SAND2016-6170PE

Title:

Measurement at the limit: single ion detection for engineered quantum systems and the critical Casimir effect at the He-4 superfluid transition

Abstract:

In this talk I will describe experimental work to develop quantum systems at the limit of single defect fabrication and perform measurements of the critical Casimir effect at the limit of the 4He superfluid phase transition. Deterministic fabrication of single defects in semiconductor systems, such as donors in silicon or color centers in diamond, is a viable path for realizing qubits. I will describe an ionization detector developed in diamond to form the basis to deterministically fabricate a system of localized color centers. Additionally, I will describe low noise capacitance measurements of sub nanometer helium film thickness changes for quantifying the critical Casimir effect at the superfluid phase transition.

At Sandia National Laboratories, we have adapted the technique of in-situ ionization detection used for low energy counted ion implantation into Silicon and applied it to the diamond substrate for the optimization of color center fabrication. The status of diamond color center yield is a critical limitation for their integration with microfabricated devices and realizing architectures to couple individual centers. Although great progress has been made with deterministic spatial formation by focused ion beam implantation, a process for the reliable activation of implanted centers has not been developed. A primary factor impeding the development of such a process is the inherent uncertainty in the number of implanted ions due to the Poisson statistics of ion implantation. As well, yields <10% are typical for SiV center formation by ion implantation. These two factors limit progress in improving color center yield. We propose a novel path for improving color center yield. The in-situ diamond detector, we have developed, allows for the counting of single ions with an SNR approaching 10 for a 200 keV Silicon implant. This SNR results in an expected ion counting error rate of less than 1%, thereby removing a known source of Poisson statistics. We anticipate that the technique of counted implantation will serve as a platform to develop a more certain understanding of how color center yield depends on factors such as the local number of vacancies, anneal parameters, and surface termination.

While at UCLA, I performed studies of superfluid ^{4}He films in contact with bulk superfluid. This arrangement forms a model system for the critical Casimir effect: the condensed matter analogue of the electromagnetic Casimir effect. The critical effect results from imposing a boundary condition, via the finite thickness of the film, on the thermal fluctuations of the superfluid. This geometric constraint generates a free energy difference between the film and the bulk. This, in turn, results in a thinning of the film as the atoms in the system move to minimize the free energy. I will describe measurements of the critical Casimir effect in superfluid 4He films which are tens of nanometers thick. A new film-thinning effect was observed precisely at the bulk (3 dimensional) superfluid transition temperature. We proposed that this is a non-universal Casimir effect originating from substrate interactions with the film.

This work was performed, in part, at the Center for Integrated Nanotechnologies, an Office of Science User Facility operated for the U.S. Department of Energy Office of Science. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.