Fiber Integrated Nitrogen Vacancy Probes: Magnetic Gradiometry and Stimulated Fluorescence Quenching

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Nitrogen Vacancy Diamonds

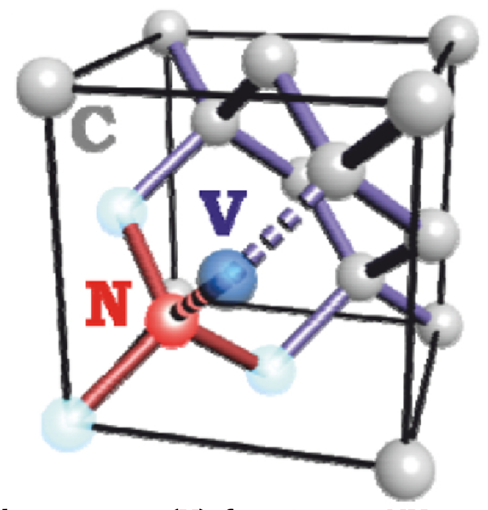

Figure 1: A nitrogen atom (N) and a vacancy (V) forming an NV center in a diamond lattice, consisting of carbon (C) atoms, note the four possible arrangements of the NV axes with respect to the diamond lattice.

Optically Detected Magnetic Resonance

The optically detected magnetic resonance (ODMR) technique is based on the nonradiative intersystem crossing of the singlet state (A_1). This decay occurs with a higher probability from the $m_s=|1|$ states. This results in a decrease in photo-fluorescent intensity from the $m_s=|1|$ states, therefore when we are on the microwave resonance we depopulate the $m_s=0$ state which is detected by a decrease in photo-fluorescence. This process allows us to detect magnetic resonances resulting from the energy level splitting due to the Zeeman effect.

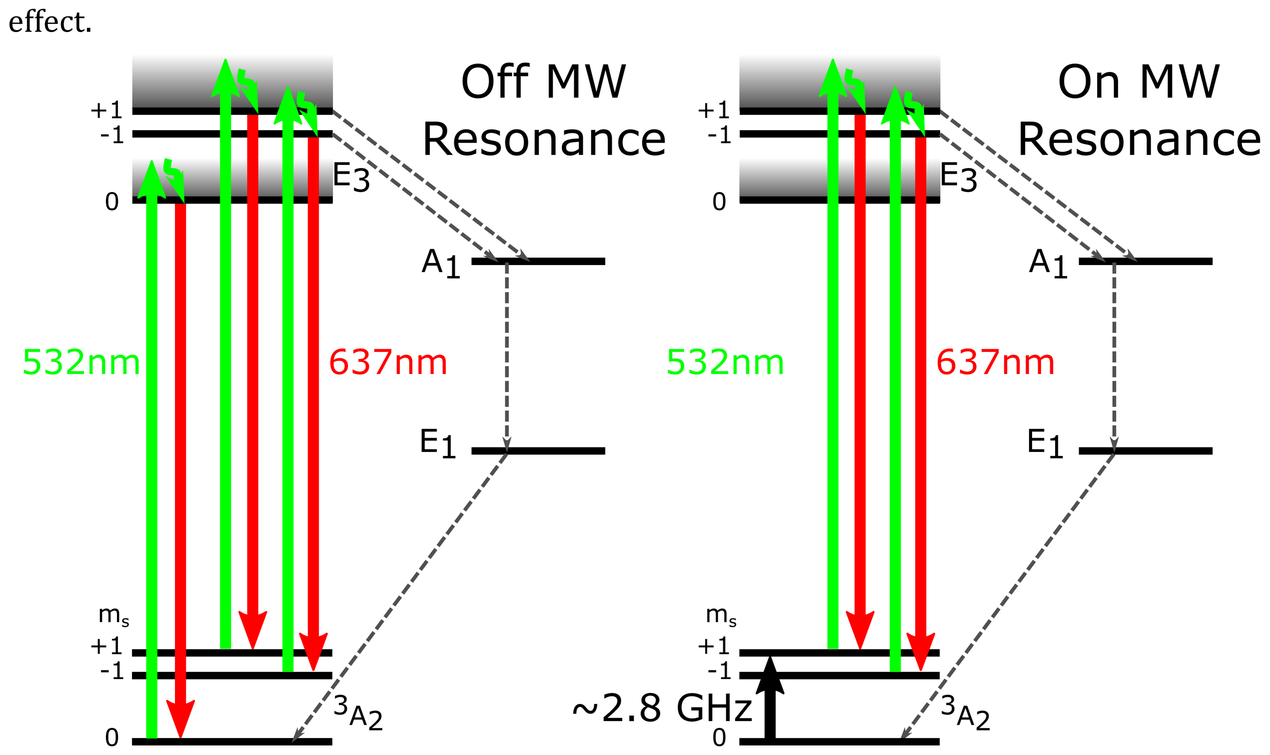

Figure 2: A visual representation of the NV$^-$ fluorescence both on and off microwave resonance.

Dual Core Magnetic Gradiometry

NV color centers in diamond have proven to be a robust solid-state quantum system. We leverage this unique system, which allows us to manipulate and polarize an electron spin at room temperature using optical radiation, to create a compact dual core fiber magnetic gradiometry probe. Magnetic gradiometry measurements have the advantage that they are insensitive to spatially uniform magnetic field backgrounds while still allowing high-spatial resolution measurements of variations in magnetic fields. Our previous work used two separate fibers to preform gradiometry measurements with a spatial resolution of 0.5 mm [1]. By integrating the two fibers into a single dual core photonic crystal fiber (see Figure 3) we have increased the spatial resolution of our gradiometry measurements to 4 microns

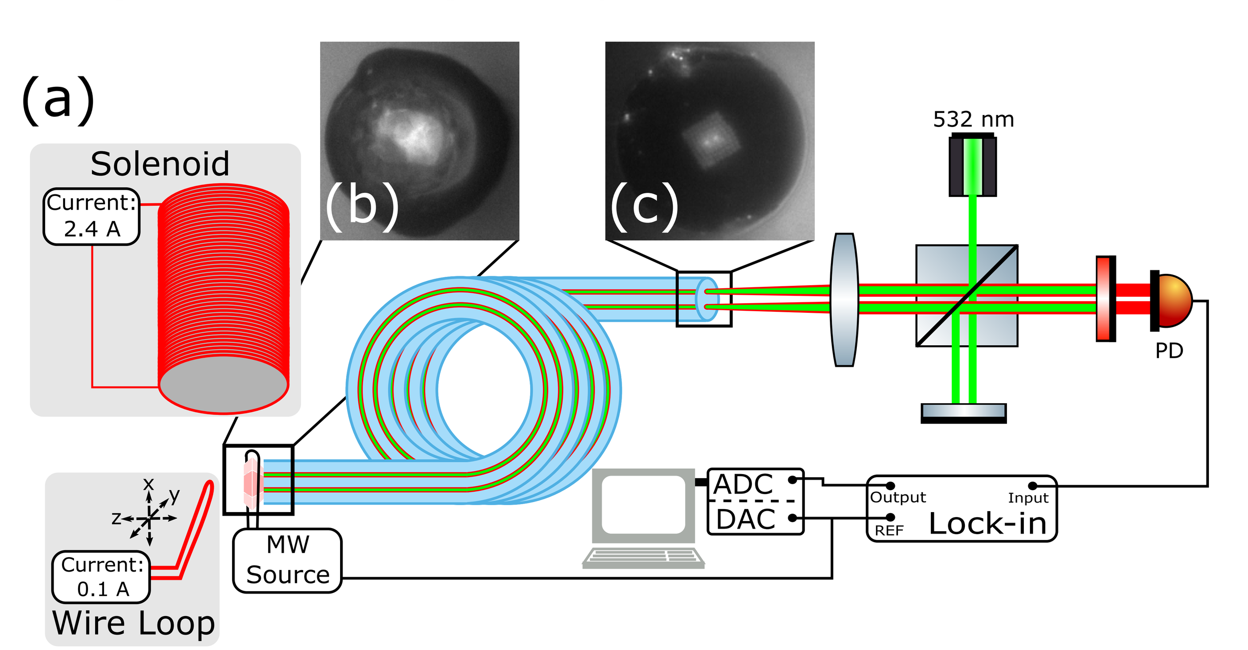

Figure 3:(a) A schematic of the dual core fiber gradiometry experiment. We used a beam splitter (BS) to split the ND:YAG 532 nm pump laser into each fiber core. The NV fluorescence was collected using the same fiber then isolated using a long-pass filter (F) and collected on a photodiode (PD). The optically detected magnetic resonance (ODMR) spectrum was measured using lock-in detection observed as dips in NV fluorescence collected at PD. (b) An impage of a NV diamond attached to the fiber end. (c) An image of the dual core photonic crystal fiber with 4 μm spacing between cores.

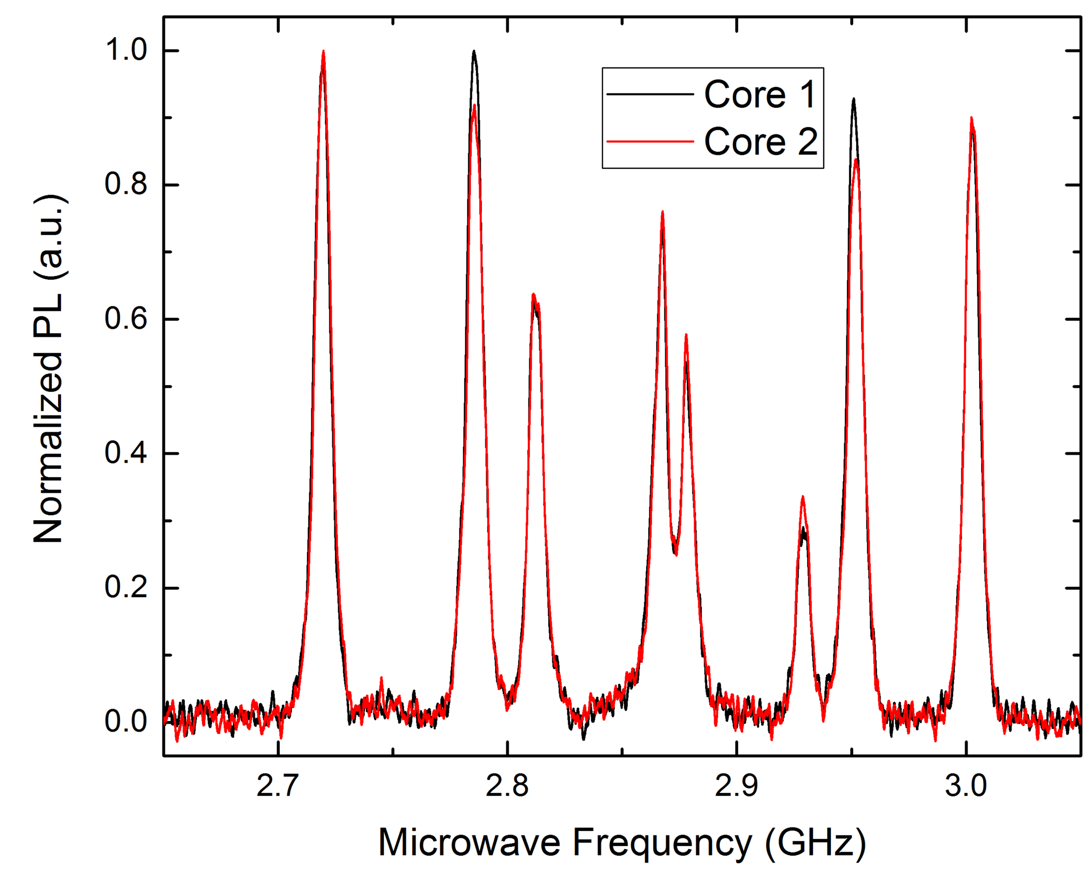

Figure 4: An example ODMR spectrum taken from each fiber core. Note the small shift in resonant peaks do to the spatial change in magnetic field between core 1 and 2. We resolve two resonant peaks for $m_s = \pm 1$ and each pair appears four times due to the four orientations within the diamond tetrahedral lattice. Resulting in the eight peaks shown.

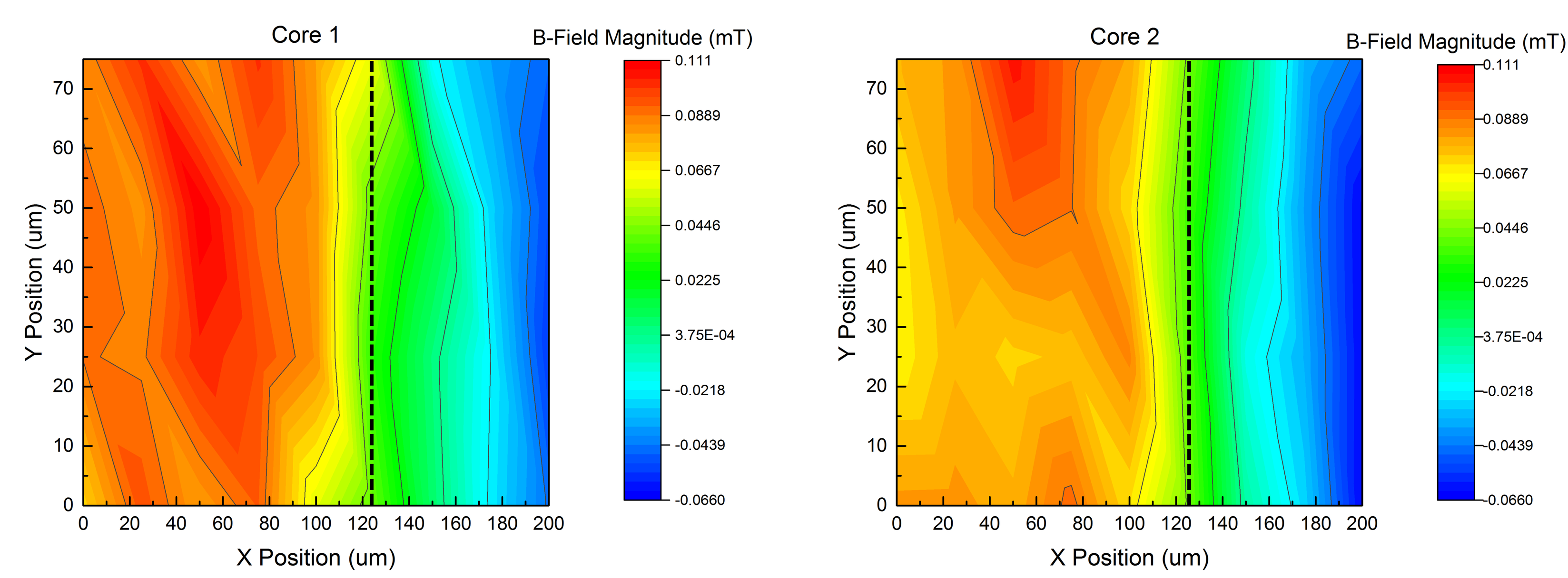

Figure 5: A magnetic field magnitude contour plot due to a current carrying wire. The magnetic field was measured using the multiple ODMR spectra taken at various locations in space around the wire. Note the black dashed line representing the location of the wire.

Stimulated Fluorescence Quenching

We also are reporting an observed stimulated fluorescence quenching seen in our system when we illuminate the NV diamond with infrared light [2]. We see that an increase in infrared power results in a shift is ODMR resonance (see Figure 7) and adecrease in ODMR photoluminescence (see Figure 8). This result can open a path toward a novel stimulated emission depletion (STED) regime for super-resolution microscopy.

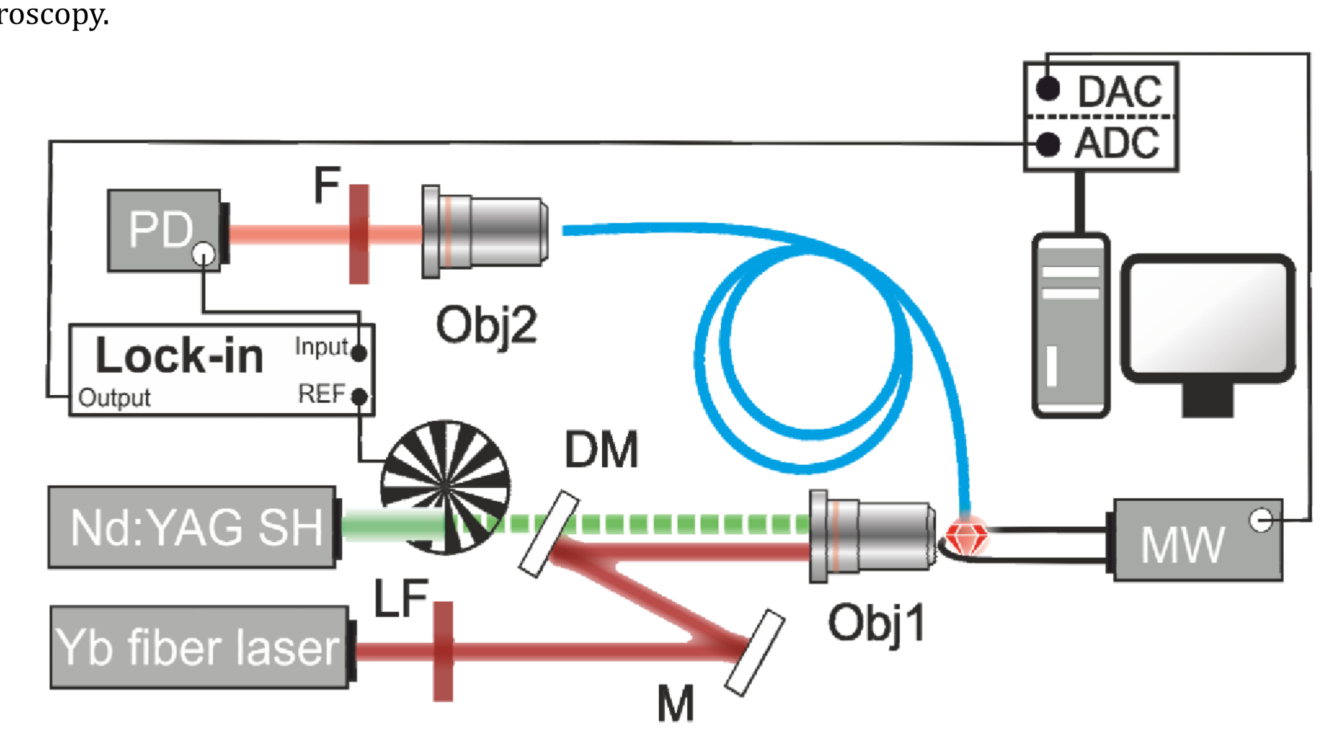

Figure 6: Experimental setup. Yb, picosecond ytterbium fiber laser; Nd:YAG SH, Nd:YAG laser with second-harmonic output; LF, long-pass filter; DM, dichroic mirror; MW, microwave oscillator; Obj1 and Obj2, microscope objectives; F, filter; Lock-in, lock-in amplifier; DAC, digital-to-analog converter; ADC, analog-to-digital converter; PD, photodetector.

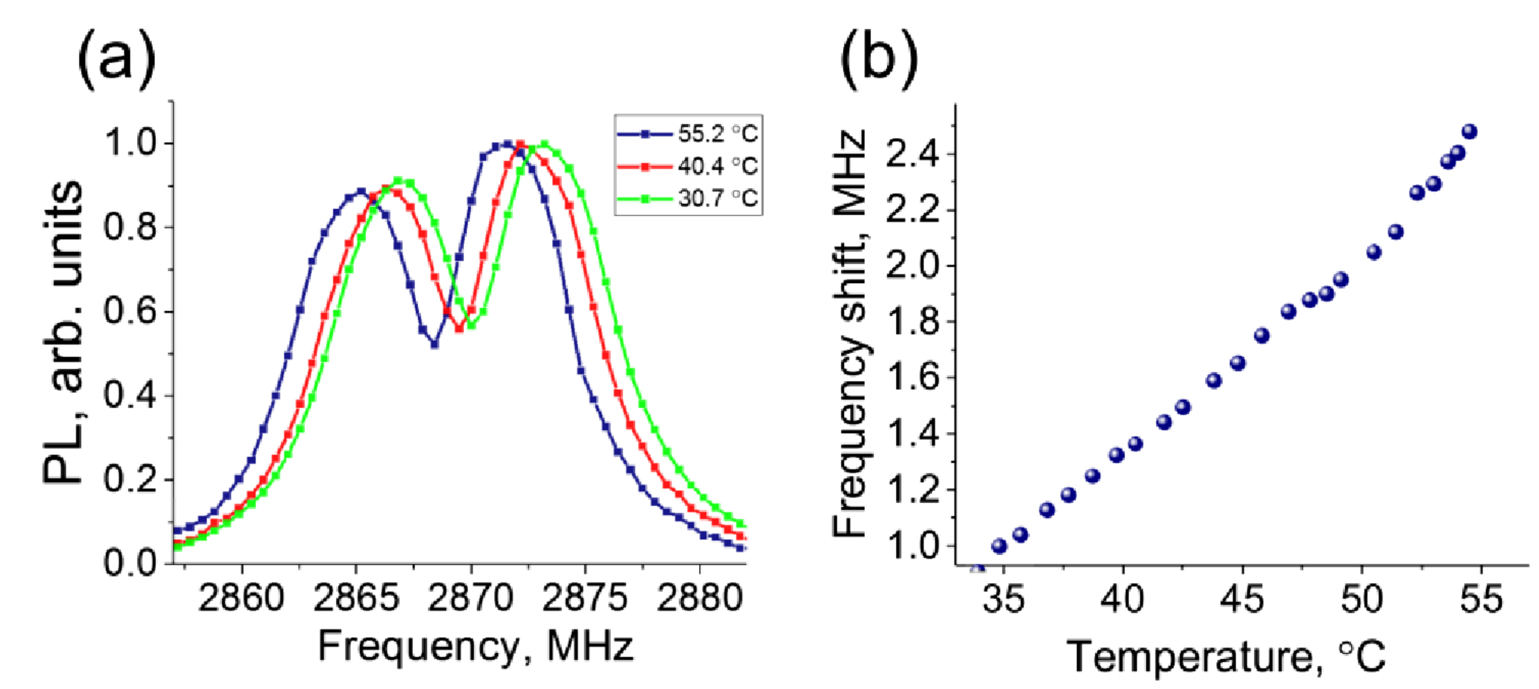

Figure 7: (a) ODMR spectra of NV$^-$ centers in diamond measured for different temperatures of the diamond crystal, as specified in the plot. (b) Modulus of the heating-induced shift of ODMR spectra as a function of the temperature measured by a thermocouple in a thermostat.

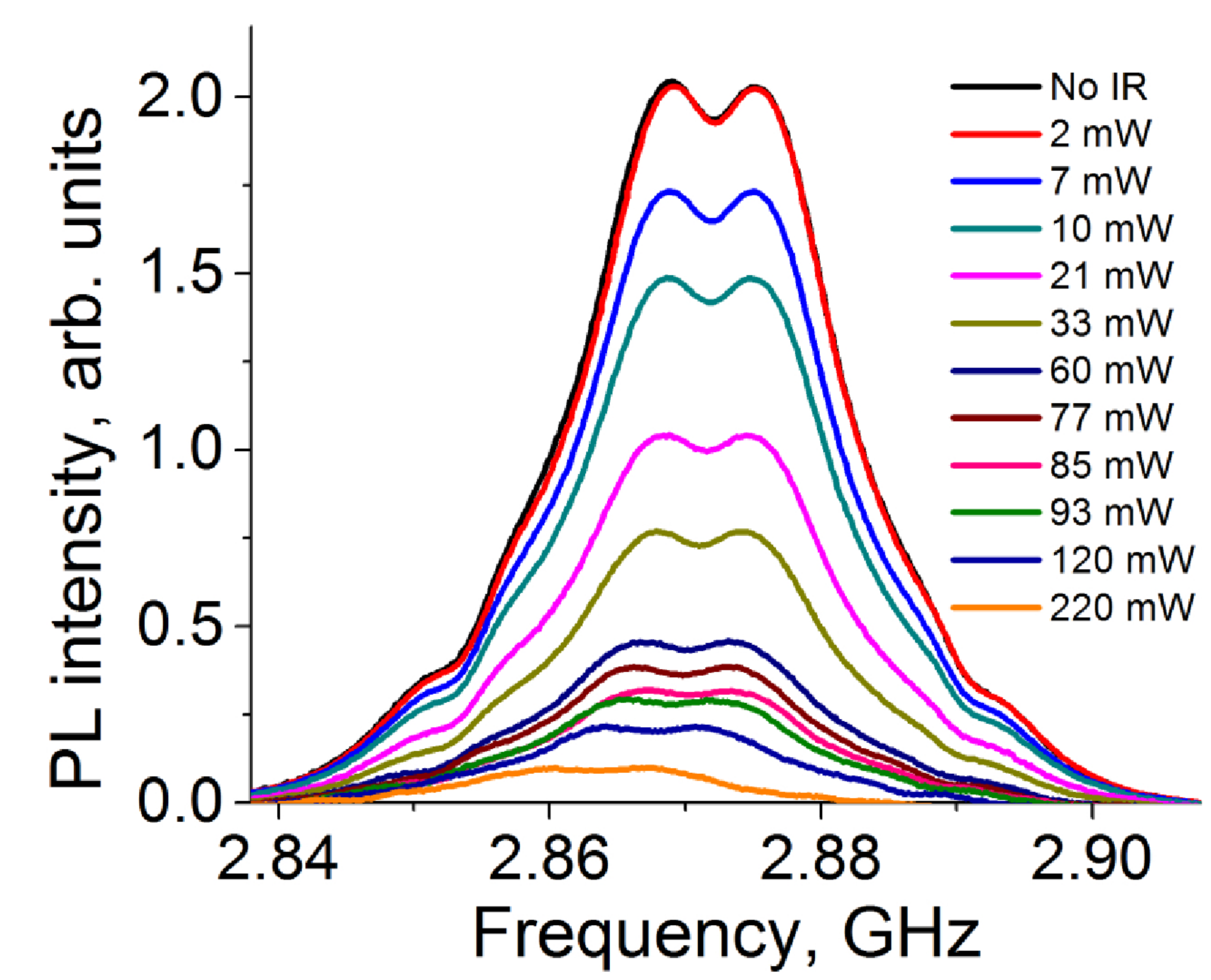

Figure 8: ODMR spectra measured for NV—NV— centers in diamond in the presence of the 532-nm pump and infrared-quenching radiation. The power of the visible pump is kept constant, while the power of infrared quenching radiation is increased from 2 to 220 mW, as specified in the plot. The black line shows the ODMR spectrum in the absence of quenching infrared radiation.

References

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[2] S. M. Blakley, A. B. Fedotov, J. Becker, N. Altangerel, I. V. Fedotov, P. Hemmer, M. O. Scully, and A. M. Zheltikov. Stimulated fluorescence quenching in nitrogenvacancy centers of diamond: temperature effects. Optics Letters, 41(9):2077, may 2016.

Acknowledgements

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