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14. ABSTRACT
The funding provided by this grant was used to purchase an Integra AC recondensing cryostat from Oxford Instruments. Acquisition of this piece of equipment has been instrumental in allowing us accelerate our efforts to develop cavity-embedded Cooper pair transistors for ultra sensitive charge detection of quantum systems such as quantum dots and nanomechanical resonators. It has done so in two ways: by significantly reducing our operating costs, and by allowing us to run two dilution refrigerator systems in parallel.

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					603-646-6569

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Report Title

Final Report: Acquisition of a Recondensing Cryostat for Ultra-Sensitive Charge Detection of Quantum Systems

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Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

TOTAL:

Number of Manuscripts:

Books

Received Book

TOTAL:

Received Book Chapter

TOTAL:

Patents Submitted

Patents Awarded

Awards

Graduate Students

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Alex Rimberg	0.00	
FTE Equivalent:	**0.00**	
Total Number:	**1**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 0.00

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

See attachment

Technology Transfer

Final Report 2014

During the past year, we have successfully ordered, received and installed an Oxford Instruments Integra AC recondensing cryostat for use with one of our existing dilution refrigerators. This cryostat has now been in operation since May of 2014, and has already both saved us significantly in He costs, and increased our research productivity by allowing us to run two dilution refrigerators in parallel.

We find that with the new Integra cryostat the daily liquid He use for our Kelvinox 100 dilution refrigerator has now dropped to only about 3 liters per day when the refrigerator is running. When not running, we find that the cryostat can be kept cold with negligible He consumption. This improved efficiency will likely more than triple the number of days per year that we can afford to keep this cryostat cold and in data collection mode.

As an example of the kind of research this purchase has enabled, we show in Fig. 1 characterization data for a SLUG amplifier needed to achieve the ultimate noise performance of our cavity-embedded Cooper-pair transistor (cCPT) electrometer. This SLUG, provided by the McDermott group at the University of Wisconsin, Madison, has a center frequency of roughly 5.6–5.7 GHz and has been shown to provide in excess of 20 dB of gain. This SLUG is currently being used to characterize cCPT samples and optimize their operation versus both gate charge and flux bias. The McDermott group has agreed to provide us with other SLUGs for both our other dilution refrigerator, and (if needed) to improve matching between the SLUG and microwave resonator frequencies.

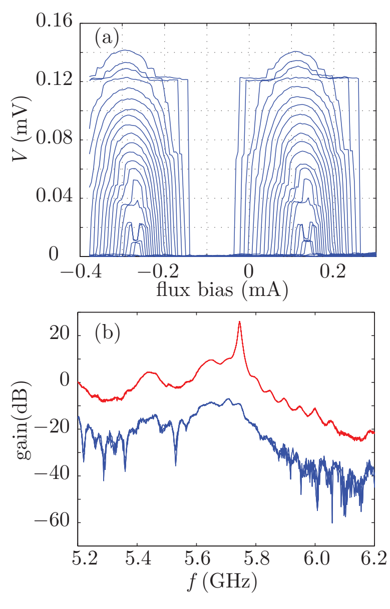

Figure 1: (a) SLUG voltage V versus flux bias current for a series of different junction bias currents. (b) Approximate gain of the SLUG versus frequency when inactive (blue) and when biased to produce near-optimal gain (red). A large gain in excess of 20dB is clearly visible near 5.7GHz, close to the resonant frequency of our microwave cavities.

Furthermore, acquisition of the cryostat has helped indirectly in other research, by allowing us to run two dilution refrigerators in parallel. As an example, we show in Fig. 2 the reflection coefficient S_{11} of a superconducting microwave cavity fabricated on a Si/SiGe substrate versus frequency for a series of temperatures T ranging from 80 mK to close to the critical temperature of the Al film used to make the cavity. These data were taken in a second dilution refrigerator roughly concurrently with the SLUG characterization measurements above.

As can be seen in Fig. 2 , there is a clear resonance at a frequency of 9.56 GHz in a microwave signal reflected off the cavity at $T = 80$ mK. As the temperature is increased, the center frequency of the resonance decreases monotonically, while the resonance itself first deepens, then becomes both shallower and broader for temperatures approaching 1.5 K. The disappearance of the resonance for temperatures above the critical temperature of our Al films clearly identifies the resonance as being associated with the superconducting microwave cavity. Related measurements of the resonance versus applied in-plane magnetic field show that the resonance disappears for fields greater than 0.07 T, further confirming our identification of the resonance. Analysis of the depth and width of the resonance allow us to determine that the external Q of the cavity is roughly 900, while the intrinsic Q is as large as 5,000 at the lowest temperatures measured. The low external Q and high resonant frequency of the cavity both suggest that the dielectric constant of the Si/SiGe substrate is significantly below the anticipated value.

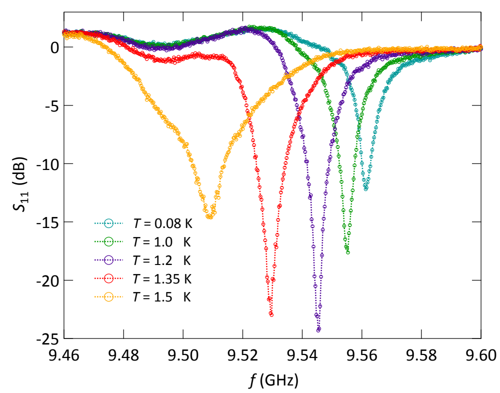

Figure 2: Cavity reflection coefficient S_{11} versus frequency for a series of temperatures ranging from $T = 80$ mK to 1.5 K.

As the above two examples show, acquisition of the Integra AC cryostat has already had a major impact on all our DOD-funded research projects. We anticipate that the cryostat will continue to enhance our research efforts for some time to come.