MQST Spring Laboratory
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Pulsed control of NV centers in Diamond

Spring quarter 2025

1 Introduction

In this lab you will learn how to setup, characterize, and operate an experiment that will perform pulsed coherent control of a small ensemble of NV- centers in diamond. You will be provided with a collection of Jupyter notebooks containing a variety of procedural information and code templates to help facilitate your work in this lab. This overview document will serve as an annotated guide to these notebooks and gives a suggested order in which to go about it.

N.B. this document is still under construction, and will be continually added to over the coming weeks. The current state has everything you need to get started on the first few weeks of work.

2 The physics of NV centers

The introductions to each of the following three papers provide clear and sufficient descriptions of the electronic structure of the NV- center in diamond, and the means by which one can perform ground state initialization via optical pumping and coherent control via pulsed microwave excitation. You will find a number of additional papers describing the physics of the NV- center in the files section on BruinLearn.

- V. K. Sewani, H. H. Vallabhapurapu, Y. Yang, H. R. Firgau, C. Adambukulam, B. C. Johnson, J. J. Pla, and A. Laucht, Coherent Control of NV- Centers in Diamond in a Quantum Teaching Lab, American Journal of Physics 88, 1156 (2020).

- E. Abe and K. Sasaki, Tutorial: Magnetic Resonance with Nitrogen-Vacancy Centers in Diamond—Microwave Engineering, Materials Science, and Magnetometry, Journal of Applied Physics 123, 161101 (2018).

- G. Mariani, A. Umemoto, and S. Nomura, A Home-Made Portable Device Based on Arduino Uno for Pulsed Magnetic Resonance of NV Centers in Diamond, AIP Advances 12, 065321 (2022).

Additionally, in the first week, we want you to thoroughly read the Sewani et.al. paper (and contained references as appropriate) to familiarize yourself with the overall architecture of our measurement setup and the major experiments that you will be developing and carrying out.

3 Introduction to our experimental setup

These two documents are designed as resources for syntax and structure to easily refer back to throughout the lab class.

Data Acquisition Tutorial Qcodes.ipynb

We will be using a reasonably common python-based data acquisition framework called QCoDeS : https://microsoft.github.io/Qcodes/ . This provides a basic tutorial introduction to the use of QCoDeS for this lab.

Instrument Introduction Lab 1.ipynb

This demonstrates the programming interface to the various instruments we will be using.

Optimizing the luminescence signal

The first thing you will do is learn how to detect the luminescence signal, which is the read-out mechanism. You will need to optimize both the optical signal and the electronic detection of that signal.

Procedure:

1. Fire up jupyter-lab in the 'base' conda environment
2. Connect the output of Bit0 (this is the lock-in reference) to channel 1 of the oscilloscope and the photodiode output to channel 2 of the oscilloscope.
3. Run a basic pulse sequence
4. Carefully adjust the focus of the microscope objective and position of the sample stage position to maximize the measured luminescence signal. Note that you can shift the location of the 'active region' due to the finite thickness of the diamond sample. Where should we aim to place this and why?

5. Notice that the luminescence signal displays substantial rise/fall times? Why is that?
6. Work with Prof Ross and Eric to solve this issue with both different terminations and the use of a preamplifier.

4 Lab 1 Sections

Lock-In Amplifier Detection Lab 1.ipynb

Before starting, read the following documentation on the basics of lock-in detection

- SR830 manual, section 3 "SR830 Basics"
- Zurich Instruments white paper "zi_whitepaper_principles_of_lock-in_detection.pdf"

T1 Time Lab 1.ipynb'

ODMR Lab 1.ipynb'

5 Lab 2 Sections

ODMR Magnetometry Lab 2.ipynb'

Hyperfine Splitting Lab 2.ipynb'

Rabi Oscillations Lab 2.ipynb'

6 "Lab Module 3"

Ramsey Fringe Lab 3.ipynb'

Hahn Echo Lab 3.ipynb'

CPMG Lab 3.ipynb'