# QUANTUM IMAGING: OPTICALLY DETECTED MAGNETIC RESONANCE OF NANODIAMOND

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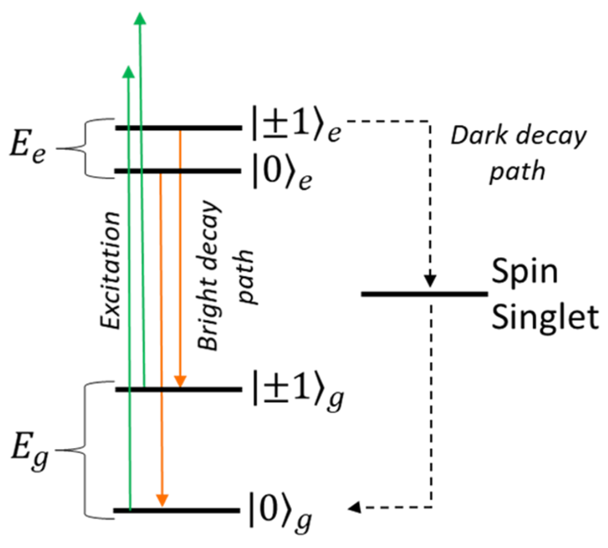
## INTRODUCTION

Optically Detected Magnetic Resonance (ODMR) imaging of fluorescent nanodiamond (FND) allows thermometry and magnetometry at a cellular level. It takes advantage of FND's biocompatibility and small size (between 5 and 100nm). Nitrogen-vacancy (NV) defects in the FND are optically excited at 532nm while applying a microwave field that is scanned around the resonant frequency of the triplet ground state of the NV (approximately 2.87GHz). There are two decay paths that offer differing emission intensities and that are coupled to the (microwave-controlled) spin state of the NV centre: By monitoring the change in fluorescence as a function of applied microwave frequency (the ODMR curve), the spin state of the NV centre can be inferred. Furthermore, this transition is both thermally and magnetically dependent; a magnetic shift sees a splitting of the detected response through the Zeeman effect and a thermal change sees a frequency shift that applies equally to all components of the curve.

There have been many implementations of ODMR-compatible imaging systems, however they typically use high-cost components in complex setups. We present here methods for ODMR using a low-cost sCMOS camera, in both wide-field epifluorescence and wide-field total internal reflection fluorescence (TIRF) microscopy. We will discuss the design of the microscope, the experimental scope of the system, a comparison to other experimental techniques already available and the benefits of a lower-cost system including its feasibility for further experimental applications.

## What is ODMR?

The nitrogen-vacancy (NV) defect, when illuminated by green light, is optically active, emitting near-infrared (~637-800nm) fluorescence [1]. The quantum spin system of the negatively charged NV centre is a triplet in the ground and excited states, optical transitions between these states are spin conserving. The emission intensity from the NV centre is spin dependent and this allows optically detected magnetic resonance (ODMR) to be performed with NV defects. Using the application of a variable frequency microwave field scanning around 2.87GHz (the resonant frequency of the |0> to |±1> spin ground state of the NV- defect), the spin state of the defect can be observed via the fluorescence intensity from the defect.

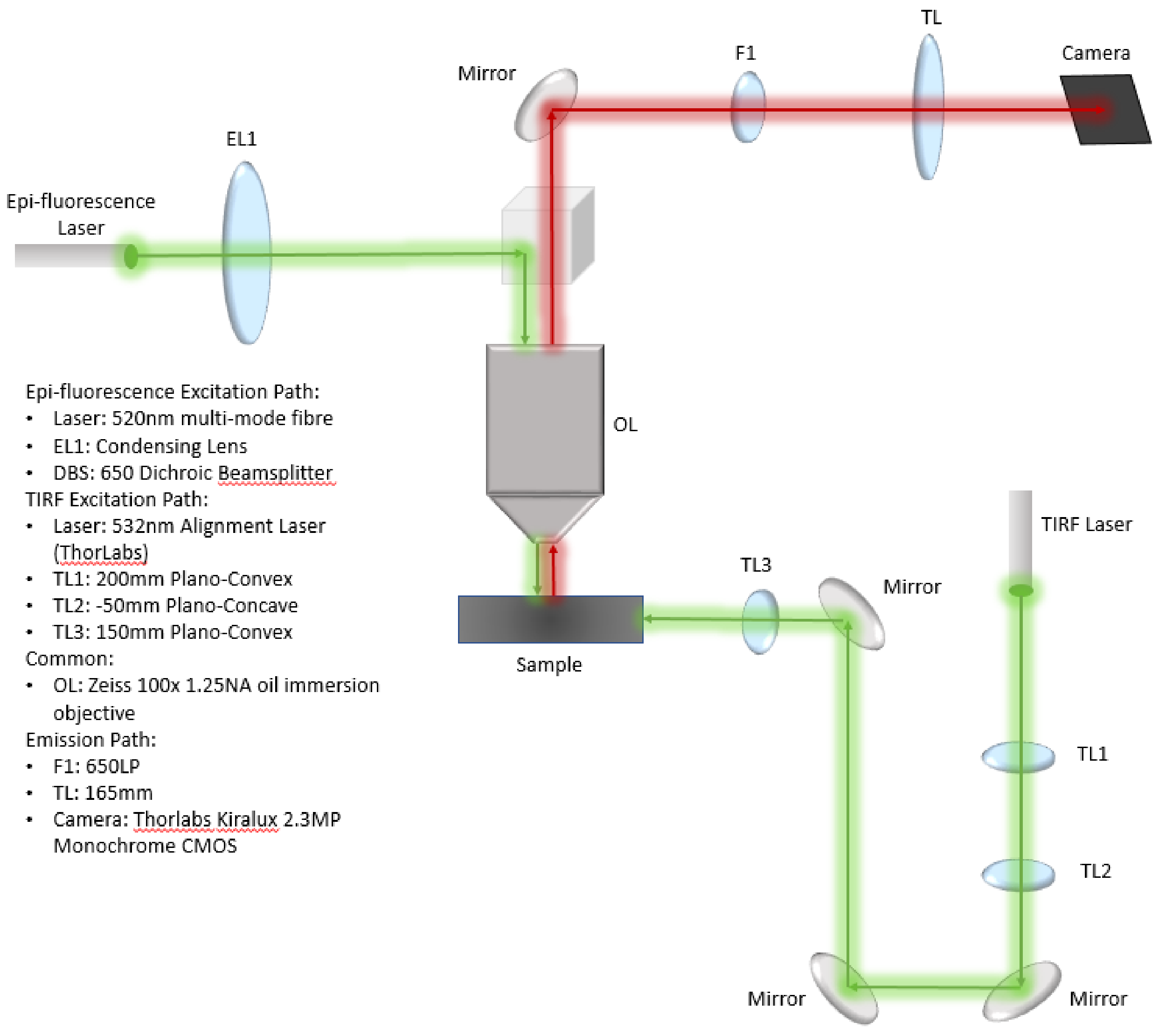


The energy levels of the NV centre allow for easy spin-initialisation of the system: after approximately 1 microsecond of green illumination it will be in the |0> state. At this point, microwave illumination can be applied and, if resonant, will drive the spin to the |±1> ground state, proportional to the microwave pulse area and resonance overlap. As the |±1> state emits fewer photons than the |0> state, this results in a dip in emission intensity when the microwaves are resonant to the spin stat transition.

To quantify the resonancy frequency and observed contrast, we fit the ODMR curves to a double Lorentzian—the data on this poster refer to this fit when giving $r^2$ and contrast values.

Monitoring the frequency where these spin state transitions occur can indicate the strength of an applied magnetic field or a relative change in temperature [2]. Here, we are developing a cheap and efficient method for research-quality characterisation of NV. This will allow us to easily assess the quality of nanodiamond (ND) samples for use in bio imaging experiments.

## Microscope



Epi-fluorescence Excitation Path:
- Laser: 520nm multi-mode fibre
- EL1: Condensing Lens
- DBS: 650 Dichroic Beamsplitter

TIRF Excitation Path:
- Laser: 532nm Alignment Laser (ThorLabs)
- TL1: 200mm Plano-Convex
- TL2: -50mm Plano-Concave
- TL3: 150mm Plano-Convex

Common:
- OL: Zeiss 100x 1.25NA oil immersion objective

Emission Path:
- F1: 650LP
- TL: 165mm
- Camera: Thorlabs Kiralux 2.3MP Monochrome CMOS

## Conclusions

We demonstrate the construction of a system that aims to obtain ODMR measurements in two different excitation regimes. Importantly, we show that even a simple system is capable of capturing the spin state splitting present in ND under an applied magnetic field. A comparison of whole field of view vs small ROI imaging has been presented showing the merits of small ROI sampling where possible but also showing that widefield ODMR is possible with an adequate SNR to definitively determine the contrast.

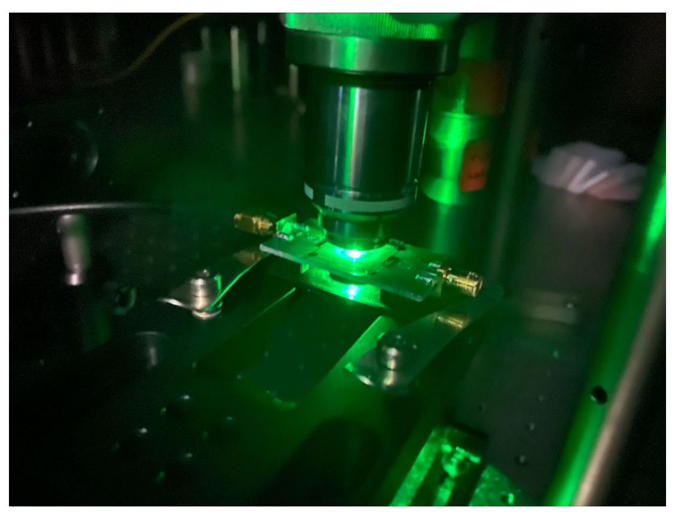
## Future Work

Microscope: addition of a AOM for pulsed measurements, applying a higher powered laser in TIRF to improve SNR to enable ODMR.

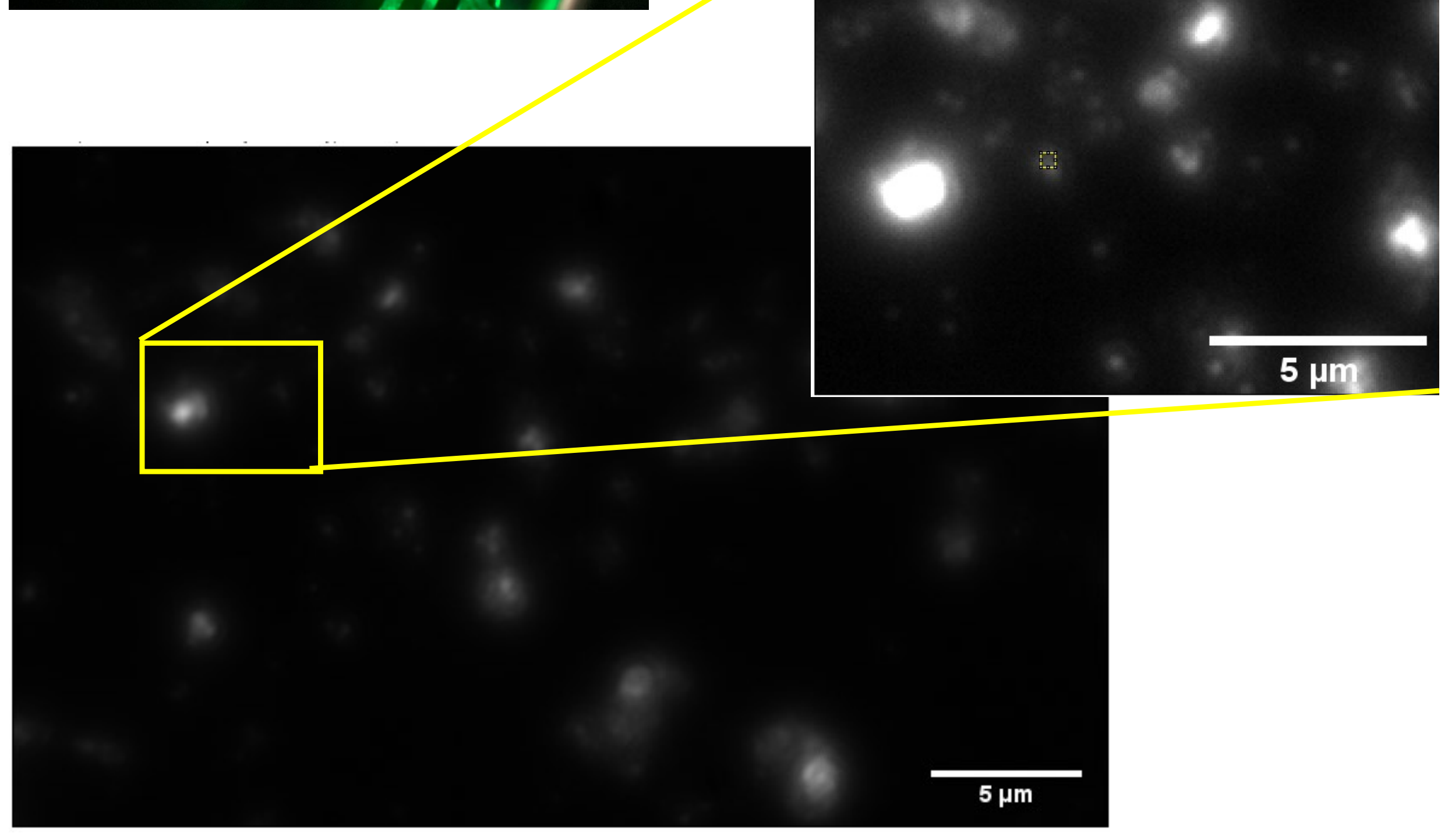
Measurements: pulsed ODMR measurements to observe Rabi Oscillations, ODMR measurements and characterisation in TIRF.

Samples: ND preparation by utilising a nebuliser to make more sparse ND samples, looking towards c. elegans imaging with ND.

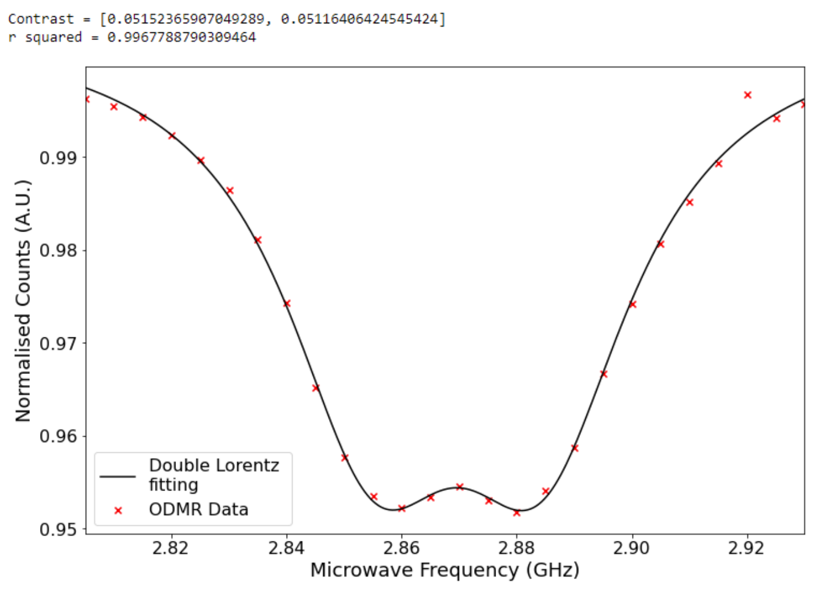
## ODMR in Wide-field Epifluorescence



Top left: ODMR sample on microscope with incident laser, ND between two coverslips with copper wire delivering microwaves along PCB.



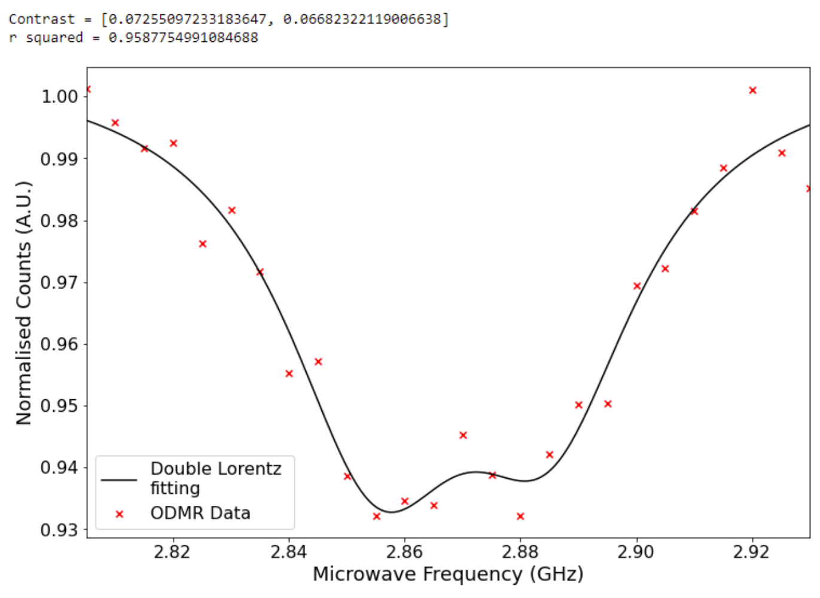
Above: (a) entire field of view of a 90nm ND sample, (b) a contrast-enhanced subsection showing the region of interest taken for the ROI analysis (shown right).



```
Contrast = [0.05152365907049289, 0.05116406424545424]
r squared = 0.9967788790309464
```

Above: Normalized ODMR scan across entire field of view. Contrast 5.1% with $r^2$ value 99%.

Below: Normalized ODMR scan 3x3 pixel ROI (shown left). Contrast 5.1% with $r^2$ value 99%.



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Contrast = [0.07255097233183647, 0.06682322119006638]
r squared = 0.9587754991084688
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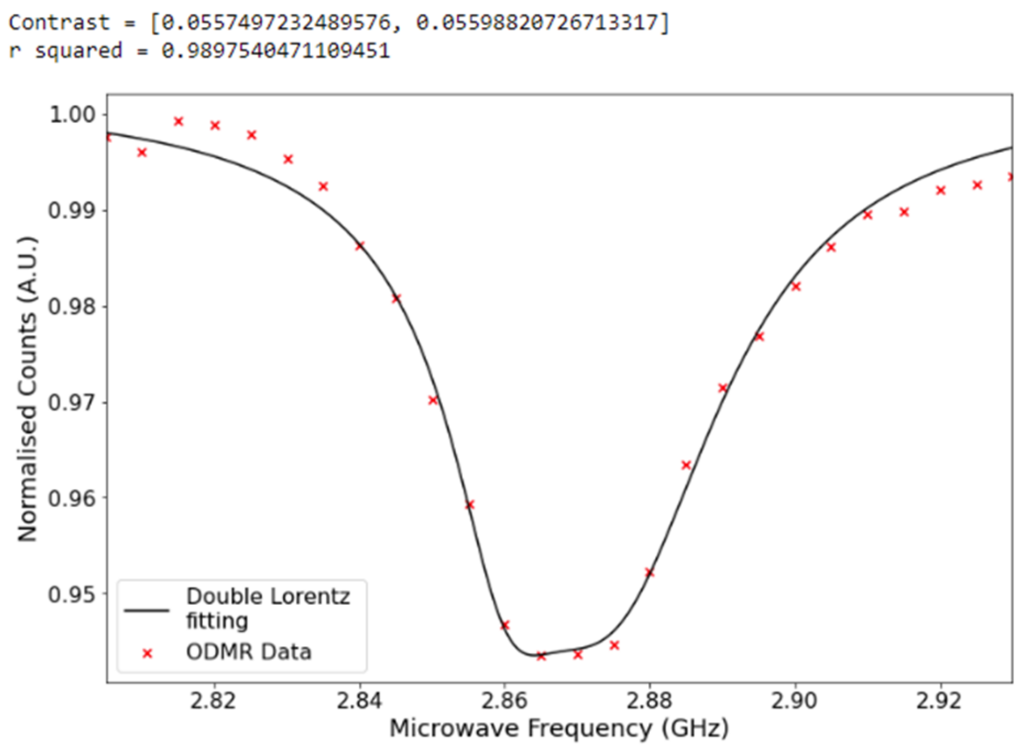
## ODMR in Wide-field Epiflourescence with Magnetometry



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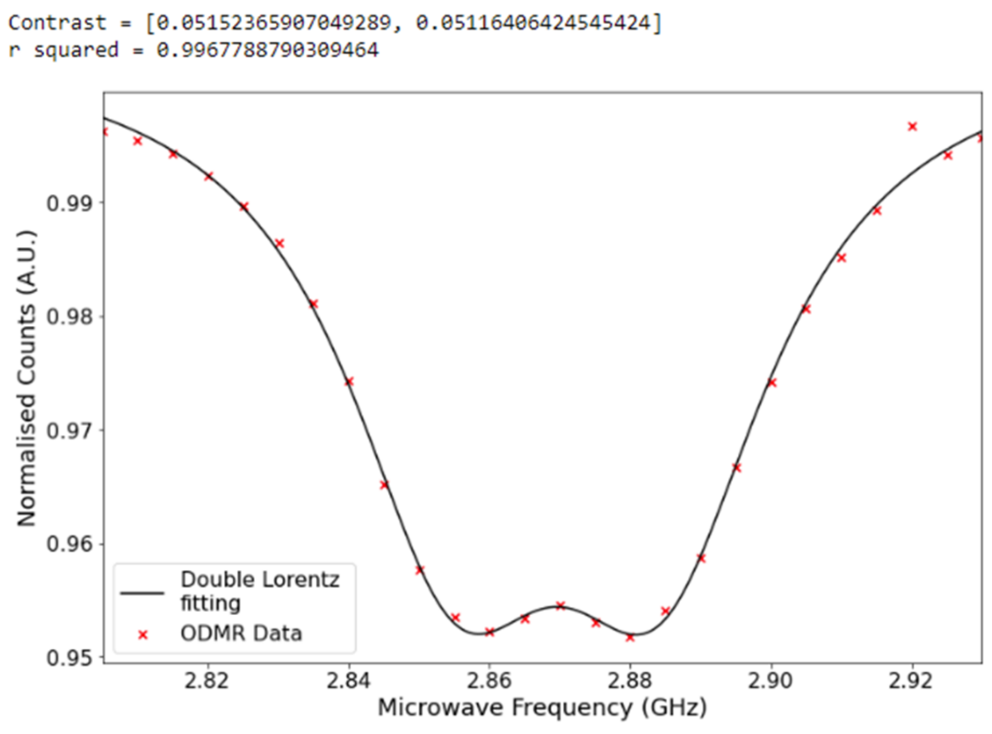
Contrast = [0.0557497232489576, 0.05598820726713317]
r squared = 0.9897540471109451
```

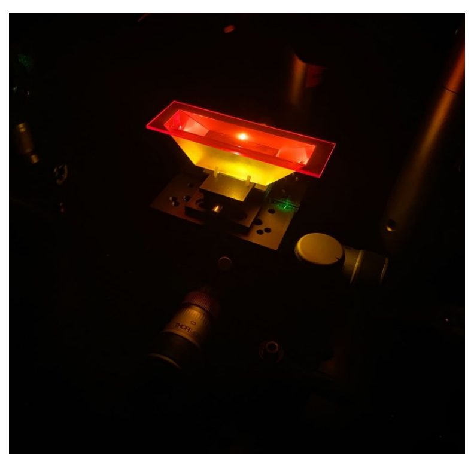


```
Contrast = [0.05152365907049289, 0.05116406424545424]
r squared = 0.9967788790309464
```

Above left: ODMR scan with no magnet field applied, no splitting present. Contrast = 5.6%; $r^2$ = 98%.

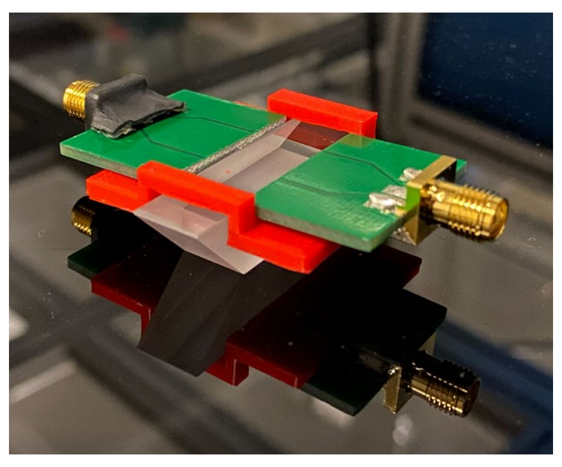
Above left: ODMR scan with magnetic field applied (neodymium magnet), splitting present. Contrast = 5.2%; $r^2$ = 99%.

## TIRF

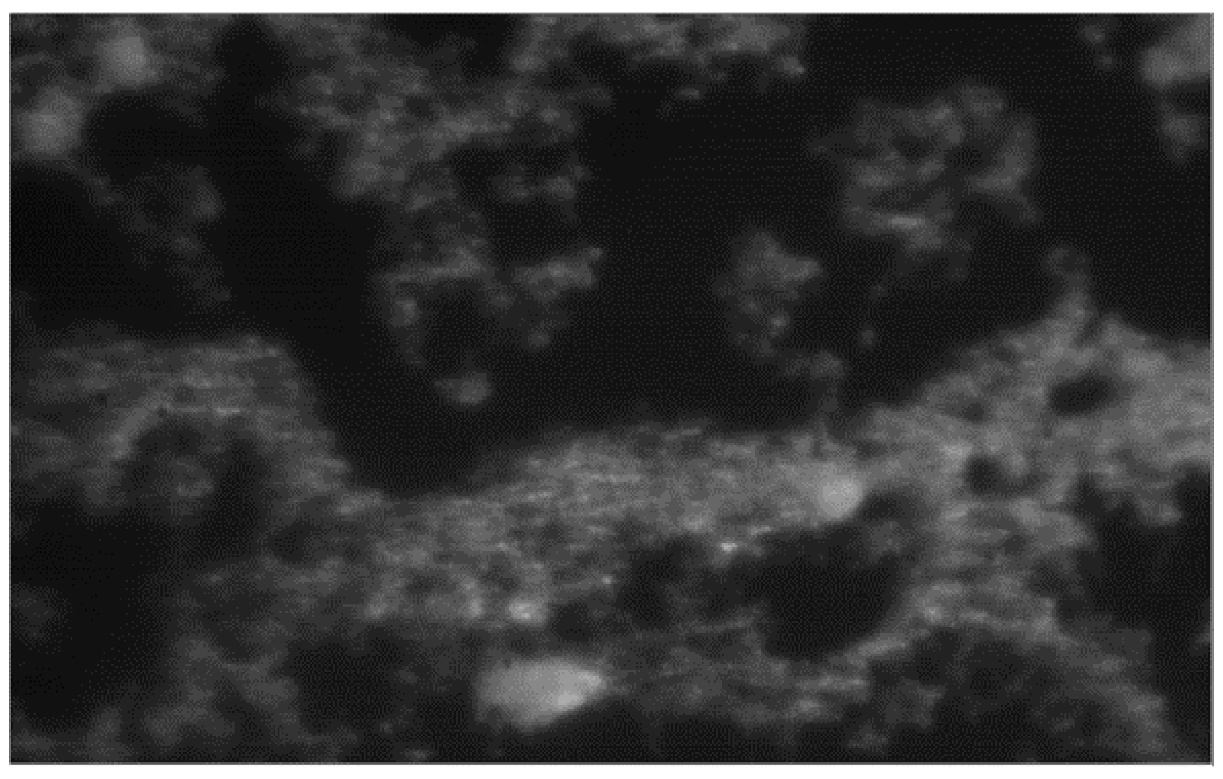


Left top: alignment protocol using a chromablock slide that allows the user to see the illumination spot easily and safely for coarse aligning.

Left centre: prism preparation for nanodiamond imaging with adhering to prism. Consists of two coverslips (ND mount on the top) which are sealed and mounted on oil to the prism.



Left bottom: ND are mounted for ODMR measurements. A bridge is 3D printed to allow both sides of a PCB board to sit either side, a copper wire runs through a sample and is connected at either side of the PCB board.



Above: widefield image of 90nm ND in TIRF

References:

[1] L. Rodin *et al.* 2014 *Rep. Prog. Phys.* **77** 056503

[2] Y. Nishimura *et al.* 2021 *Nature Sci. Rep.* **11** 4248

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