Summer REU Paper

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Abstract

The goal of this project was to use scanning tunneling microscopy to image a nitrogen vacancy center in diamond; to further characterize the defect for implementation as a qubit. The extent of my research included characterization of the diamond samples that were previously obtained. The results of the photoluminescence spectroscopy on the chemical vapor deposition diamonds, as well as a nitrogen-doped high pressure high temperature diamond, show that these diamonds are acceptable candidates for implantation of NV centers.

Introduction

As the need for greater computational power progresses, so will the need for better quantum information technology. An integral part of the quantum computer is the quantum bit, or qubit. A formidable candidate for a qubit is the nitrogen vacancy (NV), a nitrogen substitution bonded to a vacancy, in diamond. Firstly, diamond is a wide bandgap semiconducting material, allowing for adequate space between conduction and valence gaps for the NV center to exist [1]. This allows for cheap and easy manipulation of states within the NV center using microwaves [1]. The NV also has long coherence times relative to standard computing times [2]. Another feature that makes NV centers a great candidate as a qubit is the strength of their fluorescence under optical excitation; excitation and readout can be done at room temperature due to the NV's spin state dependency [2].

While there have been many studies on NV centers in the past, there has yet be an STM (scanning tunneling microscopy) image taken of the individual defect, most likely because of the difficulties in imaging diamond. Having an atomically resolved image of the defect could shine light on additional properties not yet known. For an STM image to be taken of an isolated defect, one must create or locate one. Therefore, the photoluminescence (PL) spectroscopy of the NV center takes precedence. Although the NV center is naturally occurring, the implications of accurate control of the location of an NV center is of great importance as it could be very useful for the creation of quantum computers.

The overall goal of this project is to use scanning tunneling microscopy (STM) to image an isolated NV defect. As a preliminary step to this, most of my research was concerned with the characterization of the diamond samples already obtained; as well as setting up the optics needed to detect NV centers.

Methods and Experimental Setup

To proceed with measurements, a sample was first mounted onto a glass slide using wax that would adhere the sample onto a glass slide; the wax was tested and does not fluoresce under excitation. The optical setup (Figure 4) consists of an ND filter for easy manipulation of laser power. The path is then controlled by three mirrors and into a polarizing lens. The next part of the path is a three-way junction controlled by a dichroic beamsplitter to reflect the green laser into the sample and to allow any fluorescence to travel along the collection path and into the fiber for data collection. The collection fiber is coupled into a Triax 320 spectrometer. An excitation wavelength of 532 nm was used at 137 microwatts of power.

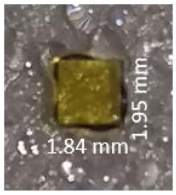

Figure 1: Nitrogen-doped high pressure high temperature (HPHT) diamond. PL of this sample is shown in Figure 7.

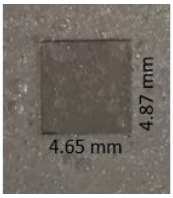

Figure 2: Chemical vapor deposition (CVD) grown diamond. Materials used for growth are unknown. PL of this sample is shown in Figure 8

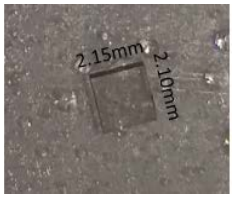

Figure 3: HPHT 2a (pure) diamond, <5ppm nitrogen present. The PL of this diamond is shown in Figure 5

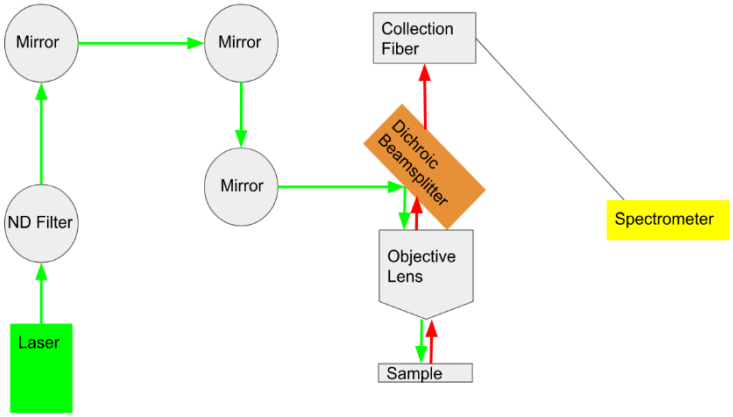

Figure 4: Optical setup used for photoluminescence.

Results and Discussion

The results obtained show that, at a relatively low power, our optical setup can detect around 100 intensity counts per second. Ideally, it could detect NV peaks from individual atomic defects. Our results from the HPHT 2a sample which can be in seen in Figure 5, match very well to the NV peak of a NV prepared diamond sample as seen in Figure 6, indicating that there is some volume of NV centers. With the amount of intensity counts per second present, it is plausible that an isolated defect can be located using a similar optical setup.

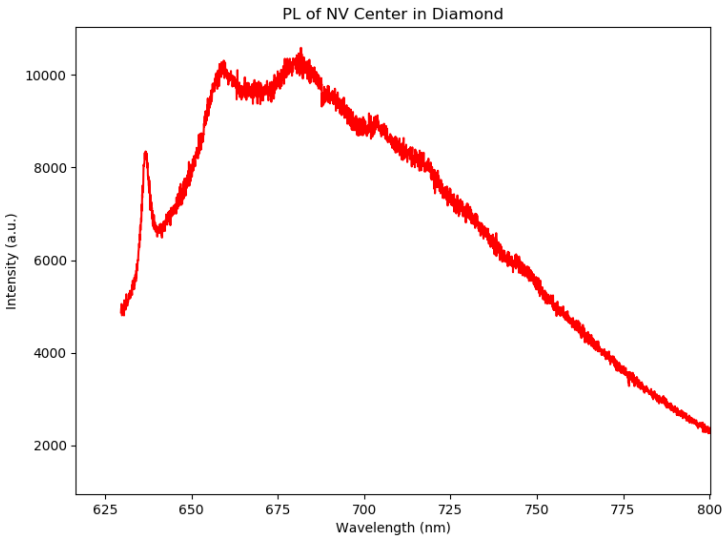

Figure 5: The NV peak in the HPHT 2a diamond.

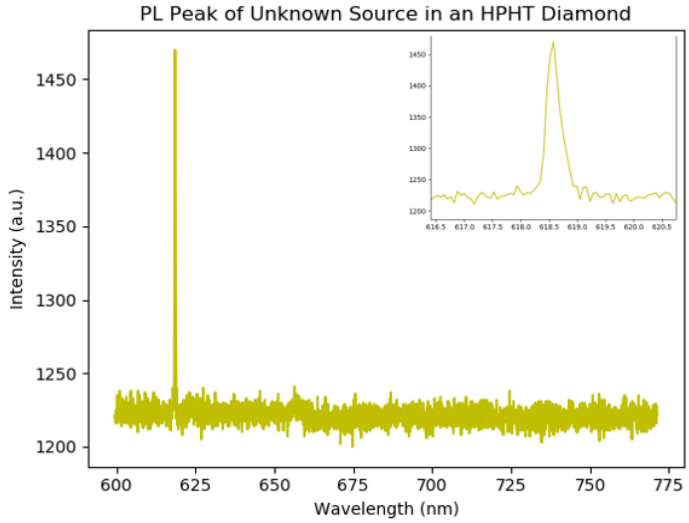

Figure 6: PL of the yellow HPHT diamond sample.

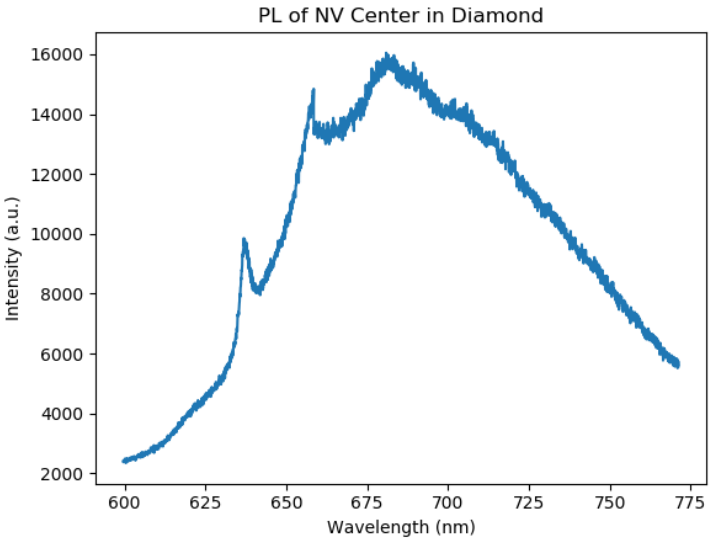

Figure 7: The PL of an NV prepared diamond. The NV^0 peak at ~680 nm has an artificial step behavior attributed to a shift of the gradient in the spectrometer. The gradient shifts when it is changing the wavelength readout range.

The peak in Figure 6 is caused by an unknown source, and there is ongoing research to locate the cause of the peak. But because there were no NV centers found, this sample is a good candidate for implantation of NV centers and further testing to locate the centers using PL. Upon sputtering and annealing of this sample, one would expect to see NV centers using a similar optical setup.

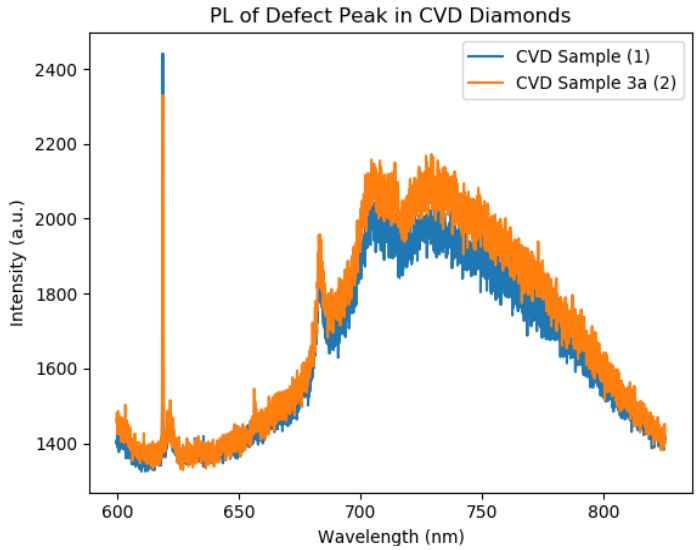

Figure 8: PL of the identically grown CVD diamonds. Exact growth methods are unknown.

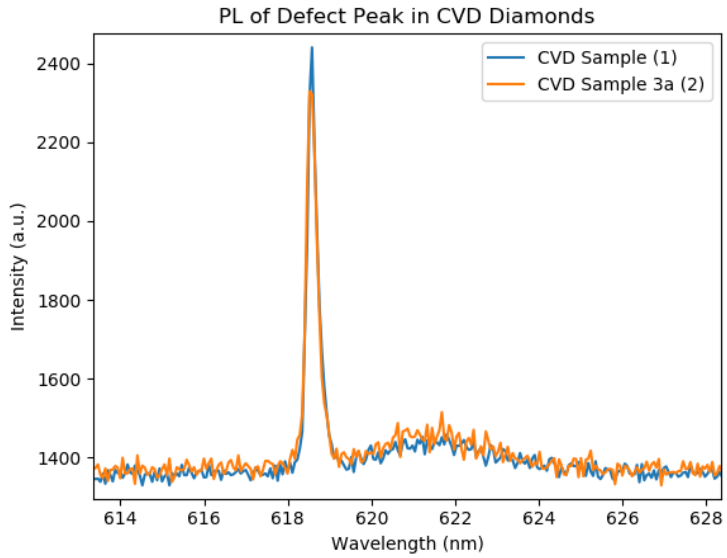

Figure 9: This plot shows the 618nm peak in Figure 8, better resolved. This is a very similar peak to the one found in the yellow HPHT diamond sample, with an identical linewidth (an indication that the peaks could result from the same source, or possibly be artificial).

There are 4 peaks in Figure 8 (618nm, 622nm, 656nm, 683nm) of interest and a broad band from ~700-750nm. The PL from these two samples do not agree with any defect peaks found in literature. It is plausible that this PL is an artifact of the optical system. Ongoing research is being done to characterize these diamonds.

The CVD samples shown in Figure 8 would also be acceptable candidates for STM imaging of NV centers. A looming issue may include the possible defects found using PL. But, the characterization of these unknown defects could be done using STM imaging.

Conclusion

The results found from PL on these five samples shows that we can sufficiently detect NV centers using our optical setup. The PL has also shown that the diamond samples in Figures 1 and 2 can be used to implant and image NV centers. Future work on implantation of NV centers will likely include sputtering to create vacancies in the diamond lattice, followed by annealing at temperatures of 800-1200 degrees Celsius to allow the coupling of vacancy to nitrogen. The size of the yellow HPHT sample has prevented immediate testing as it is too small to be mounted in the STM chamber using the current mounting paddles. However, since we know that this diamond is nitrogen-doped, there is no need for nitrogen implantation prior to sputtering and annealing.

Acknowledgements

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References

[1] Teeling-Smith, R. M. (2015). *Single Molecule Electron Paramagnetic Resonance and Other Sensing and Imaging Applications with Nitrogen-Vacancy Nanodiamond* (Doctoral dissertation, The Ohio State University).

[2] Kennedy, T. A., Charnock, F. T., Colton, J. S., Butler, J. E., Linares, R. C., & Doering, P. J. (2002). Single-Qubit Operations with the Nitrogen-Vacancy Center in Diamond. *physica status solidi (b)*, *233*(3), 416-426.