Application to Graduate with Honors

Student ID: [illegible]

I plan to defend in: FALL / [✓ SPRING] of 20 11

Personal Information:

Name: Nicholas Farrow

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I am an: [✓ IN-STATE] / OUT-OF-STATE student

Academic Information:

☒ I plan to graduate with *Departmental Honors* in: Physics

☐ I plan to graduate with *General Honors*

Cumulative GI

Please attach a brief **PROSPECTUS, BIBLIOGRAPHY**, and **TIMELINE** of your thesis project to this application. When summarizing your work, consider the following:

- What is the problem you are investigating?
- What is the hypothesis you are testing?
- What is the focus of your study?
- What is your goal in this study?

Primary thesis advisor: Name: Heather Lewandowski Dept: Phys

List the other members of your committee:
Name: John Cumalat Dept: Phys
Name: Nikolaus Correll Dept: ECCS/ECEE
Name: Dept:
Name: Dept:

Departmental and General Honors Committee Checklist:

✓ Applicant has a total of at least three committee members.
✓ At least one Honors Council Representative is included on committee.
✓ At least one committee member from an outside department.

APPLICATION CONTINUED ON BACK OF THIS SHEET

Please initial if you are pursuing Departmental Honors:

NF I have consulted with my department and have completed (or am completing) the requirements they have established.

For Honors Council Representative:

I have met with applicant and approve him/her for departmental honors.

Printed Name: John P. Cumalat Signature: John P. Cumalat

Please initial if you are pursuing General Honors:

_____ I have completed (or am completing) the requirements for graduating with General Honors.

Please list the courses you have or are taking toward General Honors:

For General Honors Council Member:

I have met with applicant and approve him/her for general honors. I agree to be on his/her defense committee.

Printed Name: ____________ Signature: ____________

For the Thesis Advisor:

I have met with the applicant to discuss the proposed work and agree to provide the necessary help and direction for this thesis project.

Printed Name: Heather Lewandowski Signature:

For the Student:

I have read the requirements for graduating with honors at the University of Colorado. I also understand that my designation will be sent to the CU email address that I have provided and will not be given out over the phone.

Signature: Date: 12/2/10

For additional graduation information including requirements, guidelines and deadlines, you can download them online at www.colorado.edu/honors

Background

In the Lewandowski Lab we are studying the interactions of cold molecules with rubidium. A molecule of particular experimental interest is the free radical NH. This experiment is studying "resonant quenching" in collisions between NH (in the singlet delta state denoted $^1\Delta$) and ground state ($5S_{1/2}$) rubidium. This collision is near resonant; the NH can transfer its energy to a Rb atom, itself decaying to the NH ground state, meanwhile pumping the Rb up to an excited state (almost exclusively the excited $5P_{1/2}$ state). This excited Rb state is "electric dipole allowed" to decay back to the ground state of Rb, emitting a photon. These are the photons we hope to count.

One of the many challenges associated with performing this experiment is the detection of the emitted photons. A photon detector is required that would have detection efficiency sufficient enough to measure the weak flux of photons emitted from the reaction chamber. The detector must also have a noise profile low enough so that background noise detection events do not overwhelm the signal. There exists commercially manufactured single photon counters, but none are currently available that meet our sensitivity and noise requirements. It is for this reason that our lab group has decided to construct our own photon detector.

Project Description

The primary component of our photon detector will be an avalanche photodiode (APD). The avalanche photodiode will be used in 'Geiger mode' meaning that it will be electronically similar to a PMT in its behavior. The APD will not have a 'gain' in the analog electronic sense of the word, instead it will simply begin to conduct (breakdown) when a photon is detected. Control electronics will need to be used to reset (quench) the APD after each detection event. The APD is also sensitive to electronic (Johnson) noise, and this will need to be minimized.

To minimize noise detection events, an APD cooling mechanism will be employed. We have identified [1] that cooling to the APD to below -70° C will aid us in lowering the thermal noise to an acceptable range (less than 10 counts/second). The APD cooling will be performed by two sets of thermoelectric coolers (TECs) and a separate water cooling block which will be directly attached to the APD case. The first set of TECs will dump heat from inside the case directly into the water cooling system. This has been shown to keep the temperature inside the case near -20° C. A second set of TECs will be employed directly below the APD. This TEC stack will pump heat away from the diode and toward the first TEC for removal from the case. This second TEC will be driven by a secondary PID temperature control circuit which will allow us to set and stabilize the operating temperature of the diode. Inside the case will be filled with Styrofoam to minimize thermal convection currents and to insulate the APD.

The APD will be driven by an active (vs. passive) quenching circuit that we have adapted from another publication [2]. Benefits of an active quenching circuit over a passively quenched circuit include allowing faster counting rates and minimizing dark counts due to after pulsing effects. This circuit will be placed inside the case which should minimize external noise and keep the APD leads as short as possible. The circuit has two primary purposes. The first is to measure a drop in voltage from the APD which indicates that a detection event occurred (a photon has hit the APD). When this happens, the circuit will quench the APD (temporarily disrupt the flow of current through the APD), which will cause the APD to rest until another detection event. The second purpose of the circuit is to amplify the detection signal into a voltage spike that will provide a signal to be passed out of the module case. The voltage spike will be passed through a BNC cable into a counting circuit. The counting circuit will then be able to give a measurement of counting rate of the photon detector. This should provide an accurate measurement of the number of photons incident on the detector.

Although, in normal operation we expect to count rate to be below 100 Hz, the photon counter should be able to handle count rates up to 10^7 Hz, due to the high speed of the active quenching circuit that we are using.

References

[1] Y. Kim, V. Makarov, Y. Jeong, and Y. Kim, Silicon Single-Photon Detector with 5 Hz Dark Counts, Conference on Lasers and Electro-Optics/International Quantum Electronics Conference, OSA Technical Digest (CD) (Optical Society of America, 2009), paper JThE103.

[2] Mario Stipčević, Active quenching circuit for single-photon detection with Geiger mode avalanche photodiodes, Applied Optics, 48, (2009) 1705-1714

[3] M. Ghioni, S. Cova, F. Zappa, and C. Samori, Compact active quenching circuit for fast photon counting with avalanche photodiodes, Rev. Sci. Instrum. 67, (1996) 3440-3448

[4] I. Rech, I. Labanca, G. Armellini, A. Gulinatti, M. Ghioni, and S. Cova, Operation of silicon single photon avalanche diodes at cryogenic temperature, Rev. Sci. Instrum. 78, (2007) 063105

[5] L. Li and L. M. Davis, Single photon avalanche diode for single molecule detection, Rev. Sci. Instrum. 64, (1993) 1524-1529

Timeline: Single photon detector/counter for 780 nm wavelength

Spring 2010
Literature search, learning how photon detectors work
Vendor search, identifying parts suppliers
Order many of the parts that will be used, photodiode, case, etc.

Summer 2010
Begin construction of case and cooling apparatus
Machining and millwork of case and photodiode mounting hardware
Layout and testing the cooling behavior of TECs.
Construction of water-cooling apparatus for extraction of TEC waste heat
Design and layout of surface mount quenching circuit

September 2010
Complete testing of photon quenching and timing circuits
Consider an alternative quenching / counting circuit

October 2010
Build alternative quenching circuit
Be able to detect avalanches of thermal origin with the circuit

November 2010
Complete construction of power sources (TEC driver)
Begin analysis of thermal noise vs. operating temperature

December 2010
Complete analysis of thermal noise vs. operating temperature
Begin analysis of thermal noise vs. breakdown voltage
Begin work on counting circuit/oscilloscope/Labview control program
Detect actual photons, not just noise
Write operation manual for photon counter
Begin writing undergraduate honors thesis

January 2011
Integrate photon detector into experimental apparatus/vacuum chamber
Take data with rubidium or NH?

February 2011
Take data with rubidium or NH?

March 2011
Practice thesis presentation
April 2011
Undergraduate honors thesis defense