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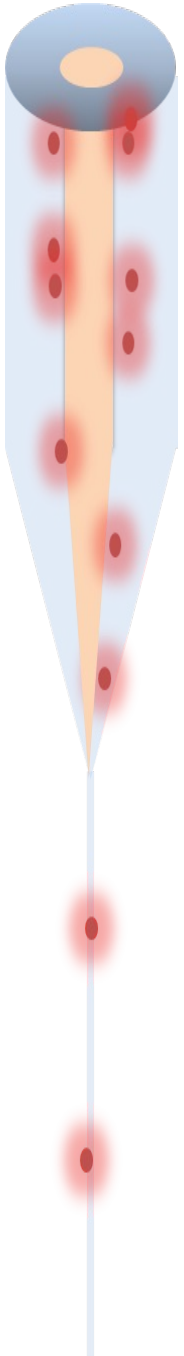

Diamond-doped Optical Fibres for Remote Magnetometry Applications

Marco Capelli[1], Dongbi Bai[1], Hoa Huynh[2], Shuo Li[1], Wenqi Zhang[3], Philipp Reineck[1], David A. Simpson[4], Shahraam Afshar.V[3], Andrew D. Greentree[1], Scott Foster[5], Heike Ebendorff-Heidepriem[2], and Brant C. Gibson[1]

[1]RMIT University, [2]University of Adelaide, [3]University of South Australia, [4]University of Melbourne, [5]Defence Science and Technology Group

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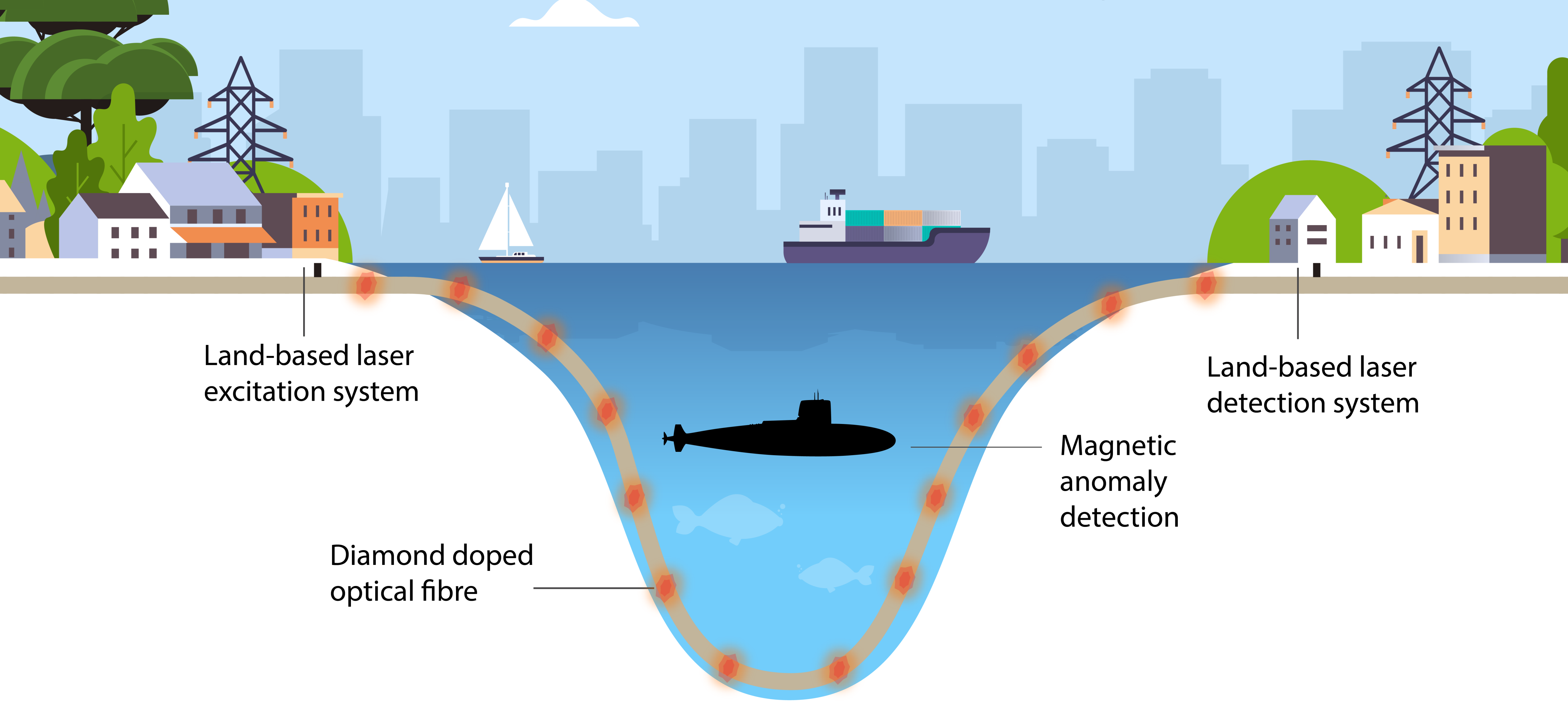
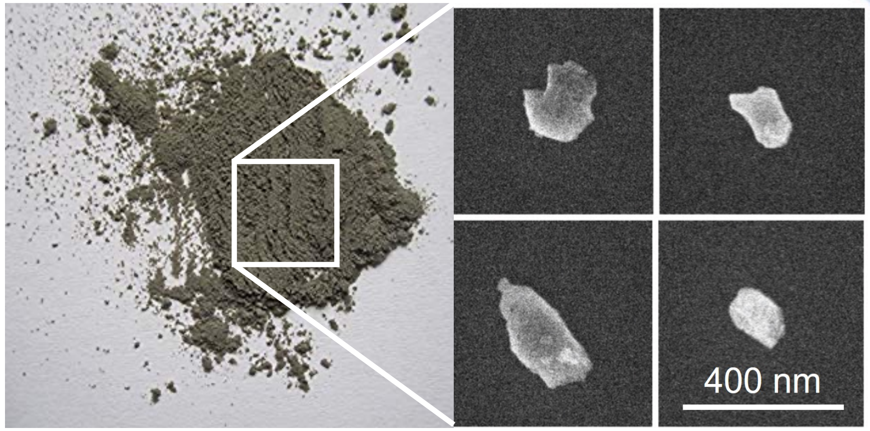
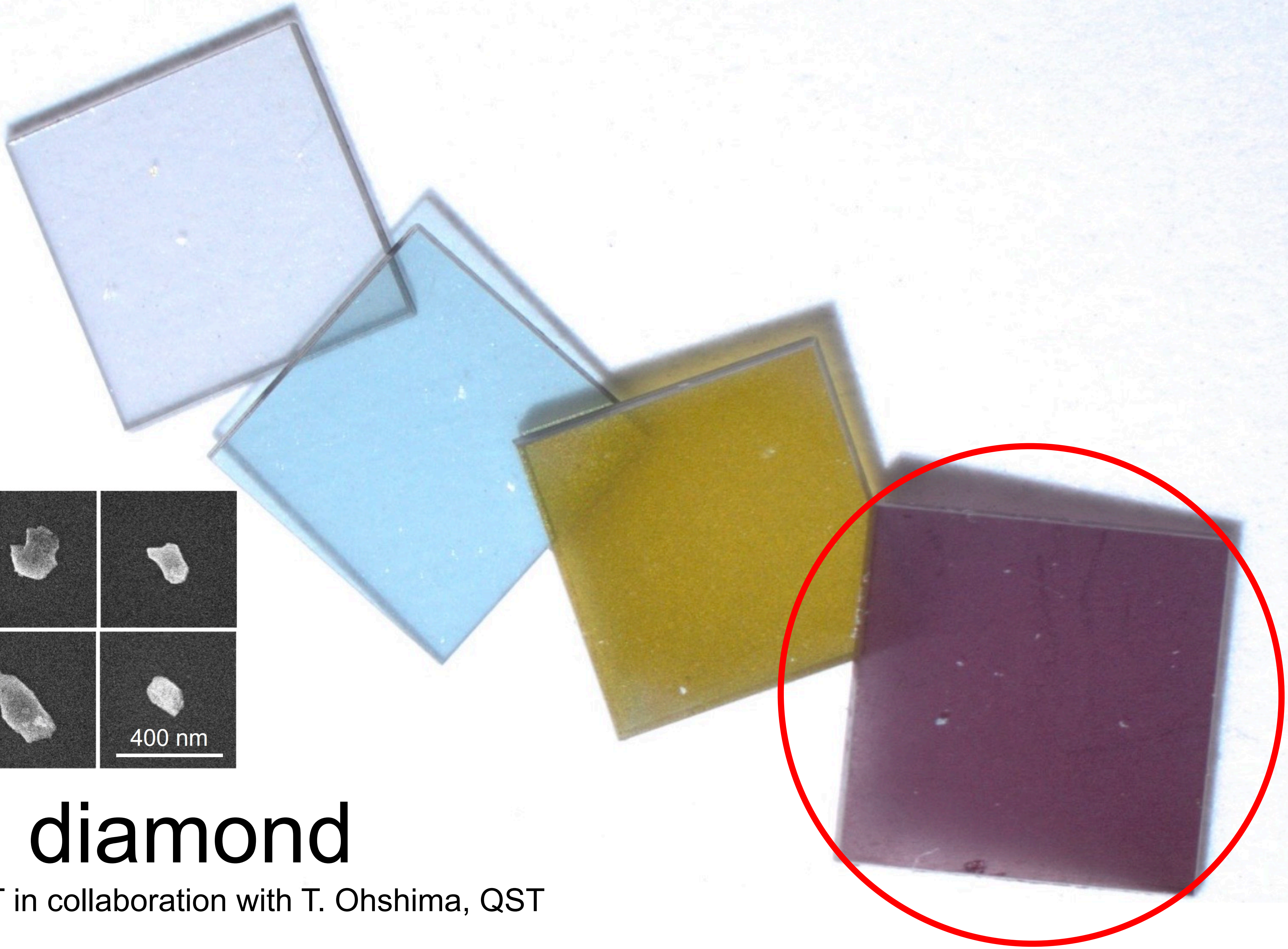
Department of Defence

Vision: choke point fibre optic magnetic sensor







Coloured diamond

Photo: M. Capelli, RMIT in collaboration with T. Ohshima, QST

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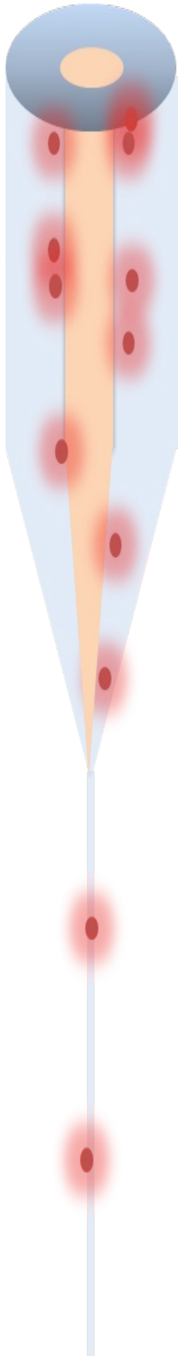
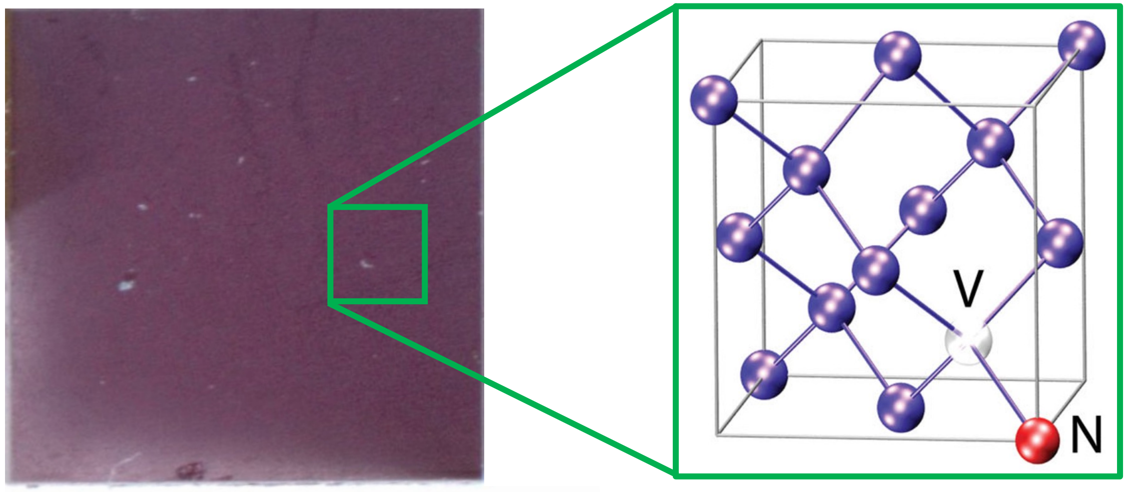
The Nitrogen Vacancy (NV^-) Centre



- Peak wavelength around 700 nm
- Robust, stable fluorescence
- Single photon or ultra bright emission
- Optical detection of the spin state
- Room temperature coherence (T_2 ~ 1 ms)

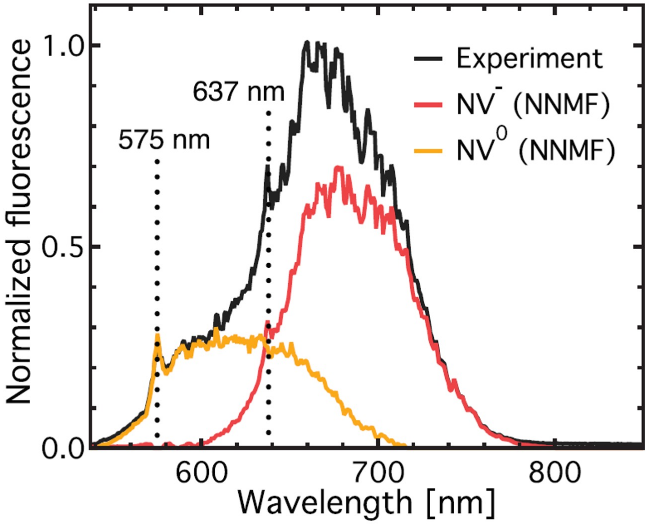
Non-fluorescent diamond

Photostable fluorescent NV centres



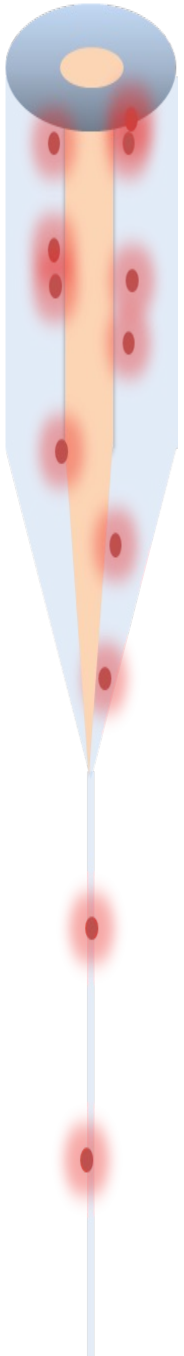
Bulk diamond with NV centres

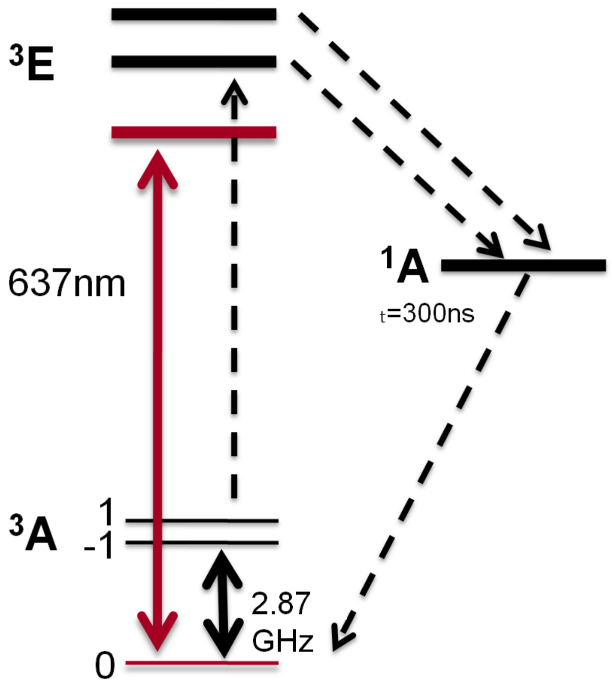
A. Stacey, et. al., Adv. Mater. (2012)

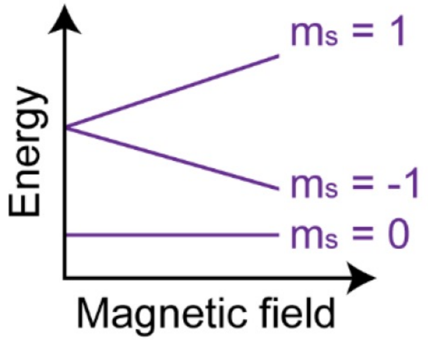


P. Reineck, et. al., Part. Part. Syst. Charact. (2019)

Optically Detected Magnetic Resonance (ODMR)







Ground state sublevels are sensitive to magnetic fields

Sensor of:
- Magnetic fields
- Electric fields
- Microwave fields
- Temperature

- Can operate in the earth's magnetic field
- At room temp (no cryogenics)
- High bandwidth operation (DC to kHz)
- Vector and scalar sensing options

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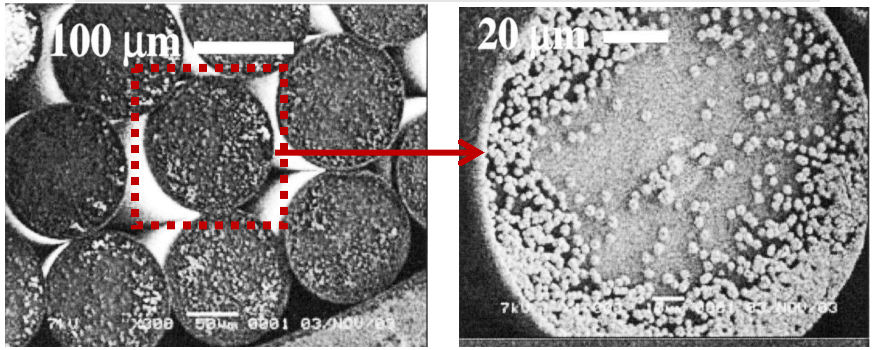
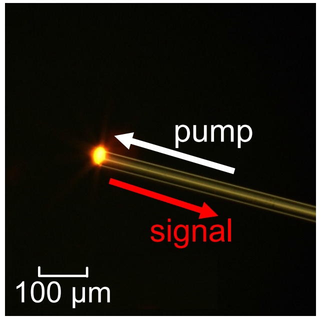
Hybrid diamond-fibre intergration approaches

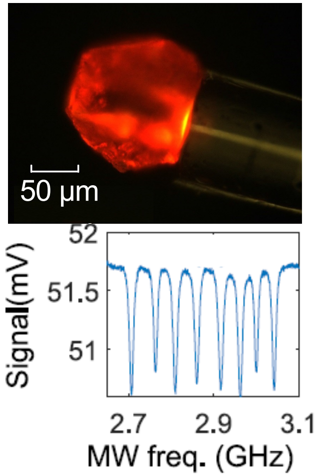
CVD diamond growth on fibre endface



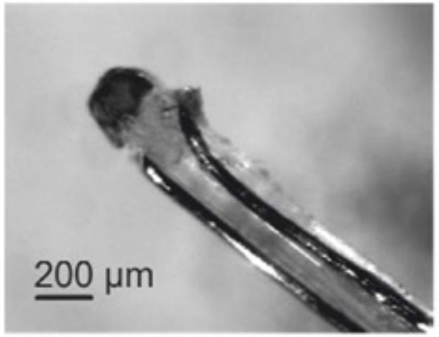
J. R. Rabeau, *Appl. Phys. Lett.* 86, 134104 (2005).

Fibre-based endoscope-type diamond sensor



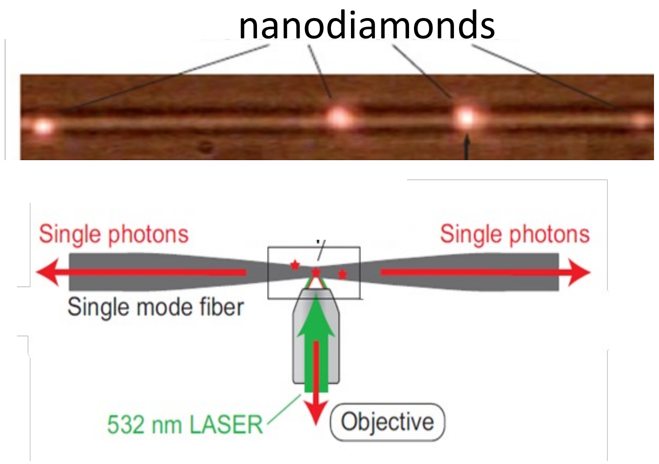


D. Duan, *Opt. Express* 27, 6734 (2019).



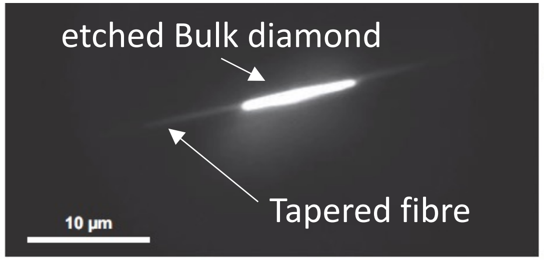
V. Fedotov, Opt Lett 39, 6954 (2014).

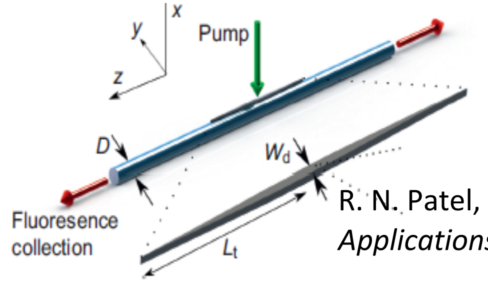
Diamond on tapered fibre interface



T. Schroder, *Opt. Express* 20, 10490 (2012).

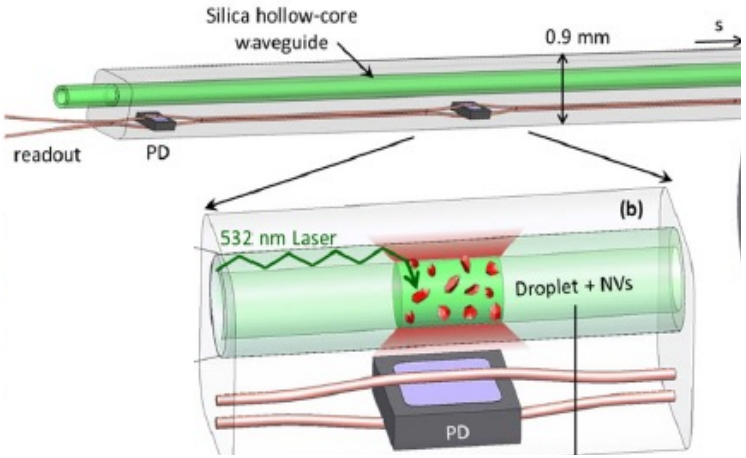
Adiabatic mode transfer





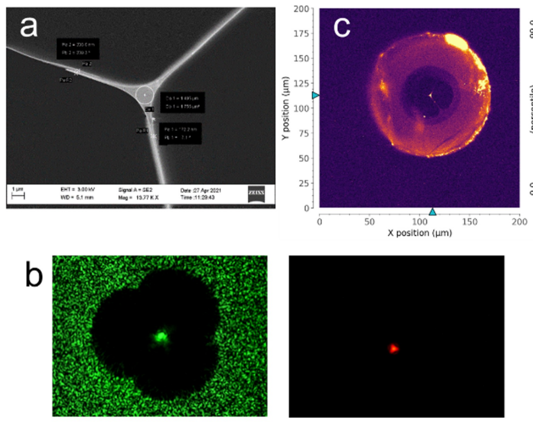
R. N. Patel, *Light: Science & Applications* 5, 16032 (2016)

Distributed microfluidic magnetometry



S. Maayani, *Laser Photonics Rev.* 13, 1900075 (2019).

Integration in suspended core



A. Flipkowski, *Optics Express*, 30, 19573 (2022).

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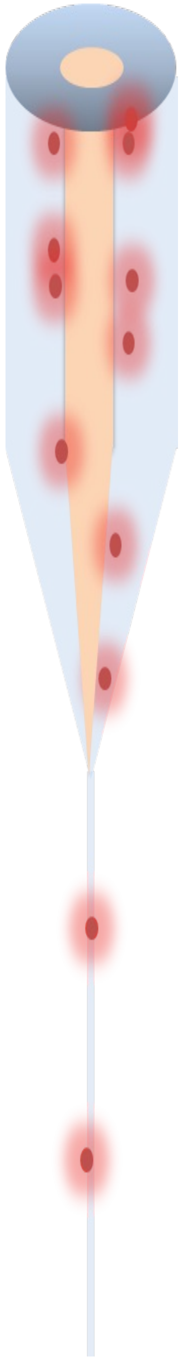
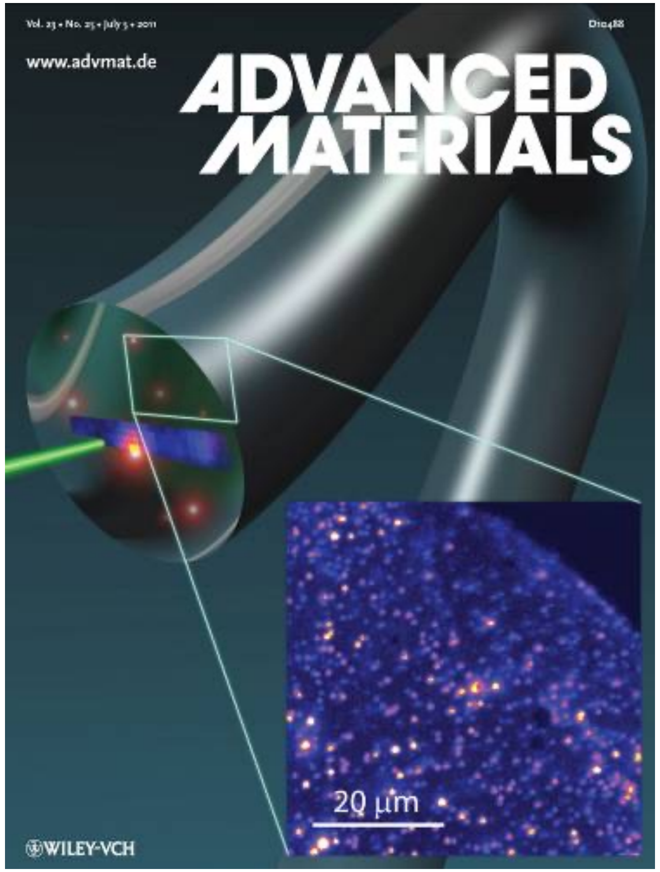


1st integration of diamond particles within optical fibre

Diamond particles

embedded in molten glass

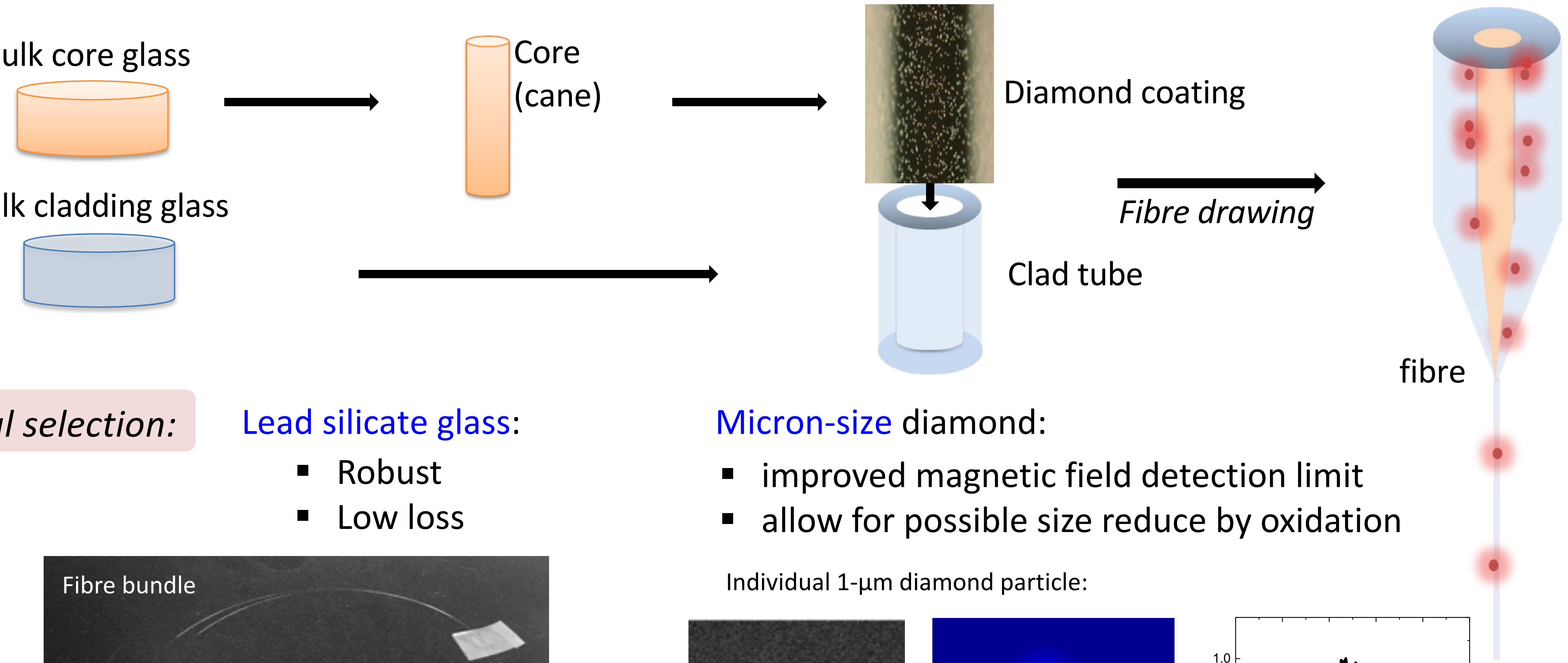
Optical fibre drawing (UoA)



M. R. Henderson, et al., Adv. Materials **23**, (2011)

RMIT Classification: Trusted

New fabrication approach: on-interface embedding



Material selection:

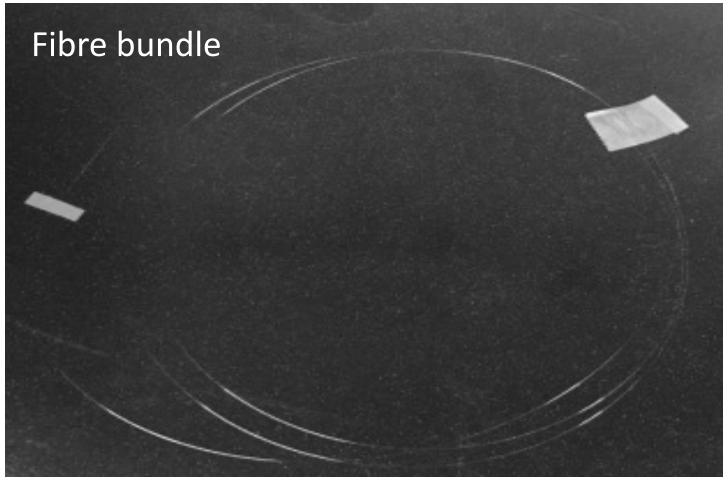
Lead silicate glass:

- Robust
- Low loss

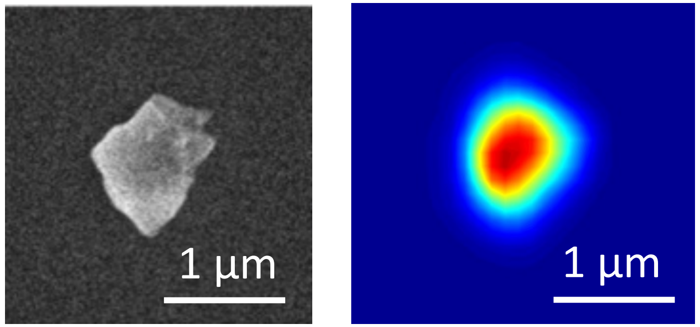
Micron-size diamond:

- improved magnetic field detection limit
- allow for possible size reduce by oxidation

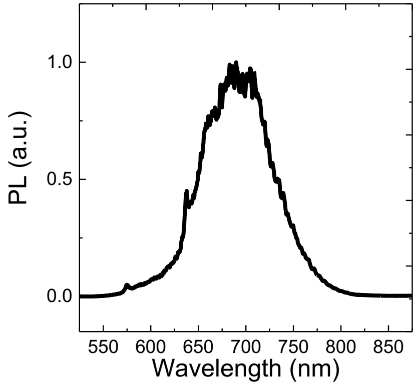
Scalable fabrication



Individual 1-µm diamond particle:



SEM and confocal fluorescence images



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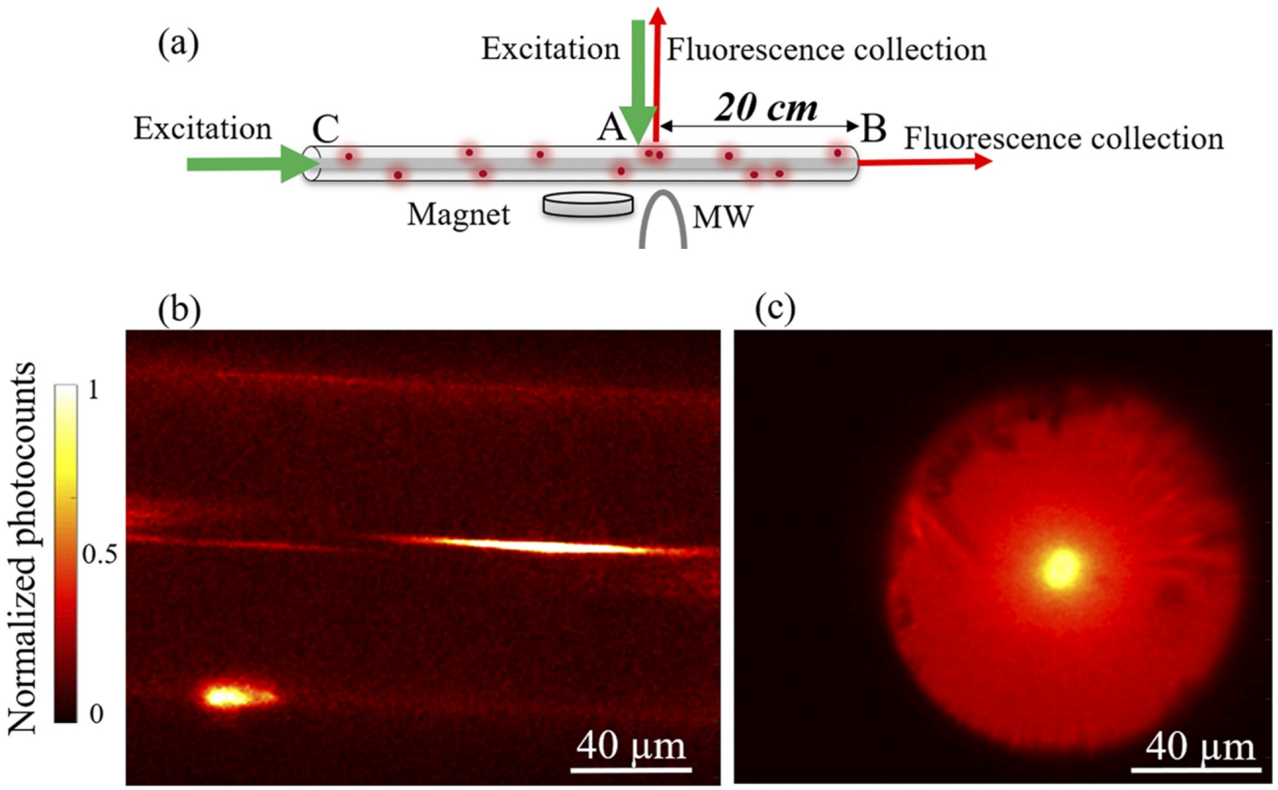
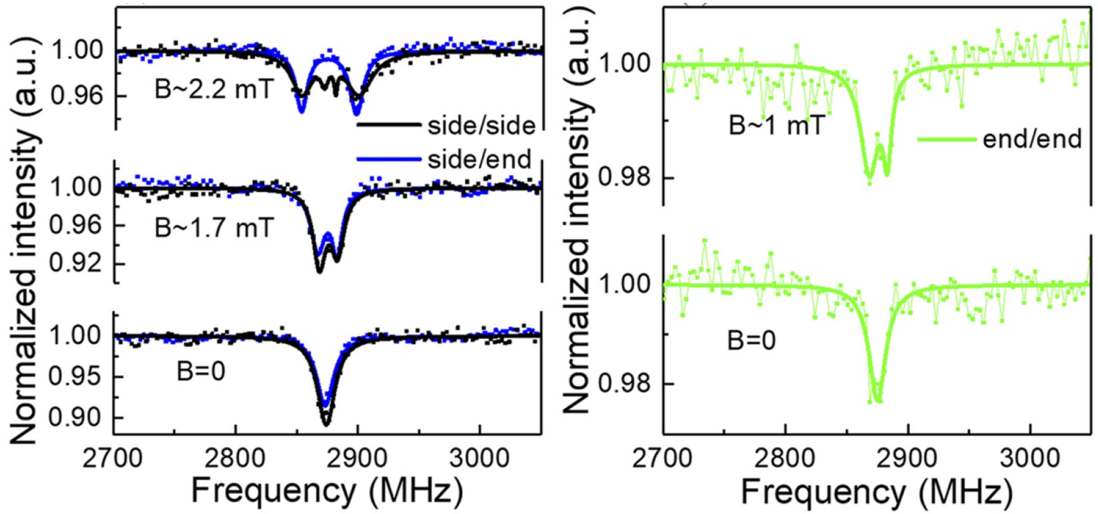
Microdiamond-doped lead-silicate glass optical fibres



Schematic and fluorescence from diamond embedded within optical fibres

Sensitivity ~350nT/√Hz



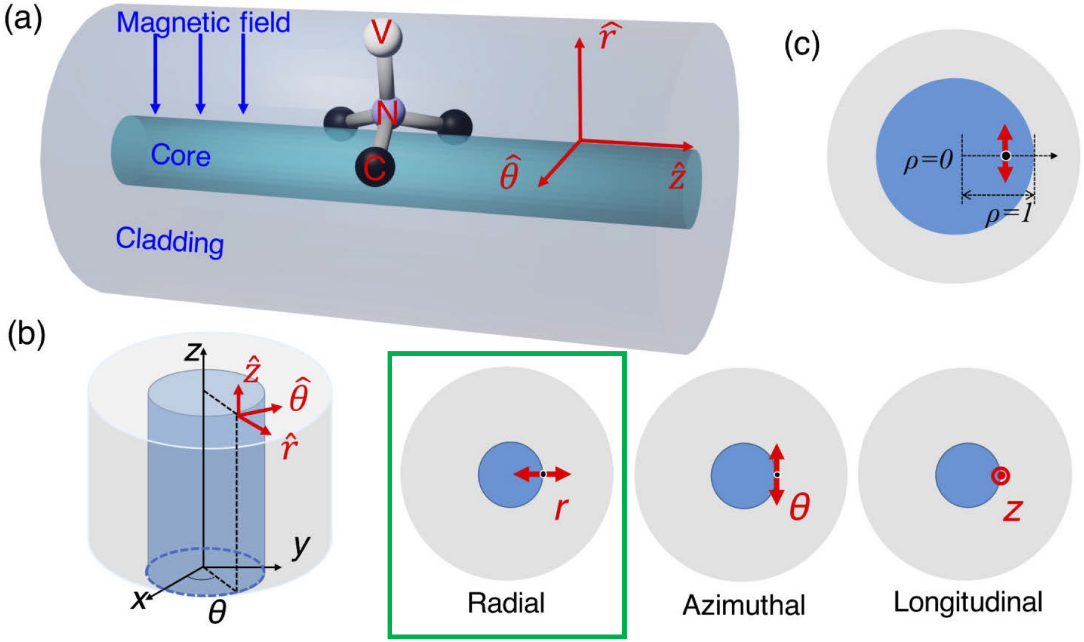
Measured ODMR as a function of B field

D. Bai, et. al., APL Mater. **8**, 081102 (2020)

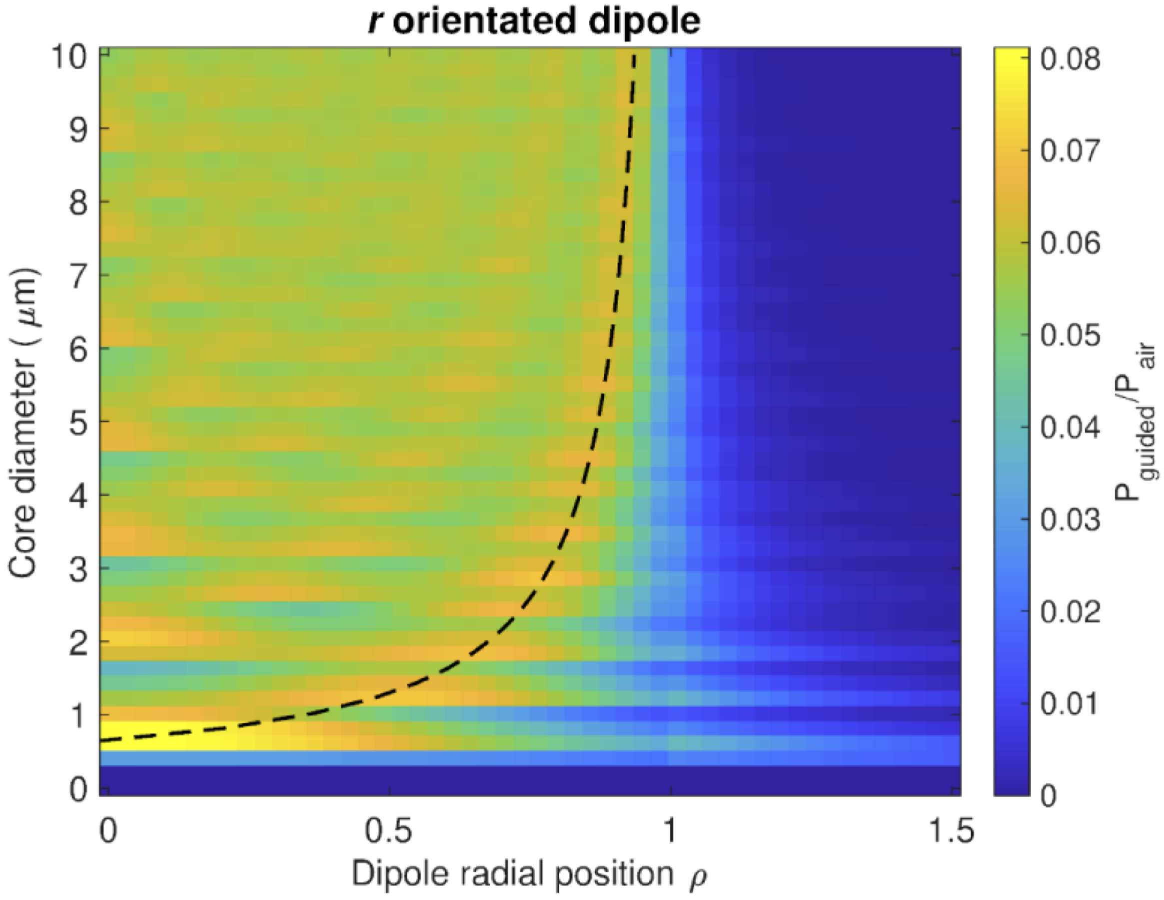
RMIT Classification: Trusted

Preferential coupling of diamond NV centres in step index fibres

Dr Shuo Li



The schematic of a diamond NV centre in a step-index fibre.



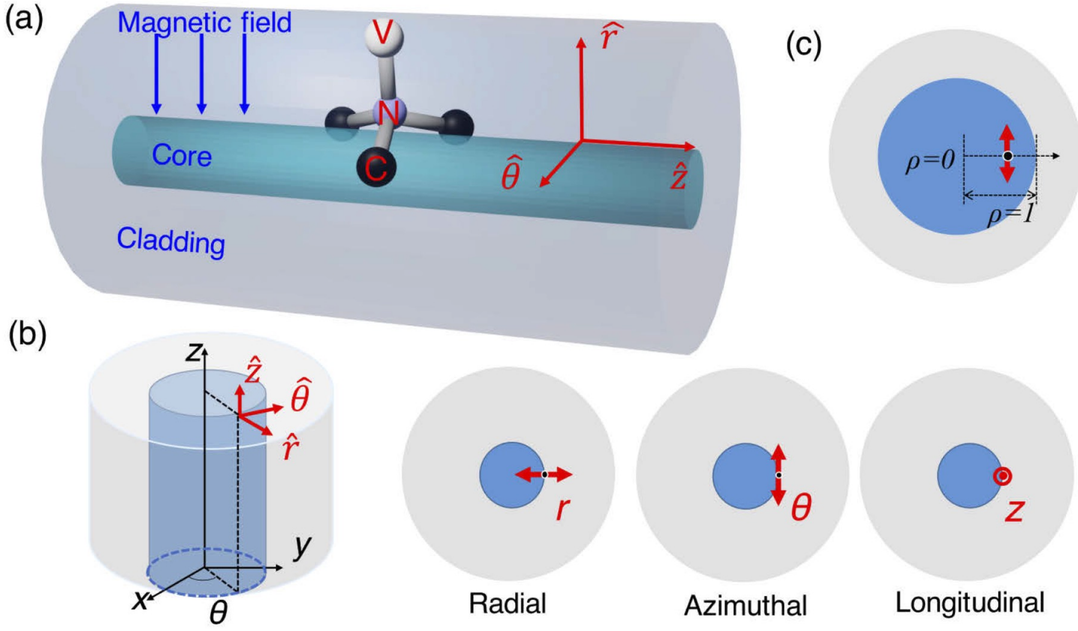
Normalized power captured by F2/LLF1 fibre (n_{co}/n_{cl}: 1.62/1.54) guided modes versus dipole radial positions and also a range of core diameters for r− orientated dipole

S. Li, et al., *Optics Express*, Vol. 29, Issue 10, (2021)

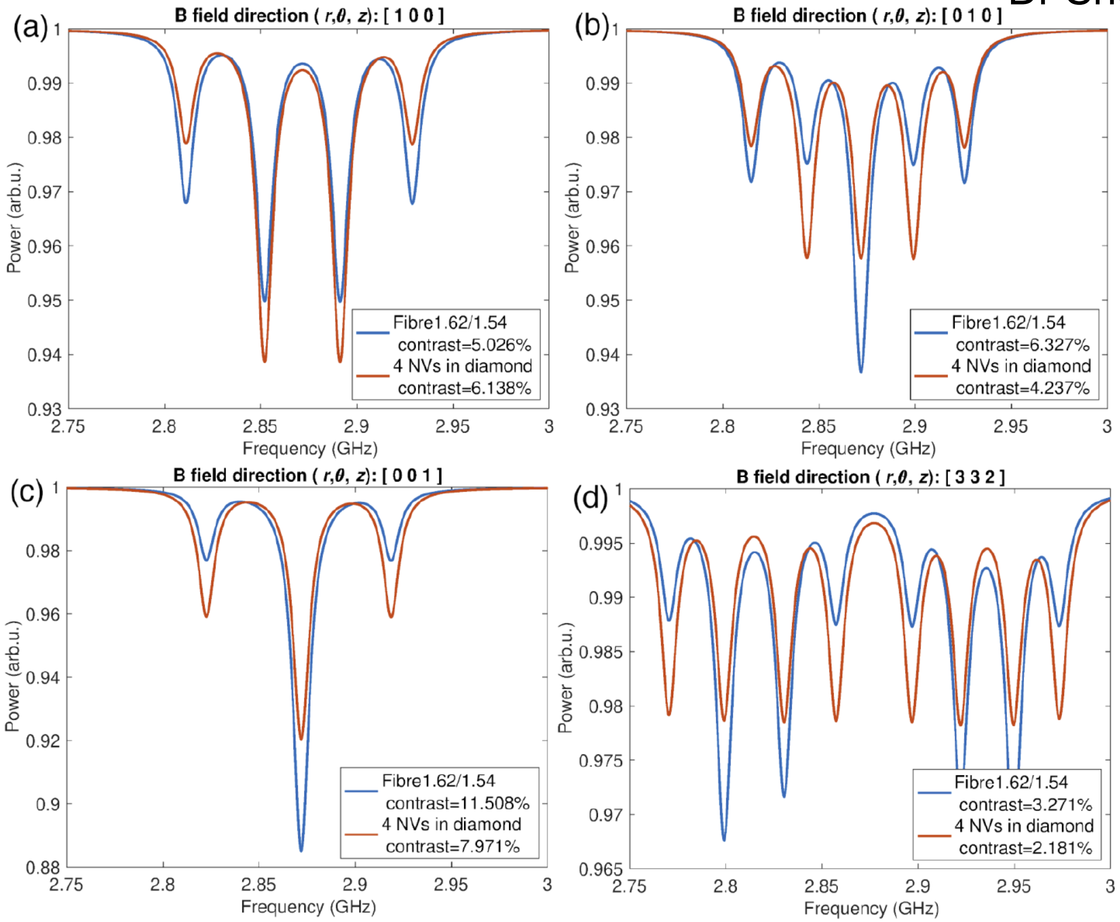
RMIT Classification: Trusted

Preferential coupling of diamond NV centres in step index fibres – ODMR contrast enhancement

Dr Shuo Li



The schematic of a diamond NV centre in a step-index fibre.



Simulated ODMR signals generated by a ensemble of four NVs in a F2/LLF1 fibre under different magnetic fields.

S. Li, et al., *Optics Express*, Vol. 29, Issue 10, (2021)

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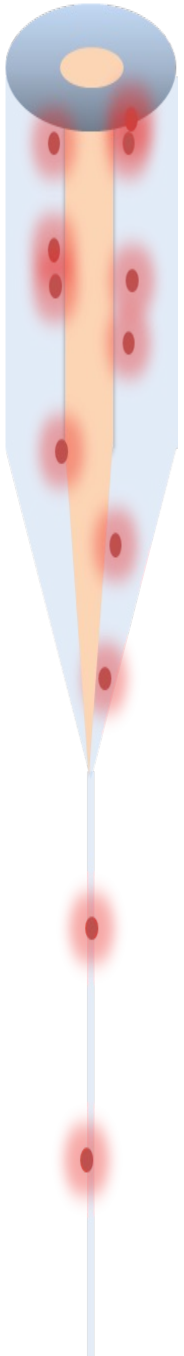
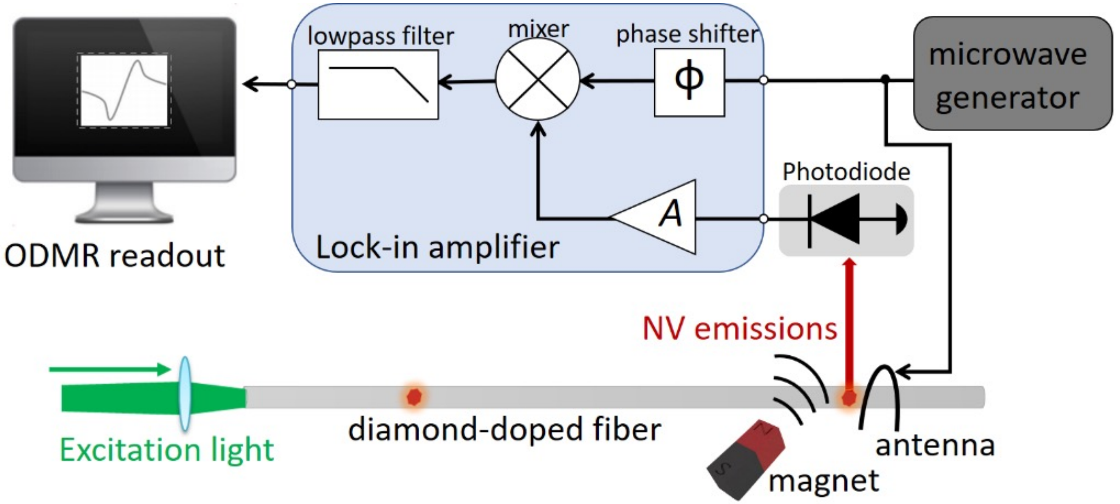
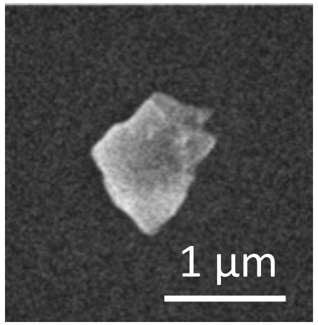
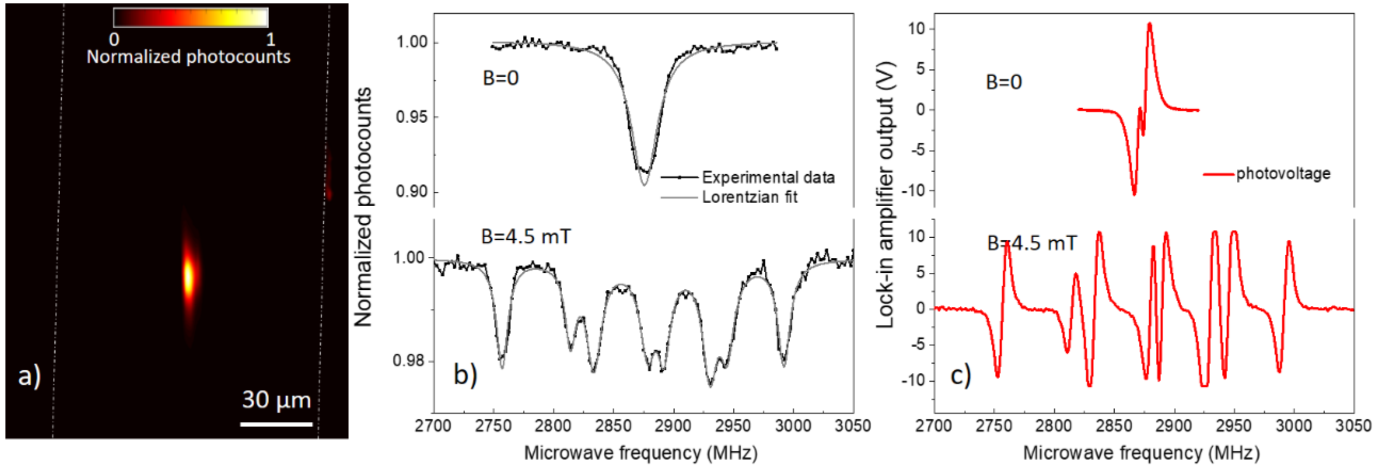
Lock-in detection of ODMR signals for diamond NV centres embedded in lead silicate optical fibre





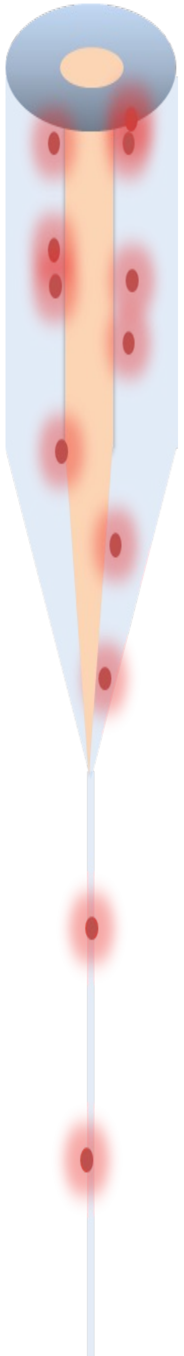




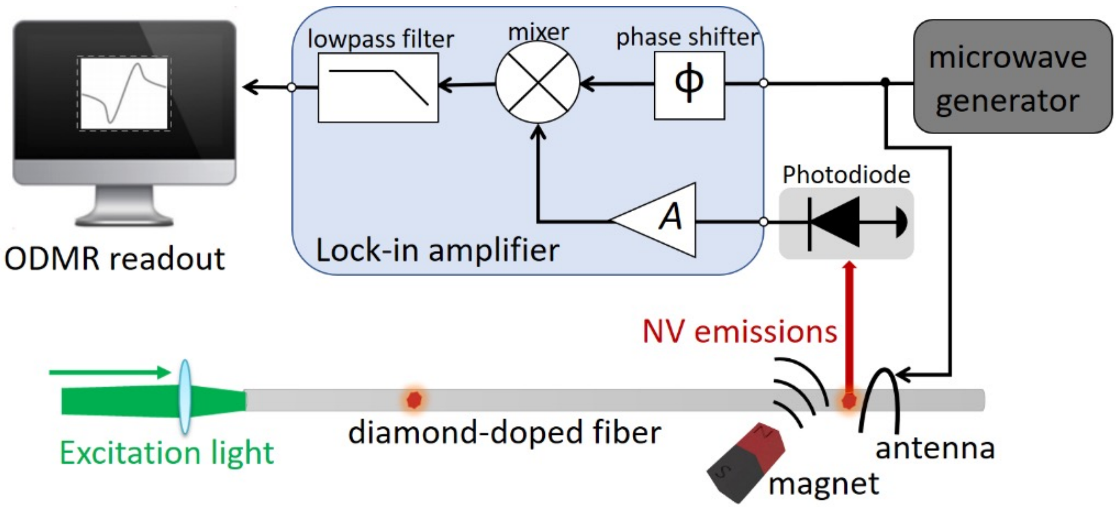
NV Fluorescence in fibre APD ODMR data Photodiode lock-in ODMR data

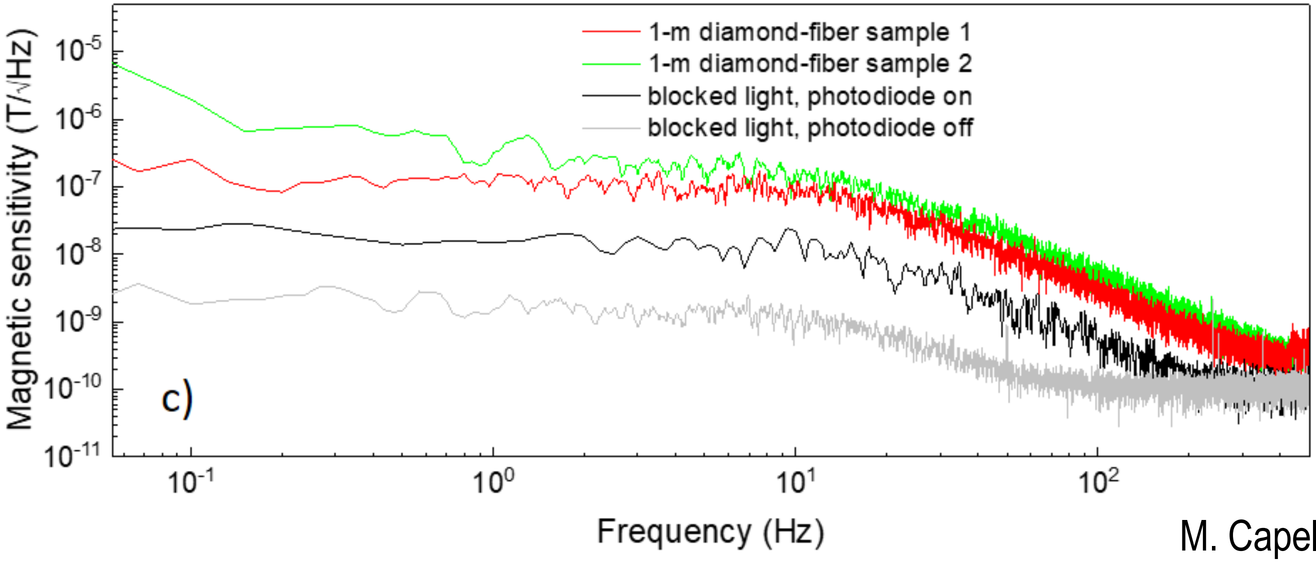
M. Capelli, et. al., in preparation (2022)

RMIT Classification: Trusted



Lock-in detection of ODMR signals for diamond NV centres embedded in lead silicate optical fibre





Unoptimised sensitivity ~100nT/√Hz at room temperature without magnetic field shielding

M. Capelli, et. al., in preparation (2022)

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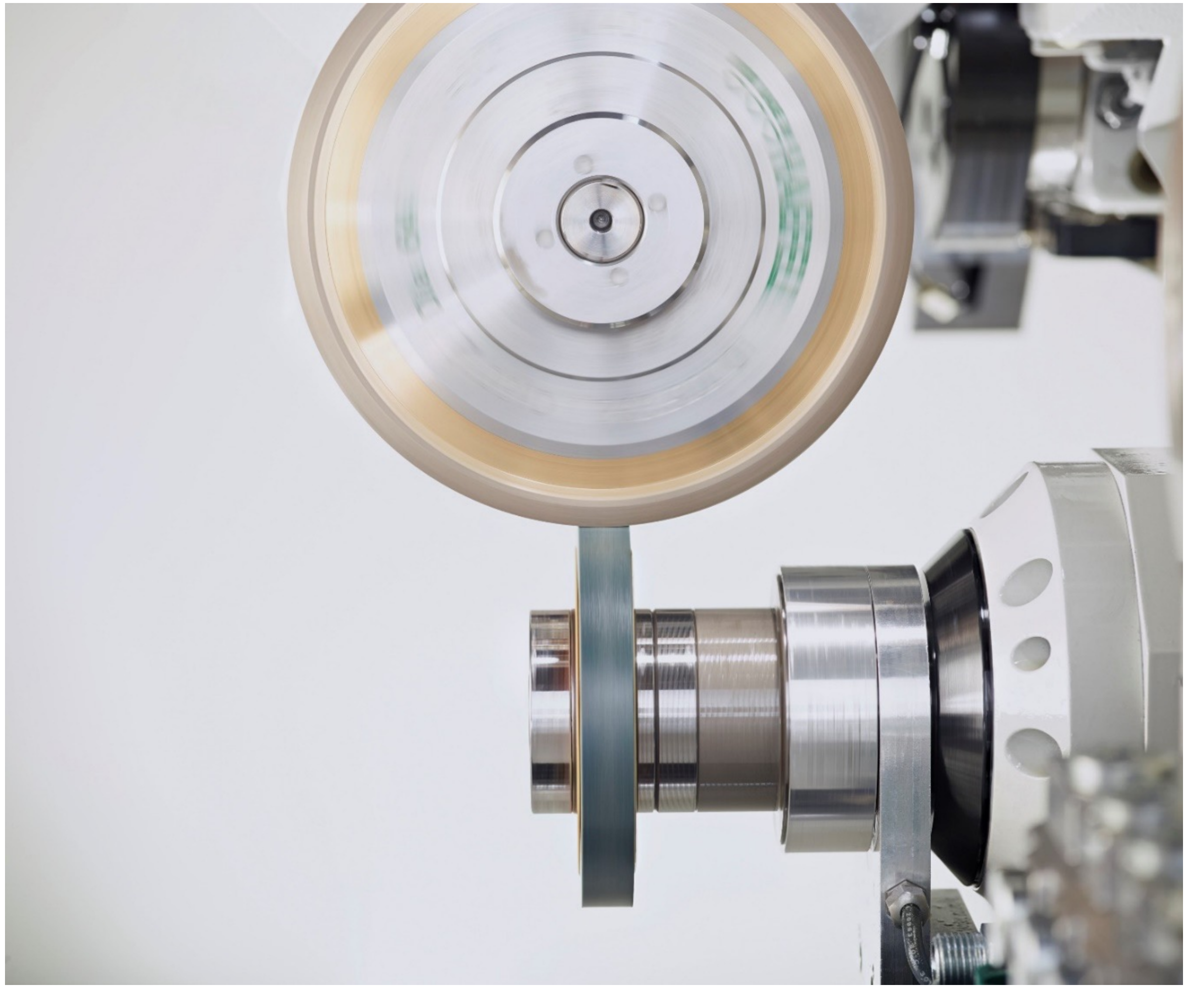
Commercial micro-diamond: is not optimised for quantum magnetic field sensing applications

Commercial diamond powder



www.productionmachining.com

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National Facility for Quantum Grade Diamond, Melbourne, Australia

Australian Government
Australian Research Council

$1M
ARC LIEF grant
(LE200100098)

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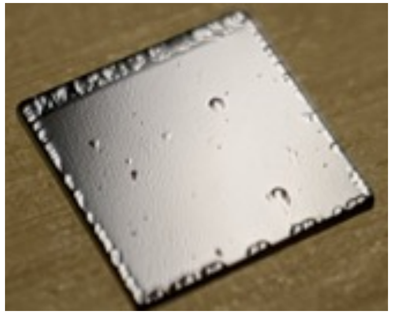
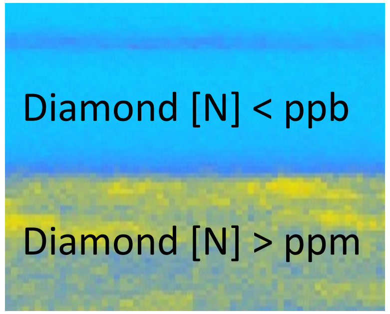
UNSW SYDNEY

Australian National University



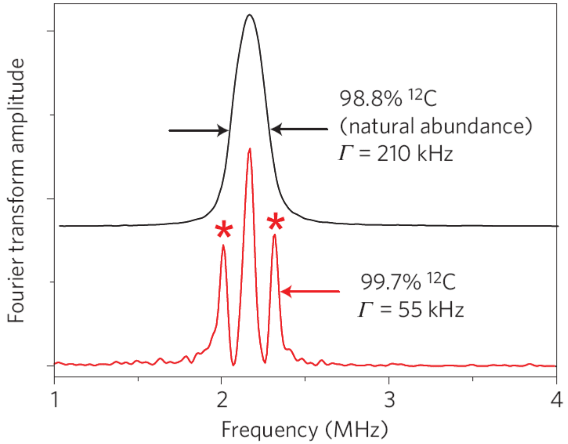
A. Stacey



D. Simpson

Delivering quantum grade diamond for precision quantum based applications:

- The presence of 1.1% of ^{13}C in commercial diamond limits measurement sensitivity.
- Isotopic engineering of diamond can reduce the ODMR linewidth and improve measurement contrast for precision magnetometry applications.



Balasubramanian, et al, *Nat. Mater.* (2009)

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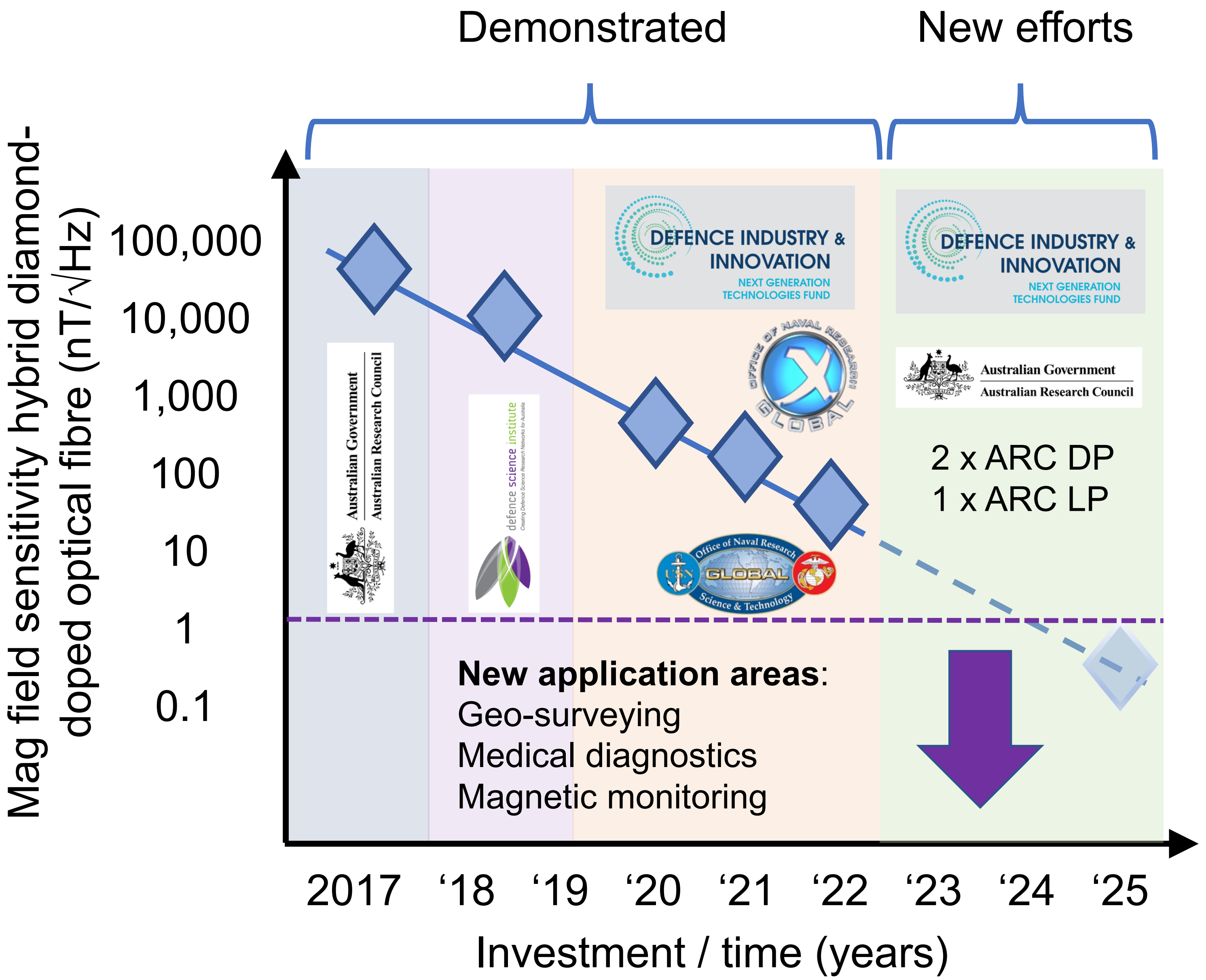
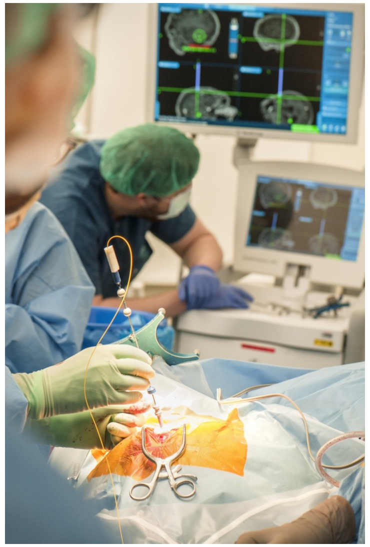
Magnetic field sensitivity vs Investment / time






The diamond-fibre project team
Left to right: Shuo Li, Christian van Engers Shahraam Afshar, Andrew Greentree, Heike Ebendorff-Heidepriem, Marco Capelli, Brant Gibson, Scott Foster, Wen Qi Zhang, David Simpson, Xuanzhao Pan
Not in photo: Alastair Stacey, Minh Hoa Huynh, Philipp Reineck


Centre for Nanoscale BioPhotonics
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Gibson & Greentree Group
RMIT UNIVERSITY
Left to right (back row): Shuo Li, Emma Wilson, Brooke Nati, Amanda Abraham, Andrew Greentree, Davin Peng, Blanca del Rosal Rabes, Asma Khalid, Katherine Chea
Left to right (front row): Marco Capelli, Giannis Thalassinos, Alastair Stacey, Brant Gibson, Daniel Stavrevski, Philipp Reineck, Roy Styles, Qiang Sun, Brian Yang,
Not in photo: Mitchell De Vries, Mohammad Javed Badaloo, Rui Yew, Laura Hung, Jean-Philippe Tetienne, Ethan Ellul, Daniel Roberts, Christian van Engers, Islay Robertson, Jaret Vasquez-Lozano, Priya Singh, James Belcourt

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Daniel Stavrevski

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Shahraam Afshar V.
Wen Qi Zhang
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Matthew Henderson
Xuanzhao Pan

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Lloyd Hollenberg

DST Group
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Tanya Monro

QST, Japan
Takeshi Ohshima
Hiroshi Abe
Shin-ichiro Sato
Shinobu Onoda

Fraunhofer IAF, Germany
Jan Jeske

Phasor Innovation
Andy Sayers
Adam Silvester

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Defence Industry & Innovation
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Phasor Innovation

AFRL
The Air Force Research Laboratory

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ANFF

defence science institute
Creating Defence Science Research Networks for Australia

Army

QST

Asian Office of Aerospace R&D

Air Force Office of Scientific Research

Office of Naval Research Global
Science & Technology

Upcoming presentations from the group and colleagues

Thursday talks (room R5)

- **David Simpson (next talk) –** Isotopic enrichment of diamond for bulk nitrogen-vacancy magnetometry applications
- **Islay Robertson (2:30 pm)** - A practical quantum sensing wide-field probe for precision magnetic imaging
- **Davin Peng (2:45 pm)** - Polarization dependent quantum correlation measurements of two nitrogen-vacancy color centres in diamond
- **Liam Hall (3:15 pm)** - Diamond-based Quantum Sensors for Next Generation NMR Applications

Poster session tonight from 5:30 pm (Halls F & G)

- **Ethan Ellul** - Microdiamond-Silk Wound Dressings for Early Infection Intervention through Temperature Sensing
- **Philipp Reineck** - Fluorescent nanodiamonds have disk-like shapes: implications for nanodiamond engineering and quantum sensing applications

Friday talks from 10:00 am and 10:15 am (Hall C)

- **Mitchell de Vries (10:00 am)** - First Observation of Fluorescence above 1200 nm from a Silicon-Related Colour Centre in Diamond
- **Wen Qi Zhang (UniSA) (10:15 am)** - Deactivation of NV- color centers in glass-sandwiched diamond particles

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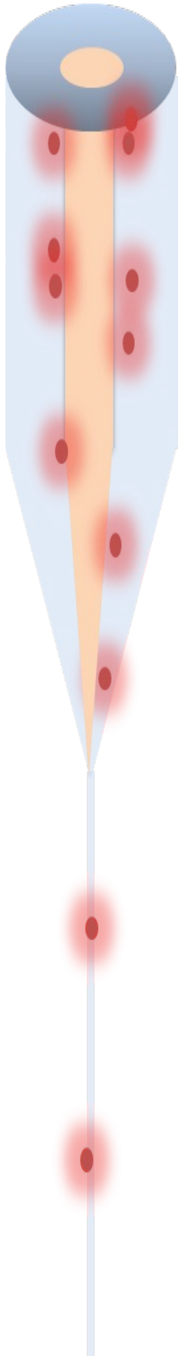
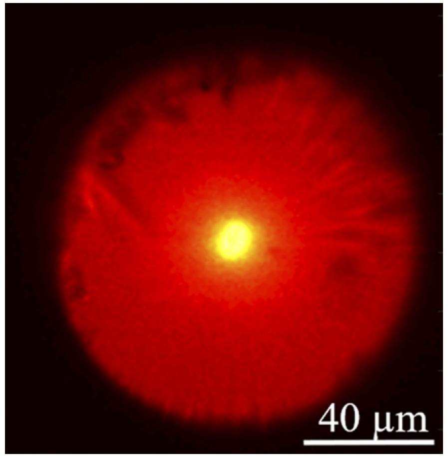
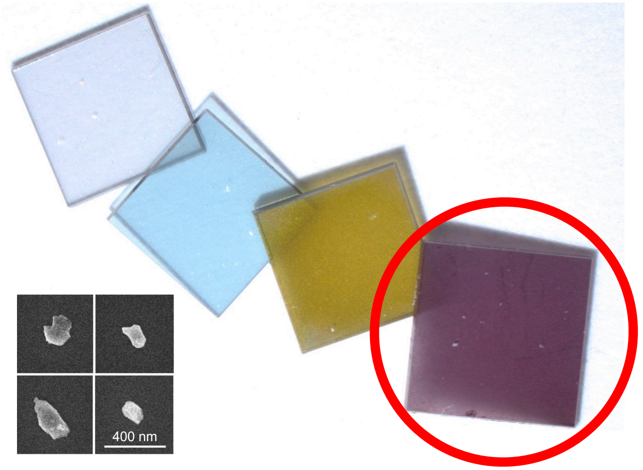
Summary

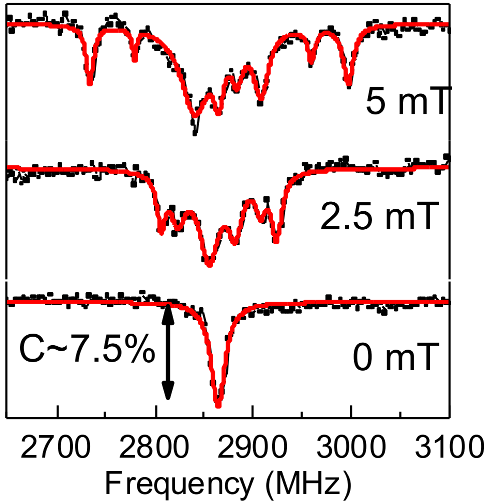




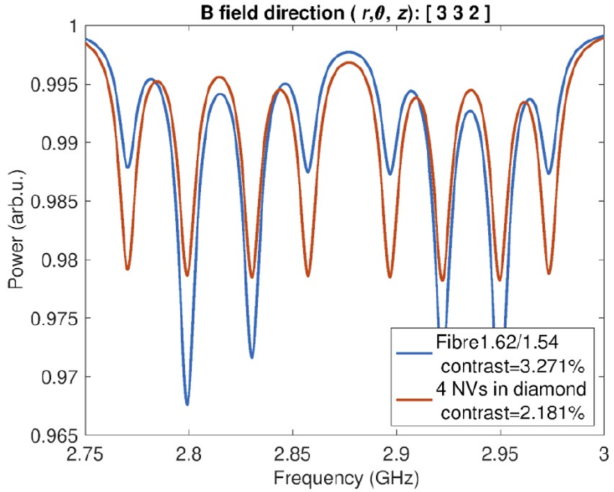
Stable NV fluorescence in fibre



NV sensing diamond materials



Optical detected magnetic resonance in optical fibre



Preferential coupling of NV emission

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