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SUPERRESOLUTION MICROSCOPY REACHES 14 NM

High Resolution Imaging for Imaging Proteins and Quantum Information Processing

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Introduction

The past decade has seen a growing interest in nitrogen vacancy colour centres (NV-centres) in diamond as prominent candidates for solid state quantum bits, single photon sources and even ultra-sensitive magnetic sensors. These NV centres can be described by a three level energy scheme (Figure 1) made up of a spin 1 ground state 3A, a spin 1 excited state 3E and a meta stable singlet state 1A. The energy separation between the ground and excited states allows NV to be optically excited with 532 nm light and produces strong fluorescence from 637 nm to 800 nm.

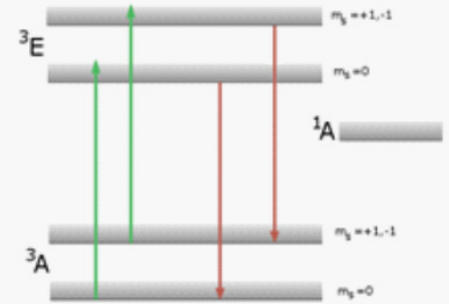

Figure 1: Energy level diagram showing vibrational states probed by Raman spectroscopy

The bright fluorescence allows NV centres to be imaged with the resolution of confocal microscopy which is limited by the Abbe criterion to:

$$d=1.22*l/\ 2n \sin a$$

and a standard confocal image can be obtained (Figure 2.)

But for certain applications it is necessary to find NV centers paired up within a few nanometers and conventional microscopic techniques simply cannot achieve the necessary resolution.

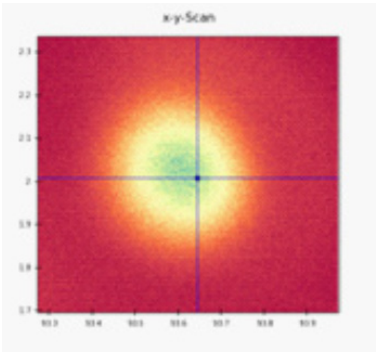

Figure 2: A normal confocal fluorescence spot from a standard microscope

Ground State Depletion of NV Colour Centres

One way to overcome the diffraction limit with a far field optical microscope is by exploiting nonlinear imaging like Ground State Depletion (GSD) to generate superresolution images.

Instead of applying a Gaussian beam as the excitation source, the excitation beam is first directed through a vortex phase plate generating a donut profile with an intensity minimum in the centre of the beam. By scanning this donut profile over the sample, the NV centre is transiently switched off from fluorescence (Figure 1). A GSD optical arrangement from the University of Ulm is shown in figure 3 below using a Gem 532nm laser from Laser Quantum Ltd as the excitation source.

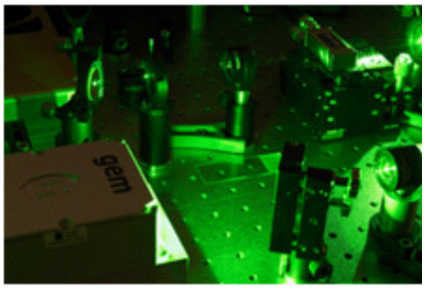

Figure 3: Detail of the GSD layout using Novanta's Laser Quantum gem 532 laser

More precisely, the NV centre is depleted if it is in the high intensity edge regions of the vortex but remains dark if it is in the dark centre region of the profile. Since NV centres show saturation in fluorescence, this dark region can be narrowed down by increasing the laser power.

Crucially, this fluorescence saturation means the resolution is no longer limited by the diffraction of light, but only by the applied laser power and donut imperfections (remaining intensity in the donut minimum).

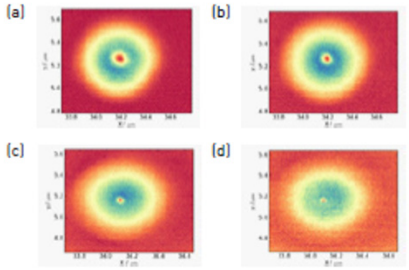

Figure 4: Pictures of a NV centre with Ground State Depletion (a) 8,3 mW (b) 17,3 mW (c) 38 mW (d) 85 mW of 532nm laser

The centre itself (see figure 4) is resolved as a dark spot (red colour) in the middle of the diffraction limited spot (blue colour) of the standard confocal spot. The size of the dark spot scales inversely with the applied laser power where d is the dimension of the spot, the λ corresponding wavelength, ζ a measure for the steepness of the donut minimum, n the diffraction index of the immersion fluid, I_s the saturation laser power of the NV centre, Imax the laser power in the peak of the donut profile and the $\mathcal{E}$ laser power in the centre of the donut.

$$\Delta d \approx \frac{\lambda}{\zeta \pi n} \sqrt{\frac{I_S}{I_{max}} + \varepsilon}$$

GSD applied to a stable single photon source like NV centres allows for very high resolution imaging. In this case, we reached a resolution of 14 nm (FWHM) as shown in Figure 5. Such high resolution imaging is important in biology for imaging proteins attached to nano-diamonds and in quantum information processing for finding close NV centres that are suitable as coupled quantum systems.

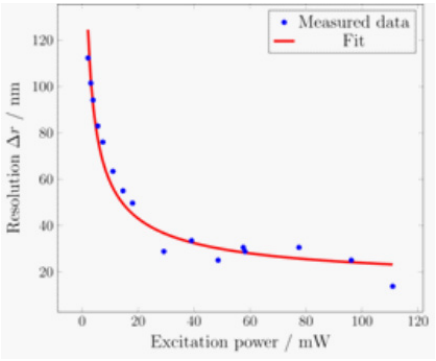

Figure 5: Measured resolution for different laser powers. The data was fitted to the above function

Novanta Benefits

Novanta is uniquely positioned to solve even the most complex challenges for OEMs, system integrators, and end-use customers seeking to advance their manufacturing processes with high precision laser systems. With some of the most well-known brands in the industry and in-country application and service support, Novanta delivers reliable, precise, and durable components and sub-systems.

Our Applications Testing Labs offer application and proof-of-concept testing to OEMs, system integrators, material manufacturers, processors, and end-users of automated machinery. Novanta Application Engineers are laser processing experts, and understand the parameters that will ensure successful, efficient laser processing. Using laser and beam steering equipment from well-known Novanta brands, our Application Engineers will determine the key product parameters and processing know-how to achieve the desired results.

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