Magneto-Transport in Photoexcited Diamond

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Abstract and Introduction:

Diamonds are uniquely suited for electronic and spintronic device applications. Ultrahardness, a wide band-gap of 5.5 eV, and a high thermal conductivity are ideal material properties for electronic devices requiring high power, high frequency, or high temperature. Additionally, defects in diamond are a single-spin system and single photon source, with potential for room temperature quantum computation. However, little is known about certain electrical properties in diamond. Here, we attempt to determine the carrier type and density of a single-crystal, nitrogen-rich diamond, by measuring the photoexcited Hall effect. Using a physical properties measurement system (PPMS), it is possible to take these measurements over varied temperatures and magnetic fields.

Experimental Procedure:

In this investigation, we explored single crystal, type Ib diamond, grown by the high-temperature, high-pressure method with a substitutional nitrogen concentration of 10^{19} atoms/cm^3. Using small-scale photolithography techniques and electron-beam deposition, we evaporated 100/500/900 Å of titanium/platinum/gold in a four pad Van der Pauw geometry (Figure 1). Each contact pad was 1 mm^2 and the gaps between neighboring contacts were 50 μm. The large contact pads allowed for an optical fiber to be glued to the area at the center of the pads in a process known as pig-tailing. The fiber was attached directly onto the sample with optical glue [1]. After metallization, one sample was annealed at 230°C for 36 hours to eliminate any surface conduction effects caused by hydrogen-terminated bonds.

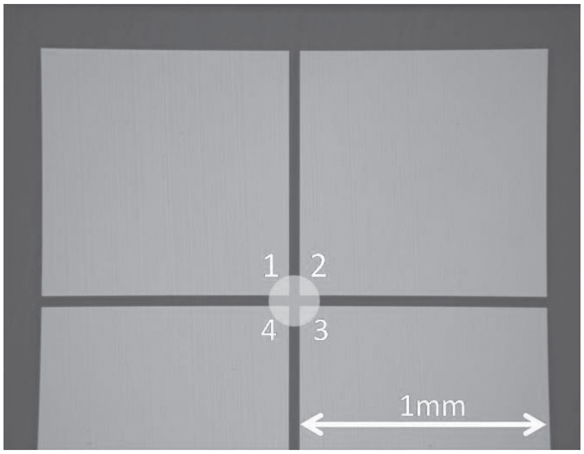

Figure 1: An optical micrograph of a diamond sample (dark color) with 1 mm x 1 mm Ti/Pt/Au contact pads (light squares). The contact pads are numbered in the Van der Pauw geometry. The lightest circle represents the photoexcited area.

The measurements were taken using a PPMS, which is a cryogenic chamber capable of cooling down to temperatures as low as 1.8 K. A superconducting electromagnet, within the PPMS, can apply magnetic fields to the sample up to 14 T normal, which is optimal for Hall effect measurements. The integrated electronics in the PPMS allow for a large array of measurement capabilities; however, it does not provide a system for optical illumination. Two modifications were critical for photoexcitation with a powerful, external laser.

First, a custom probe stick insert was designed and fabricated to lower the fiber and sample down the length of the sample chamber and into the measurement space (Figure 2 a,b). The stick was made of G-10 fiberglass with non-magnetic brass fixtures. The G-10 pieces were bonded together using cryogenic epoxy. The thermal expansion of all materials used was carefully considered for cycling from room temperature to 10 K to ensure that the stick insert remained shorter than the PPMS sample chamber.

Once the fiber was fed through the probe stick, it was pigtailed directly onto the sample (Figure 2c). The diamond was photoexcited using a sub-bandgap 532 nm (2.3eV) laser beam which passed through a series of expansion optics and focused into a 105 μm core fiber. To withstand temperatures as low as 4.2 K, the fiber had aluminum cladding. The other end of the fiber was directed via a Teflon® ferrule out of the PPMS through the second modification: a specialized vacuum fitting consisting of a Swagelok and KF flange [2].

In our setup, the 2.3 eV laser was used to optically bridge the center region between the pads, and excite carriers from within the diamond. These nitrogen-rich diamonds have

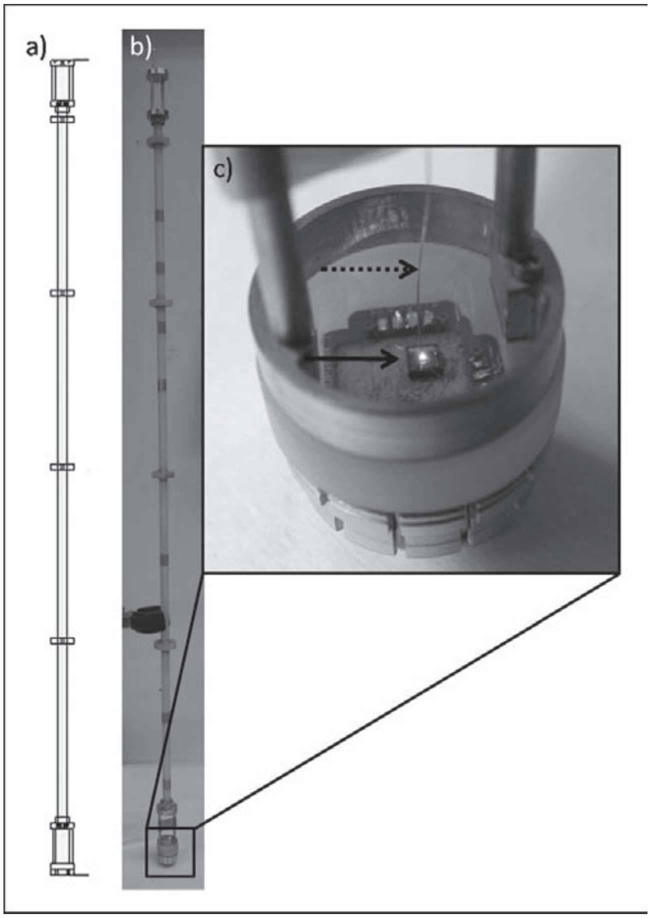

Figure 2: a) A schematic drawing of probe stick insert design. b) Image of the fabricated probe stick insert. c) View of the lower portion of stick insert including sample (solid arrow) and pigtailed optical fiber (dotted arrow).

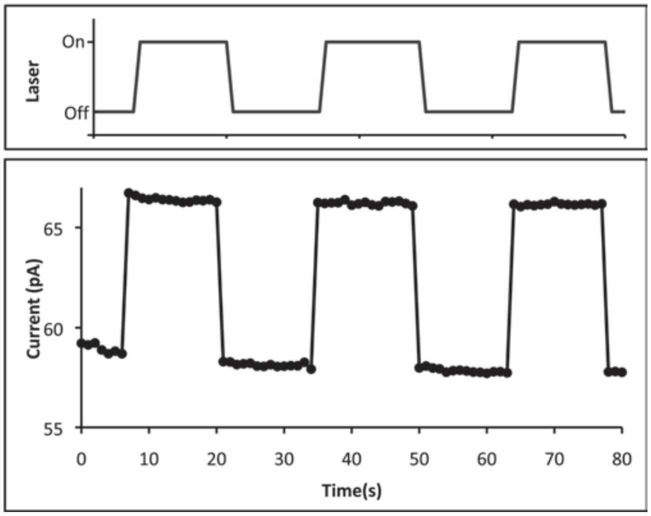

Figure 3: Plot of current (pA) and laser state vs. time (s) showing an increased current corresponding to times when the laser is used to photoexcite the sample.

shown photoinduced charge storage effects likely due to the presence of substitutional nitrogen defects, believed to reside 1.9eV below the conduction band [3]. To verify photoconductivity, the stick assembly was tested at room temperature by applying a DC voltage across two pads, between which the current was measured using a current preamplifier. Figure 3 shows the measured current between pads 2 and 4, dependent on the laser illumination as plotted on a time axis. Under illumination, there should be an increase in the current due to the excitation of carriers and a decrease when the laser is blocked. This is a successful proof of concept that the pig-tailed fiber can indeed demonstrate photoconductivity in type Ib diamond.

Conclusions:

We have demonstrated a successful photoconductivity technique using a custom designed PPMS probe stick insert and pig-tailed optical fiber on single crystal, nitrogen rich diamond. With this, we are now able to subject samples to normal incident magnetic fields of a few Tesla over a large range of temperatures. Having successfully seen photoconductivity in this system, we can begin to investigate the photoexcited Hall effect in type Ib diamond.

Acknowledgements:

I would like to thank my mentors, Joseph Heremans and Shawn Mack, my principal investigator, Prof. David Awschalom, fellow cohort, Matthew Brehove, and the rest of the Awschalom group for their constant support and guidance during the program. I would also like to thank Angela Berenstein, the UCSB REU site coordinator. This work was sponsored by the National Science Foundation, the Air Force Office of Scientific Research, and the National Nanotechnology Infrastructure Network Research Experience for Undergraduates Program.

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