observe the resonant frequencies of vibrations. (See Figure 3)

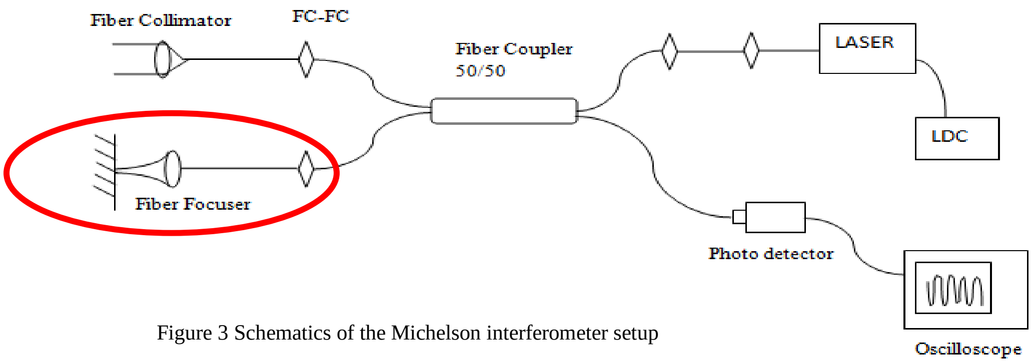

Figure 3 Schematics of the Michelson interferometer setup

A fiber collimator is used as a suitable reference as the back-reflection from this end is not sensitive to external vibrations on the reference end. The interference system is outside the cryostat, and the single mode-fiber coming out of cryostat is used as an input channel of light for interference measurements.

An input optical power of around 3mW is used to obtain back-reflection from the detector that is in the same order of magnitude as the back-reflection from the fiber collimator. This system is extremely responsive to external vibrations, including vibrations induced by acoustic coupling (See Figure 4). Change in the resonant frequencies as the system is cooled from room temperature to cryogenic temperature will be useful to understand the misalignments introduced while cooling.

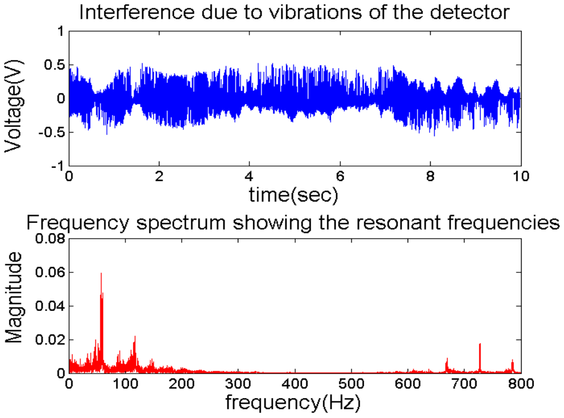

Figure 4 Interference due to vibrations of the detector are recorded and the frequency spectrum is obtained to look at the resonant frequencies. A constant sinusoidal sound of 701 Hz was played using a computer speaker to test acoustic coupling.

Optical Alignment Procedure for Snappy

1. Outside Pre-alignment:

To perform outside pre-alignment we follow the following steps:

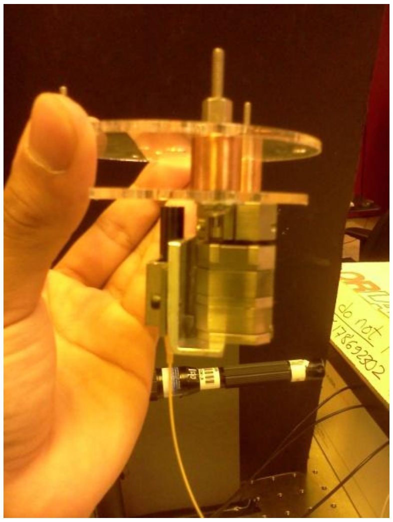

Figure 5 Three attocube piezos mounted on the piezo plate with the fiber focuser attached to them

a. Mount the Attocube Piezos (two ANPx101s and one ANPz101) on top of each other.[4] Make sure you are grounded while working with the Piezos. Do not apply large amount of torque while tightening screws onto the Piezos as this may damage them.

b. Now attach the L-mount and the fiber focuser (FF) to the Piezo stack base.

c. Attach the Piezo stack with the FF on the piezo-plate and attach this plate to the chip-plate using 3 screws and 3 metal spacers. Make sure you use the three small screw holes on the chip-plate. (See Figure 5)

d. The chip-plate and the piezo-plate move relative to each other a few millimeters to allow for a rough alignment of the FF on to the detector.

e. Glue the detector chip on the chip plate such that one of its edge is parallel to the edge of the Piezo stack.

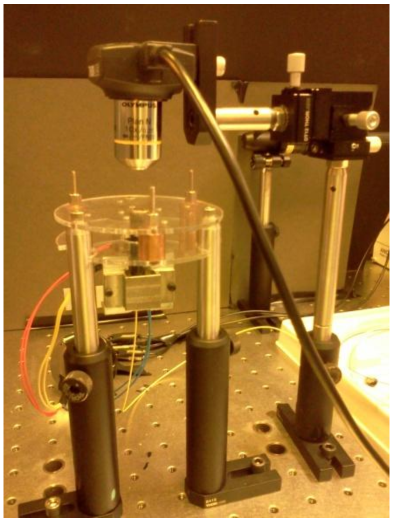

Figure 6 Outside alignment setup with chip plate mounted on optical posts and a 10x microscope objective with a CCD to look at the detector

f. Mount the chip plate horizontal using two optical posts.

g. Attach a 10x microscope objective (RMS10x) to a CCD camera (Thorlabs DCC1545M)[5]. Mount this on a simple xyz stage such that the lens is horizontal and approximately 3cm above the detector. Use the UC480 viewer software to see the CCD image and adjust the xyz position of the objective until a clear image of the detector is observed. (See Figure 6)

h. Connect the Piezos to Piezo Step Controller (ANC 150), which connects to computer through a RS232 to USB connection.

i. Hook up the single mode fiber (SMF) attached to the FF to the reference end of the interferometer setup.

j. Use the power meter (Thorlabs PM 100D with S122C detector) to measure the back-reflected power. The power meter is connected to the computer through a USB connection. Zero the power meter manually for a wavelength of 1550nm.

k. For rough pre-alignment, attach the input end of the interference setup to a red-laser source (5mW).

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[4] http://www.attocube.com/nanoPOSITIONING/combining_positioners.htm

[5] http://www.thorlabs.com/NewGroupPage9.cfm?ObjectGroup_ID=4024

l. Open the uc480 viewer to look at the detector chip. Use the auto contrast option on the viewer to adjust the contrast so that a clear spot of light is seen on the chip.

m. Turn of the Piezo Step Controller and set the mode on all three axes to 'CCON'.

n. Run the LabVIEW based *Piezo Virtual Controller.vi*.(See Figure 7) Set the volts and frequencies to appropriate values depending on the distance you want to move. Frequency can be usually set to 5000Hz and voltages can be set to 15 V. However, a voltage of 25V is more appropriate for Axis 3 (Z direction) as this Piezo carries a load on it.

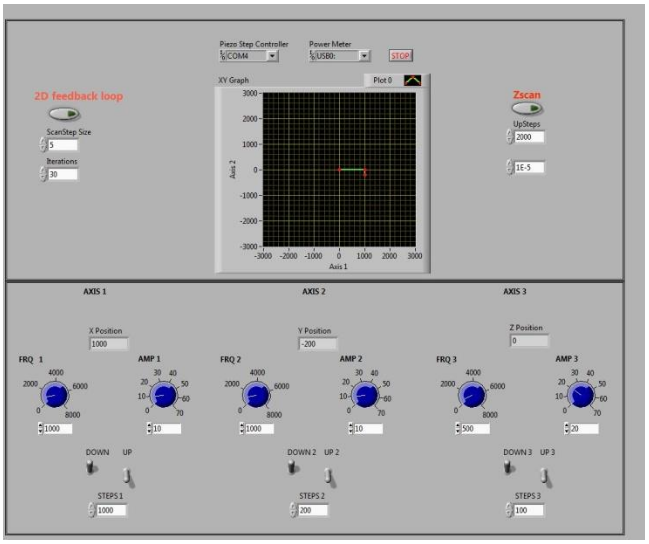

Piezo Step Controller: COM4
Power Meter: USB0:
ScanStep Size: 5
Iterations: 30
UpSteps: 2000
1E-5
X Position: 1000
Y Position: -200
Z Position: 0
FRQ 1: 1000
AMP 1: 10
FRQ 2: 1000
AMP 2: 10
FRQ 3: 500
AMP 3: 20
STEPS 1: 1000
STEPS 2: 200
STEPS 3: 100

Figure 7 Piezo Virtual Controller

o. Move the detector in Axis 1 and Axis 2 (X and Y direction) up or down until you reach the detector that you want to couple light to.

p. Place the spot on the gold surface so that the light being reflected off the gold surface can be used for alignment in the Z-direction.

q. Now connect the input end of the interferometer to a CW laser source (Thorlabs S1FC1550) instead.

r. Turn on the laser and the set the input power to maximum (2.24mW). Be careful handling the infrared source.

s. Run the *Piezo Virtual Controller.vi*. Setup the Voltage on Axis 3 (Z axis) to 25 V and frequency to 5000Hz. Set the 'UpSteps' to 1000 and 'DeltaPThresh' to 1E-5 and 'Tolerance' to 0.99. Upsteps insures that the FF is closer that working distance (3.5mm) from the detector. DeltaPThresh is used to define a power change value to look for position of maximum back-reflection. 'Tolerance' accounts for the random fluctuation in power output of the laser.

t. Perform the Zscan. (If a scan does not stop itself and the loop keeps running, it is possibly due to low voltage or higher tolerance value. Increase the voltage and decrease the tolerance to debug this.)

As a confirmation of alignment of the beam waist on the Z-direction you will see a peal back-reflection at the power meter.

u. Use the red-laser as an input end of the interferometer to a red laser.

v. Run the *Piezo Virtual Controller.vi* move the beam spot on the detector.

w. Switch the laser source back to the infrared 1550nm. Since you are near the detector you should be in the trench.

x. Perform the 2D feedback loop first with a larger step size and then gradually decrease the step size. In one such procedure, an initial step size of 10 steps with 10 iterations was performed, and the step size was refined to 5 steps and then 2 steps. Performing 2D feedback loop with right parameters is essential. The back-reflection from the detector is going to be significant and even more than that from the gold surface.

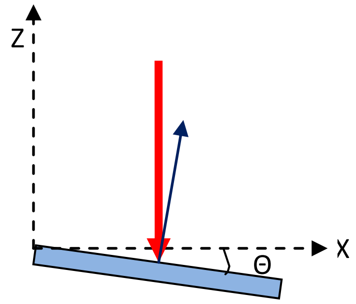
y. Make sure you transfer the detector to the cryostat carefully and by holding just the chip plate. Perform the transfer in one go to preserve the alignment. Also, be careful while unplugging the connection to the Piezos.

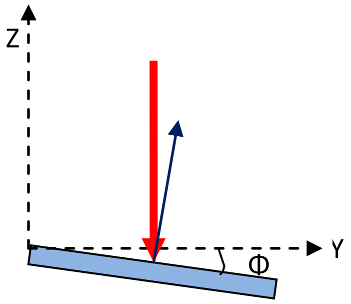
2. In-situ Alignment

A 2D feedback loop procedure that looks at the photon count rate of the device instead of the back-reflected power is used to align the beam in XY direction. The photon count rate is also used to position the lens at a working distance of approximately 3.5mm away from the detector surface.

Outside Snappy correction for angular misalignment

Scanning the back reflection in XY direction can also be used to check for angular misalignments (Θ and Φ) in both X and Y direction





As we scan the beam in X-direction presence of an angular tilt Θ affects the back-reflected power. The beam waist is no longer at the detector or it is out of focus. Hence, the back-reflection decreases. Angular misalignment Φ can be determined similarly by observing the back-reflected profile in Y-direction.

Although our nanopositioners do not have roll and pitch degrees of freedom, a simple correction for the misalignment would be in the mechanical positioning of the detector chip on the chip plate. The chip can be adjusted until the back-reflection profile is not sloping downwards, as

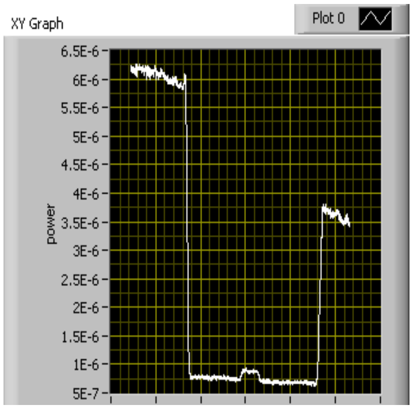


Figure 8 Back-reflected power slopes downwards due to angular misalignment Θ of about 2.2°

shown in Figure 8. This way we can ensure that the angular-misalignments are removed.

Accurate XYZ positioning of the beam waist on the detector is only complete after angular misalignments have been removed.

In conclusion, I set up a single mode fiber based Michelson interference setup that can be used to determine resonant frequencies of vibration of single photon detector. I devised a method to understand the degree of angular misalignment and correct such misalignments. I also wrote a labVIEW based program to control the Attocube nanopositioners and an algorithm to align the beam in XYZ direction onto the detector surface looking at back refection from the detector and the photon count rate of the device.

Acknowledgement:

The work that I did over the summer would not be possible without the help of following people at QNN group at MIT: Dr. Karl K. Berggren, Faraz Najafi, Hasan Korre, Dr. Franscesco Marsili, Andrew Dane and Franscesco Bellei.

Note: This report is not for a publication purpose.