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Applied Physics Master Lab:

Diamonds for Sensing Applications

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Abstract

ptical detection of electron spin resonances of nitrogen-vacancy (NV) centers in diamond [14, 15, 42]. This system offers the possibility to detect magnetic fields with an unprecedented combination of spatial resolution and magnetic sensitivity [43, 41, 13, 42, 44], in a wide range of temperatures (from 0 K to well above 300 K), opening up new frontiers in biological [14, 45, 46] and condensed-matter [14, 47, 48] research. Over the last few years, researchers have developed techniques for scanning magnetometry using nanoscale imaging techniques in bulk diamond [15, 42, 49], as well as in nanodiamonds [50, 51, 52] combined with scanning probe techniques [14, 53]. Sensors employing ensembles of NV centers promise even higher sensitivity and the possibility to map out all vector components of the magnetic field [13, 12], and pilot NV-ensemble magnetometers have recently been demonstrated by several groups [48, 47, 54, 44]

Contents

1 Introduction

Diamonds are not just known and appreciated by their beauty but also for it important technical properties like their mechanical hardness which they mainly get from their crystal structure. Nevertheless there are defects in their lattice structure which enable us to use diamonds more variously. Colour centres, for example, are fluorescent lattice defects which can be used for many sensing applications [**anleitung**]. In this experiment we will examine the properties of the so-called nitrogen vacancy (NV) centre and it's sensitivity to magnetic fields.

Colour centres (CC) are regular spacing in the lattice that absorbs a particular colour in light. This not just gives a special colour to the diamond but also relates to more interesting properties like fluorecence. where the lattice atoms gets lifted into an excited state and then decaying back into the ground state by emitting a photon with a wavelength in the visible range. The fluorescence here examined are the NV-centres that can be used to detect magnetic fields givin place toOptical Detection Magneto resonance or ODMR.

ODMR is done using the measurement method in which the NV-centres are excited by microwaves which leads to a loss in fluorescence at a certain microwave frequency. The recorded frequency spectrum in a frequency range around that frequency depends on the external magnetic field.

Also the fluorescence spectrum of the diamond as well as its size will be measured using an optical spectrometer and a CCD camera.

2 Theoretical Background

In the following some physical concepts needed for the understanding of this experiment are explained.

2.1 Colour Centres

Diamond structure is a well know and stuidies in crystalography, It lattice consist in a cubic structure based on 8 Carbon atoms, two tetrahedrally bonded atoms in each primitive. The diamond lattice is basically two face-centered cubic lattices, being the face centeres (FCC) atom on one cell the vertice of the other. Since there are two identical atoms per unit cell, there is no Absortion of photon in the IR-region, This mean that a purediamond can not have fluorecence properties (in first order) but this propertie can be achive with changes due impurities in the structure. This properties are call Colour centers.
Colour centres (CC) are a kind of point defects in crystal structures which contain a electron that absorbs light of certain wavelengths. This basic defect in the regular spacing of atoms within a solid that absorbs visible light of a particular colour, lending a characteristic colour to the solid.

There are more then 100 luminescent defects in diamond. another name that is knowsn is F-centre (German Farbe, "colour"), results from the absence of a negatively charged ion from a particular point in an ionic solid. This vacancy, which acts like a positively charged particle, attracts and traps an electron, and their combination constitutes an Colour-centre. One of the most abundant and also studied one is the Nitrogen related defects, or Nitrogen-Vacancy centeres (NV) , because nitrogen is a prominent impurity in the material, In next section we will talk in more detail about its oproperties.

2.2 NV-Centres in Diamonds

The NV-centes are a defect or imurity in the diamond structure, where two carbon atom in the secondary fcc are replaced , one by a nitrogen atom and the second one by a vacant. The single substitutional nitrogen has an infrared mode of vibration. Nitrogen aggregates are, pairs of neighbouring substitutional atoms, the nitrogen aggregates, and it neibours that leed to different combination (eigthin total usually labelled according to corresponding Miller indices) in the laticies that have distinct infrared spectra. In the next figure, the Fist Fcc latice of the diamond is shown and in the ceond structure one of the carbons was reaplced by the N. NV-center can exist in two charge states, the neutral NV^0 state and the negatively charged NV^- state that have diferent energy levels and alloud transition.
The most interenting properties of the NV centers is its absortion and emission fluorecence at red region, properti fundamentalthat will be studied in this experiment, and is mostly due to physical effects by the magnetic moment. A simplified quantum structure of the NV center can be seen in the fig .... where the ground stade and exited stade are contructed by triplet stades with a distance of 1.945 eV in between, here calles $^3A_2$ and ^3E respectivelly. The main radiative connection between the ground state and the excited state is due to the zero phonon line (ZPL). For the negatively charged NV center, this transition contributes to a wavelength of $\lambda_{zpl} = 637\,\text{nm}$ and has a lifetime of 10-30 ns.(To observe the ZPL, a simple absortion emition proces was done with a 519nm laser was done, identifin this peak at... .) An aditional proces from the exited stade is a nonradiative emission into the metastable singlet state $|s\rangle$. This can either occur from the state $|e,ms\rangle$, in a weak non-radiative decay.

2.3 Optically Detected Magnetic Resonance

3 Experimental Set-up and Procedure

3.1 Set-Up

3.2 Calibration

3.2.1 convertion factor camera

The strip was meassure with a calibrator at 1.2 ± 0.1 mm and the camara used was a Thorlabs CCD camera with dimentions of 1280x1024 pixels, each pixel with $5.2 \times 5.2\mu$m according to the manufacturer. In order to know the actual resolution of our microscope a calibration was done based on the magnification and calibration factor of the set up. Theoritically our C_f can be calculated as:

$$C_f = \frac{1px \cdot M}{d_p} = 1552px/mm \tag{1}$$

Where M is the magnification and d_p is the pixel sizes. And with a Magnification icual to the lenses used for the confocal setup is equal to the magnification $M = f2/f1 = 8$. In this case the tool of Thorlab's software was used to determine and measure the width of the microstrip. Using the equation above and the respective measumente we denote that $C_f = 1346\,\text{px/mm}$, with a magnification factor close to $M = 7X$.

3.2.2 Electronic components

In order Performe our ODMR, is crucial to determine the amount of microwave power deployed into the microstrip and the diamonds. we can not have an absolut power that is been pluging into the set up. The microstrip by defoult have some transmition T_{Ms} and reflecctions R_{Ms} that are unkown. For this a power coupler was added to the setup and four meassument with diferents arranges where performed as shown in the fig... First, the power coupler was conected to the DSA in out- out possition to knoe the transmitio of it, T_{cpl}. on the other hand the secon setup is an Out conection to the DSA and help to determine the reflection of the CPL R_{cpl}. for the thirt and fouth display, the mmicrostrip was added, in the Out-Out possition (CPL-DSA), messurion the Reflection R_{cpl-Ms} and transmition T_{cpl-Ms} of the hole set.
The DSA was set at 0 Dbm and a sweep centered at 2.8GHz frequancy. A 50Ω resistance was used for the losses ends as shown. The next figure display the four signals of the diferent arranges.
The total transmition and reflection ws simply calculated by a sustraction of the Ms trasmition in the diferent processes as next.

$$T_{Ms} = T_{cpl-Ms} - T_{cpl}R_{MS} = R_{cpl-Ms} + T_{cpl} - R_{cpl} \tag{2}$$

The atenuation in this cases for the transmiition remains close to cero, specially in the center of the sweep while the reflection as shown reducs drastricly. This gives us the facts that the power trasmited is close to the 0dBm used in the DSA and few of it is been reflected.

3.3 Measurements

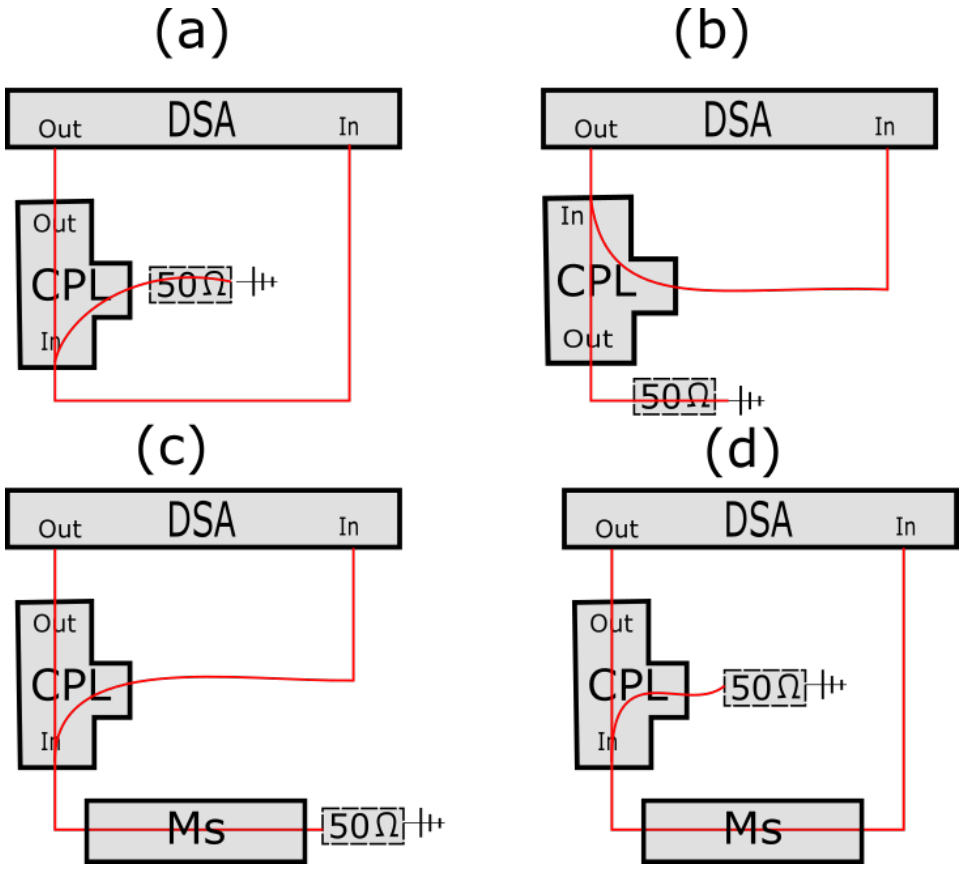


Figure 1: (A) CPL conected to the DSA in Out-Out direction messuring T_{cpl}, (b) Cpl conected in Out-In secuence and meassuring R_{cpl}, (c) CPl and microstrip conected in Out-Out mode and measuring the R_{cpl-Ms} (d) CPL and Microstrip conected in Out-Out moded and meassuring T_{cpl-Ms}

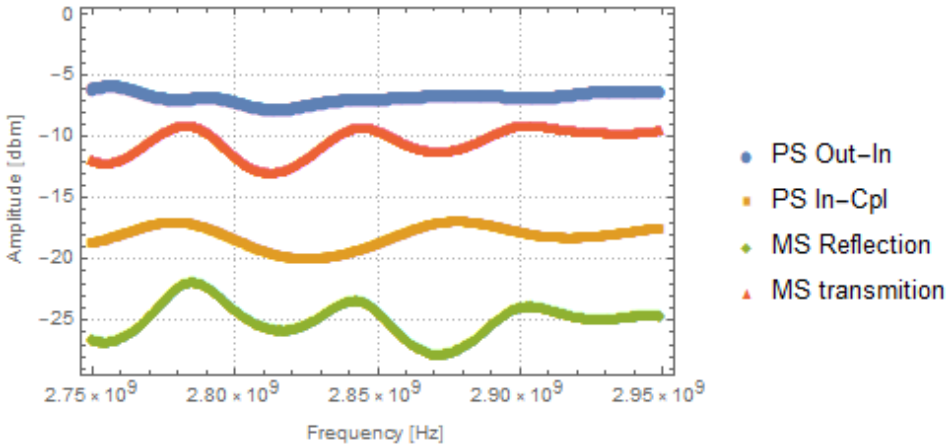


Figure 2: Atenuattion od the power at 0dBm from top to bottom: T_{CPL},T_{Cpl-Ms}, R_{CPL} and R_{Cpl-MS}

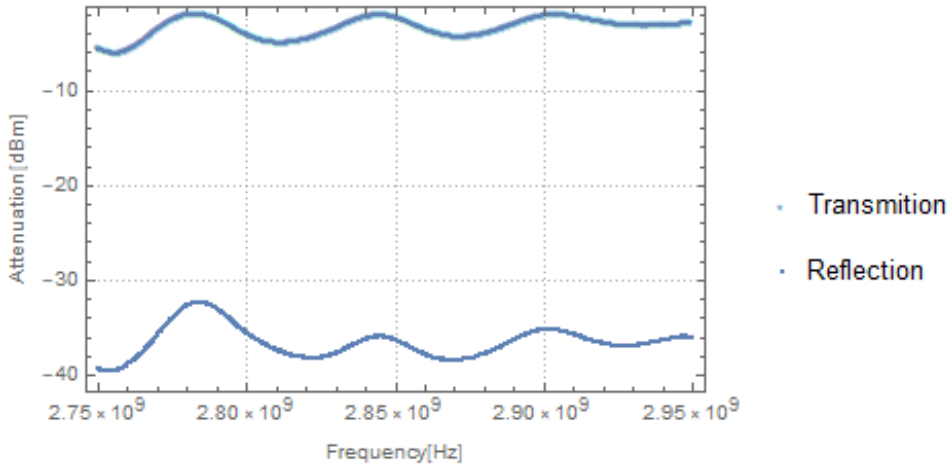


Figure 3: Ateniation of the resultant transmition (top) and reflectrion (bottom) at the Micristrip, at 0dBm in a 2.8GHZ frequency center.

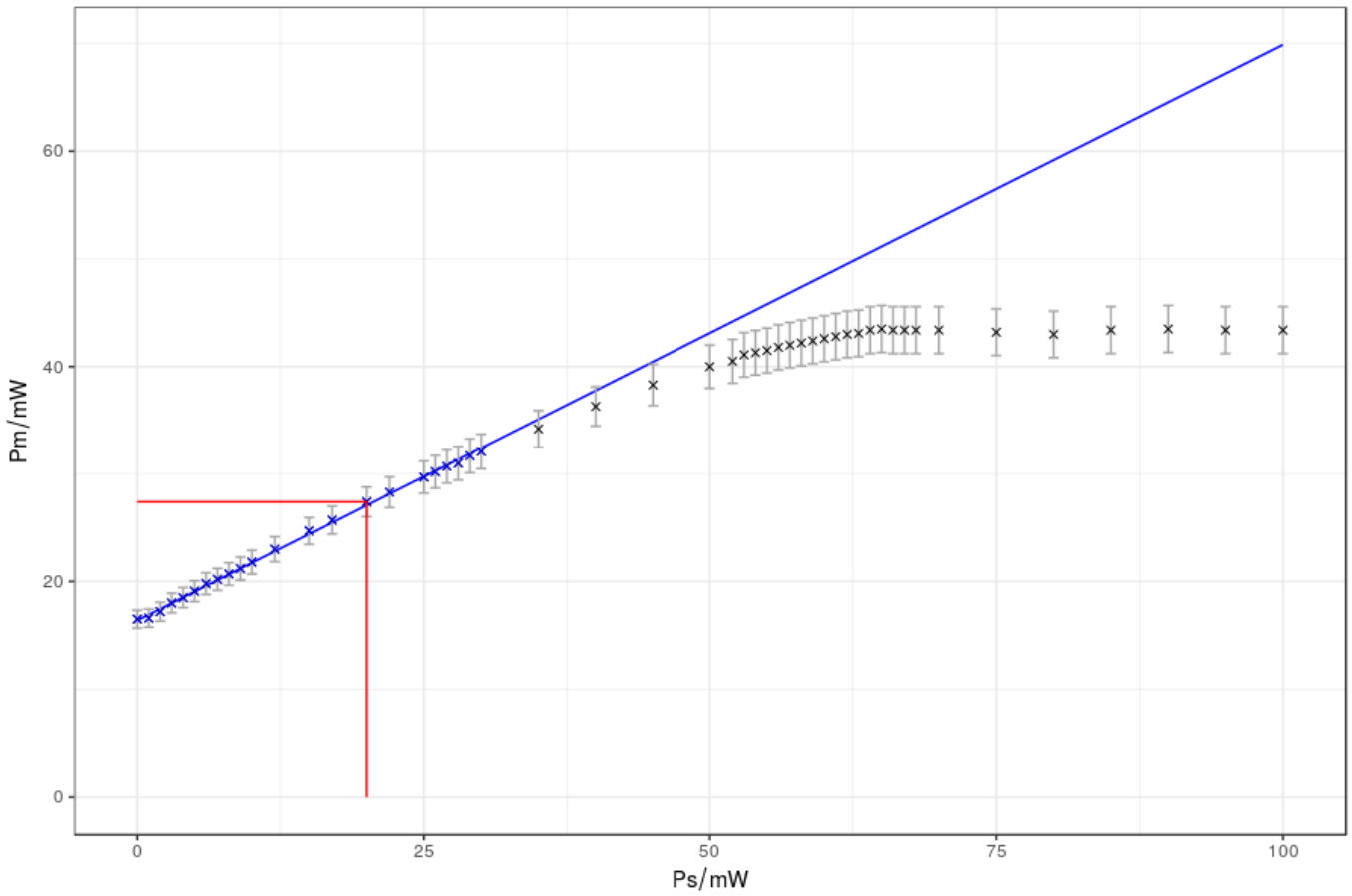


Figure 4: Measurement of the laser power

4 Evaluation

4.1 Calibration

4.1.1 Laser Power

4.1.2 Optical Spectrometer

4.1.3 ODMR calibrations

Shielding

Peak	Position	Element	Position [**fraunhoferlines**]	Difference
1	526.8 ± 1.7	Fe I	527.0	-0.2
2	590.0 ± 0.5	Na I	589.6	$+0.4$
3	628.9 ± 0.3	Fe I	630.3	-1.4
4	657.2 ± 0.3	H α	656.3	$+0.9$
5	688.6 ± 0.5			
6	763.5 ± 1.3			
7	824.7 ± 0.3			

Table 1: Positions of the Fraunhofer Lines compared to the literature values

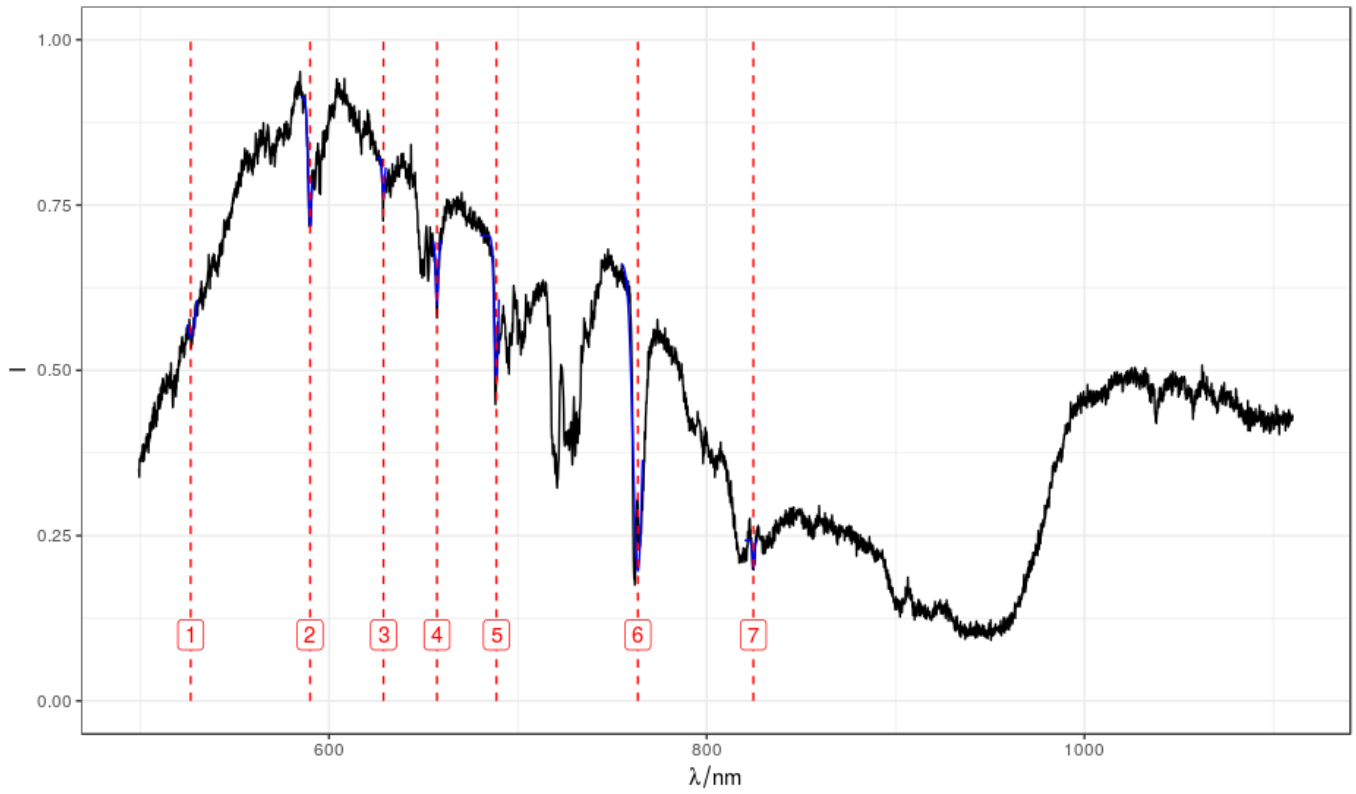


Figure 5: Spectrum of the sun with identified Fraunhofer lines for calibration of the optical spectrometer

Time-to-Frequency Conversion Performing ODMR measurements we achieve the ODMR spectra on the oscilloscope. Therefore the spectra are time-resolved. To gain frequency-resolved spectra we need to calculate the conversion factor from time to frequency. We do this by performing two sweeps with shifted centre frequencies which allows us to calculate the conversion factor and also the offset since we know the frequency at which the peak appears.
The conversion can be expressed by the following equation:

$$f(t) = \frac{f(t_1)(t_1 - t_2) - (f(t_1) - f(t_2))t_1}{t_1 - t_2} + \frac{f(t_1) - f(t_2)}{t_1 - t_2} \cdot t \tag{3}$$

Inserting the values achieved from figure 8 we get the following conversion function:

$$f(t) = (1.003 \pm 0.003)\,\frac{\text{GHz}}{\text{s}} \cdot t + (2.708 \pm 0.011)\,\text{GHz} \tag{4}$$

Later in this document all spectra are converted by this function and therefore shown in the frequency domain. The errors are gained from the fit and propagated using Gaussian error propagation.

4.2 Size of the Diamonds

4.3 Fluorescence Spectrum

4.4 ODMR Measurements

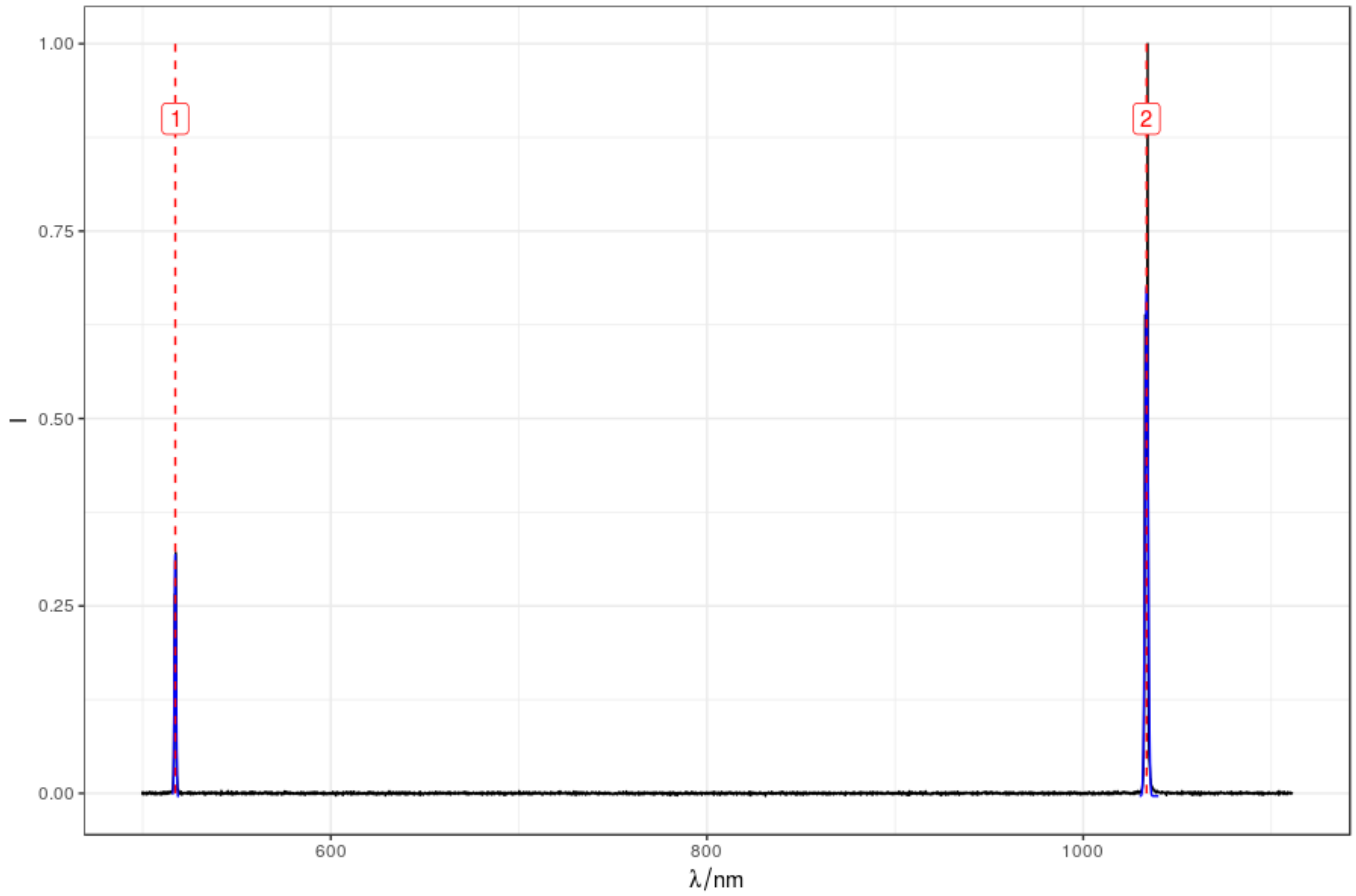
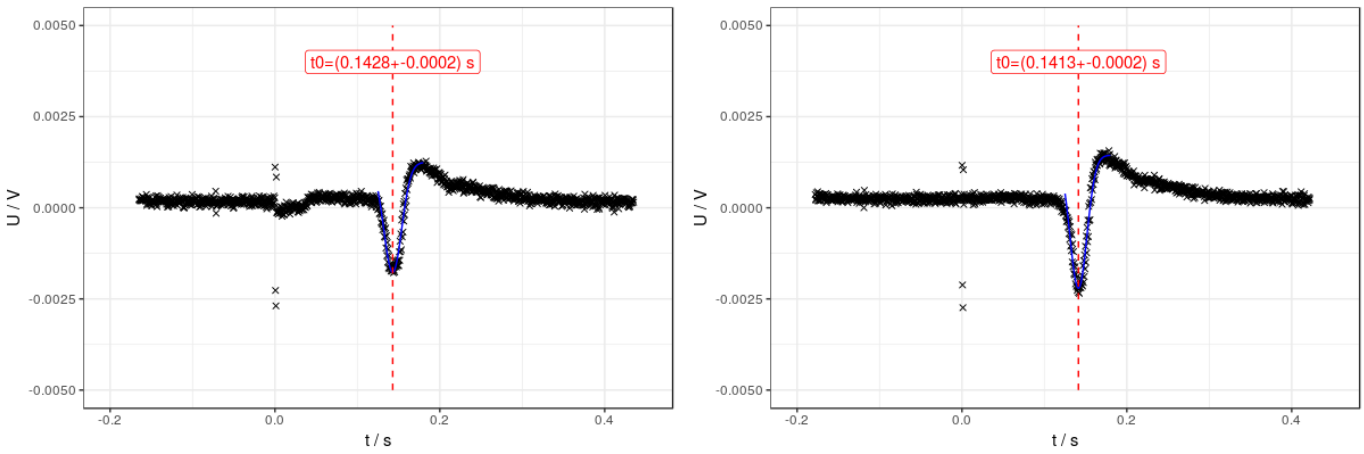
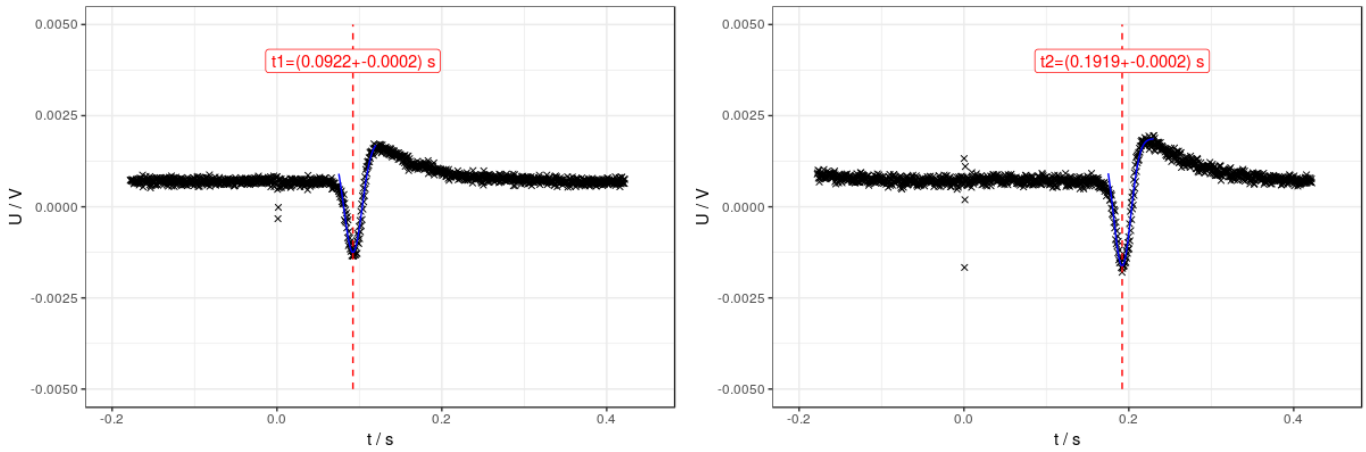


Figure 6: Spectrum of the laser with identified peaks at the wavelengths $\lambda = (517.3 \pm 0.2)\,\mathrm{nm}$ and $\lambda = (1033.7 \pm 0.4)\,\mathrm{nm}$



(a) without shielding **(b)** with shielding

Figure 7: ODMR spectrum



(a) shifted to the left **(b)** shifted to the right

Figure 8: ODMR spectrum for time-to-frequency calibration

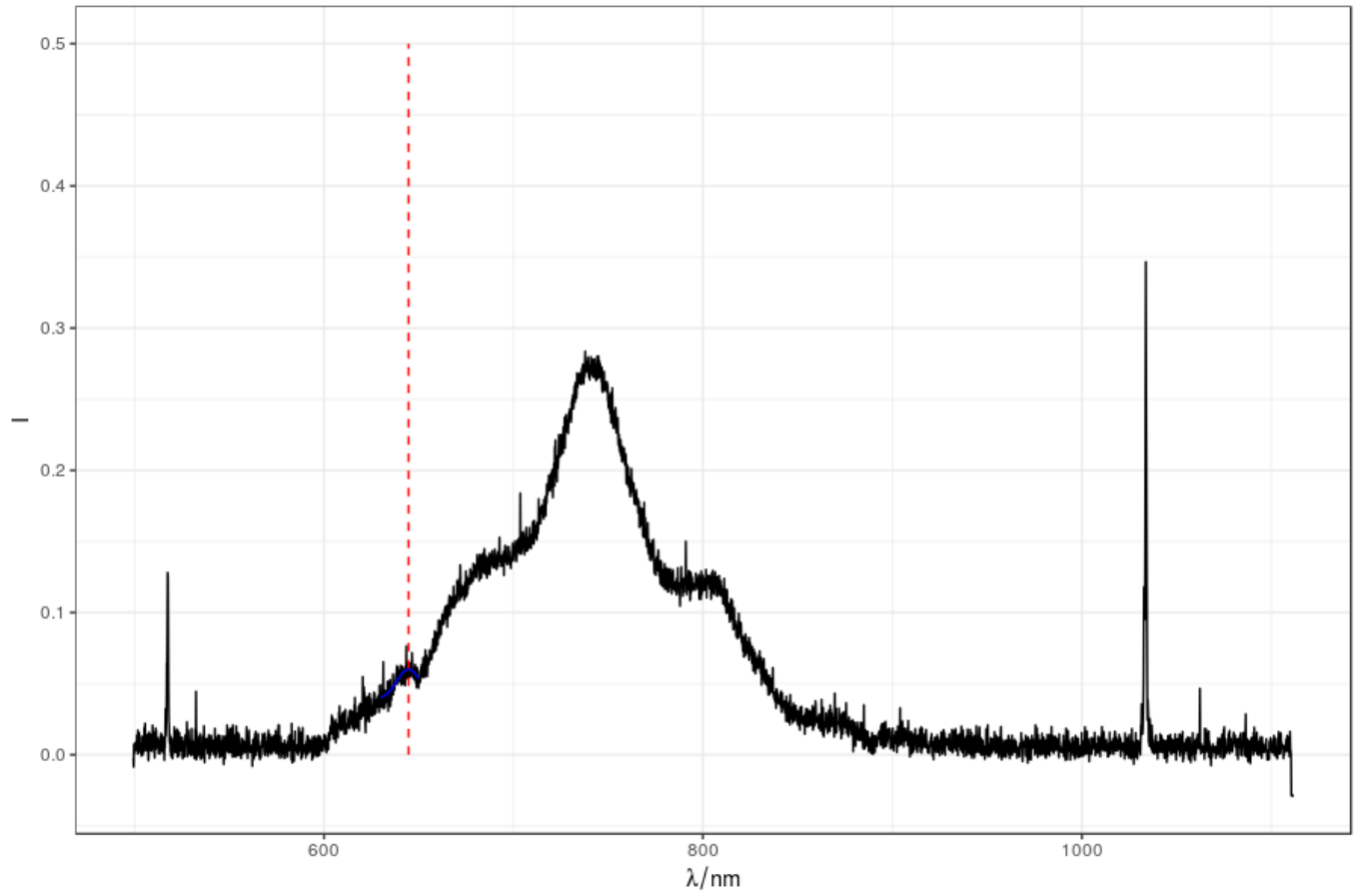


Figure 9: Fluorescence spectrum of the diamond with the zero phonon line (red line) at $\lambda = (645 \pm 3)\,\mathrm{nm}$. The spectrum was achieved by averaging over 10 measurements.

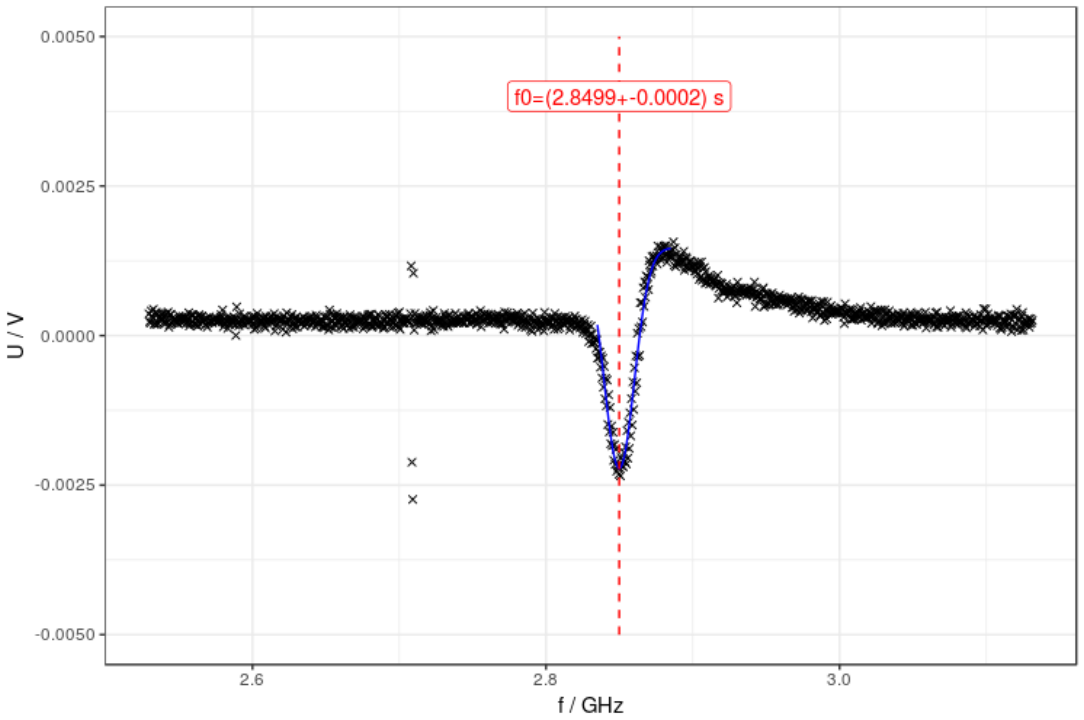
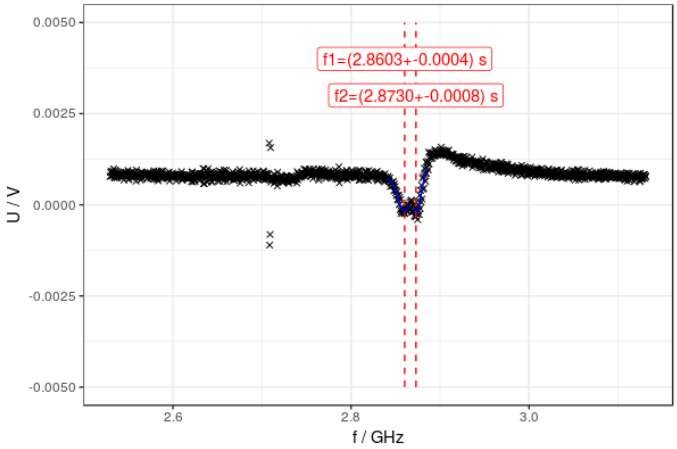
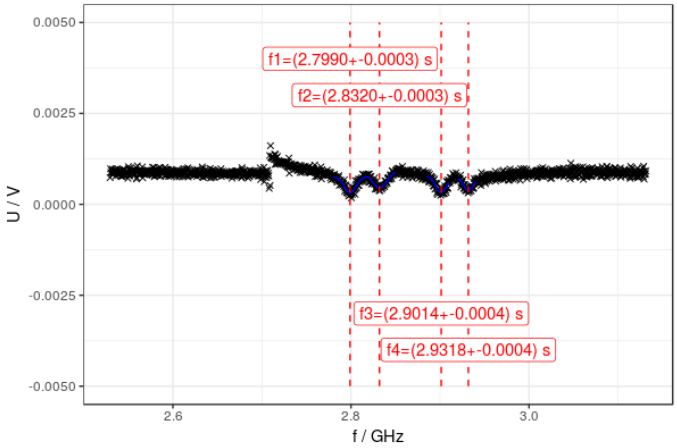


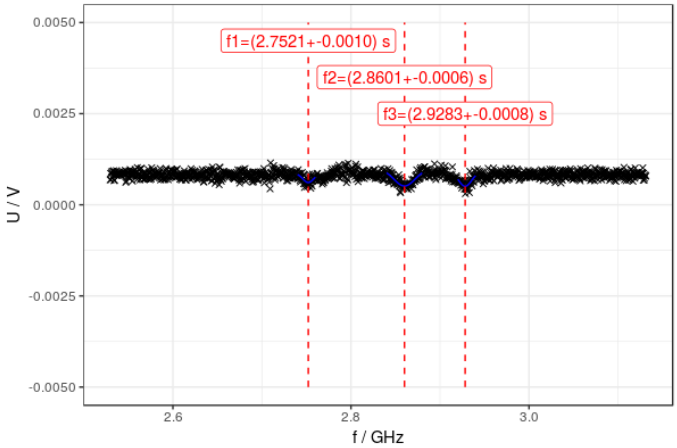
Figure 10: ODMR Measurement of the diamond without a magnetic Field



(a) Magnetic field in x-Direction



(b) Magnetic field in y-Direction



(c) Magnetic field in z-Direction

Figure 11: ODMR spectrum within a magnetic field

5 Summary and Discussion

6 Appendix

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