



Centre for
**Nanoscale
BioPhotonics**
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RMIT
UNIVERSITY

Multimodal Sensing with Hybrid Fluorescent Nanodiamond Complexes for Quantum Biological Measurements

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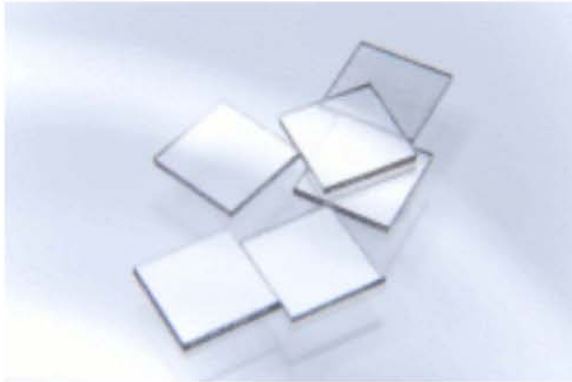
Fraunhofer, Germany

Jan Jeske



The color of diamond

Two main forms of diamond materials



Bulk material

- natural diamonds
- high pressure high temperature (HPHT)
- CVD growth

elementsix.

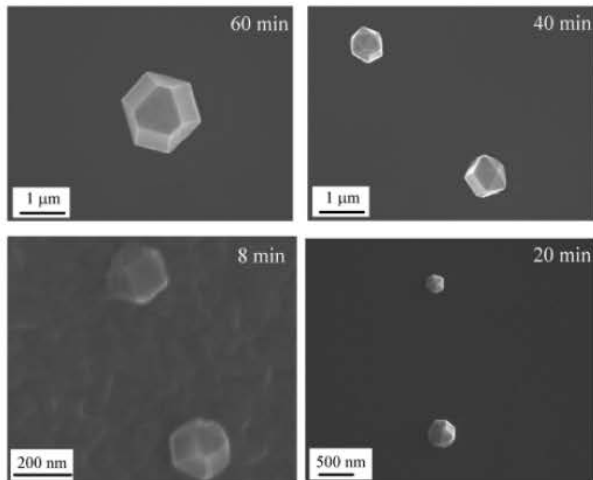
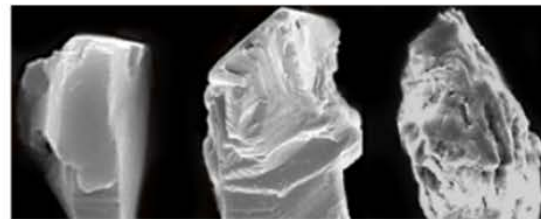


Fig. 1. SEM images of diamond crystals deposited for different periods of times. Clockwise from top left: 60, 40, 20 and 8 min of deposition.

Stacey et al, Dia. Rel. Mat. 18, 51 (2009)

- CVD growth

Nanodiamond

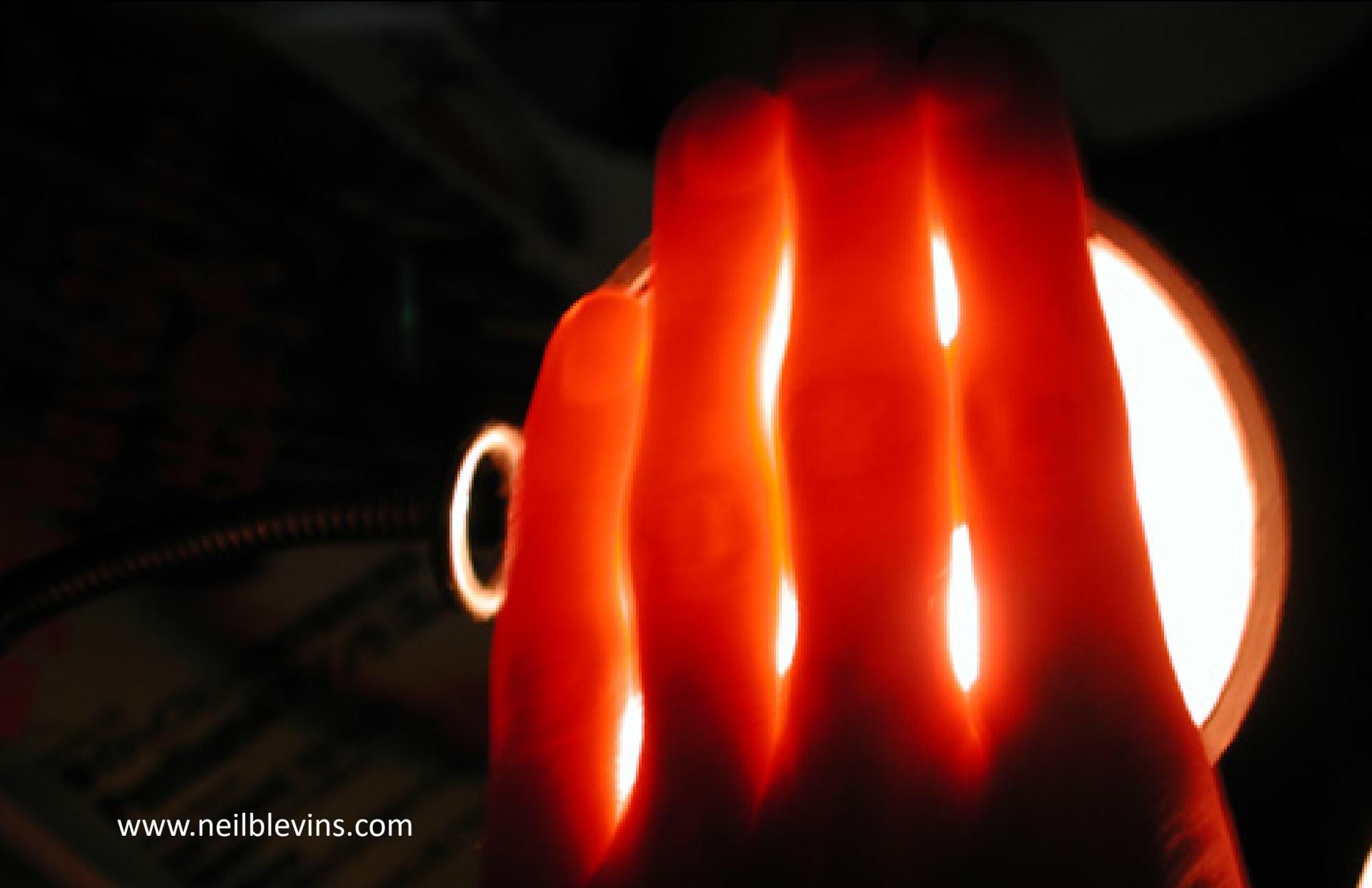


<http://www.vanmoppes.ch>

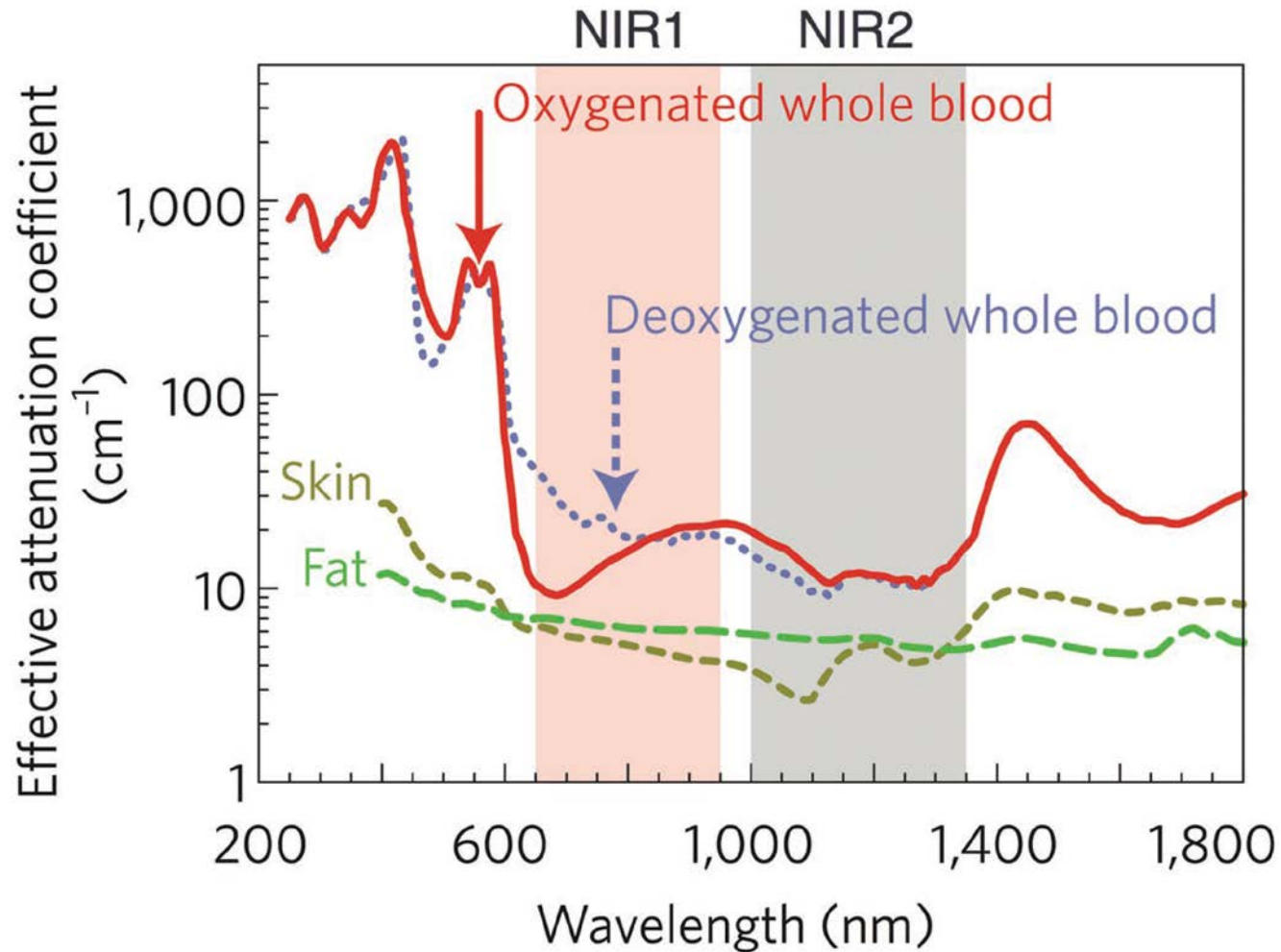


- milled or detonation

Light penetration through tissue

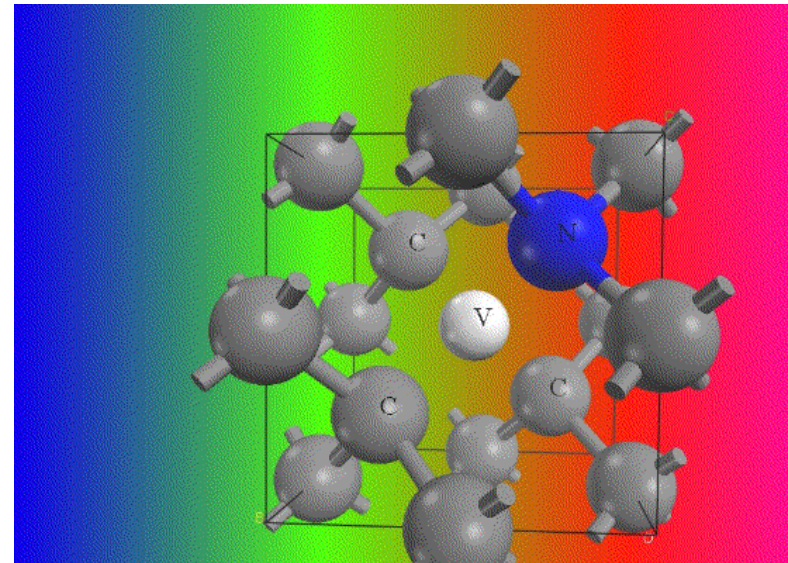
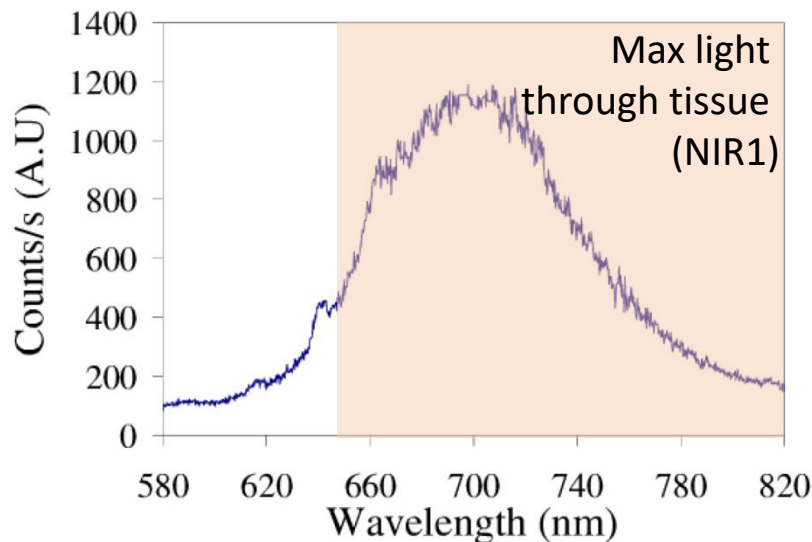
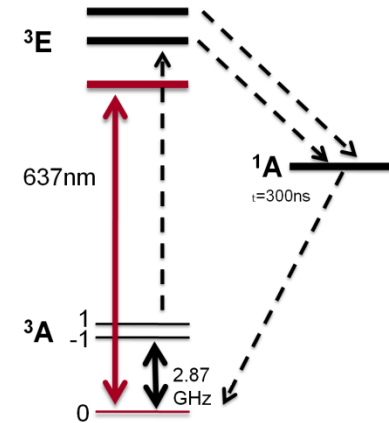


Light penetration through tissue

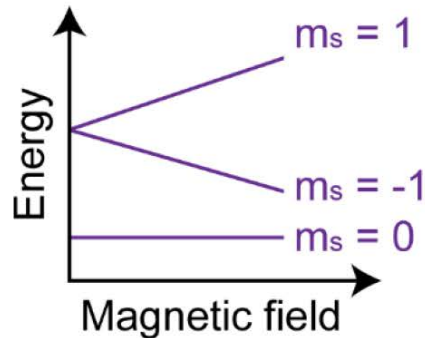
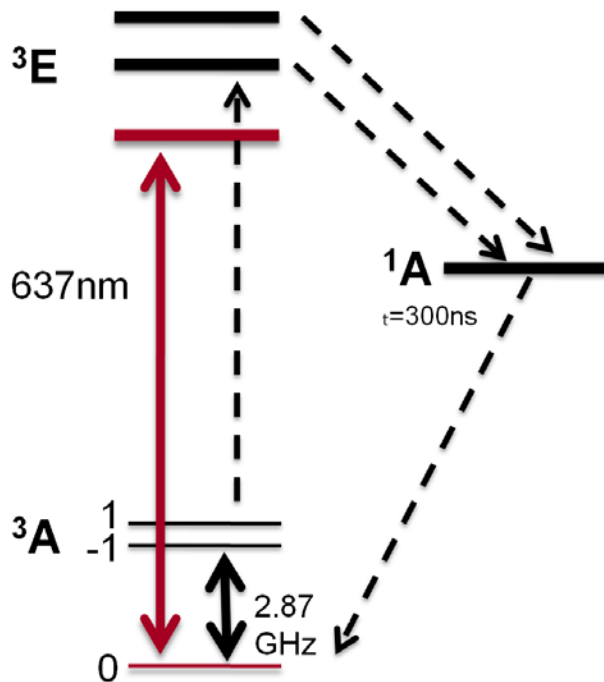


The Nitrogen Vacancy (NV⁻) Centre

- Peak wavelength around 700 nm
- Robust, **stable fluorescence**
- Single photon or **ultra bright emission**
- Optical detection of the spin state
- Room temperature coherence ($T_2 \sim 2$ ms)



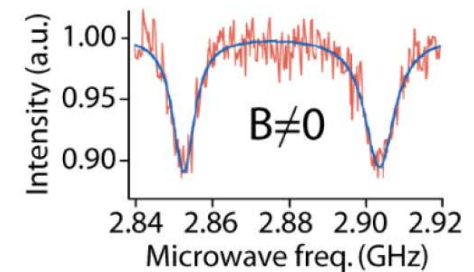
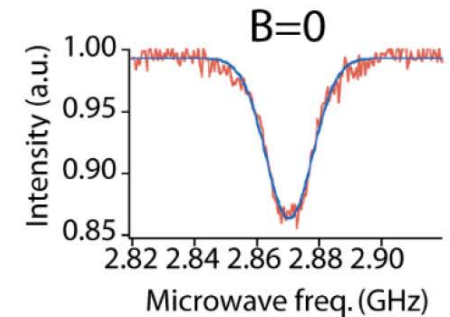
Optical Detected Magnetic Resonance (ODMR)



Ground state sublevels are sensitive to magnetic fields

Current best sensitivity in single crystal diamond is 0.9pT/VHz

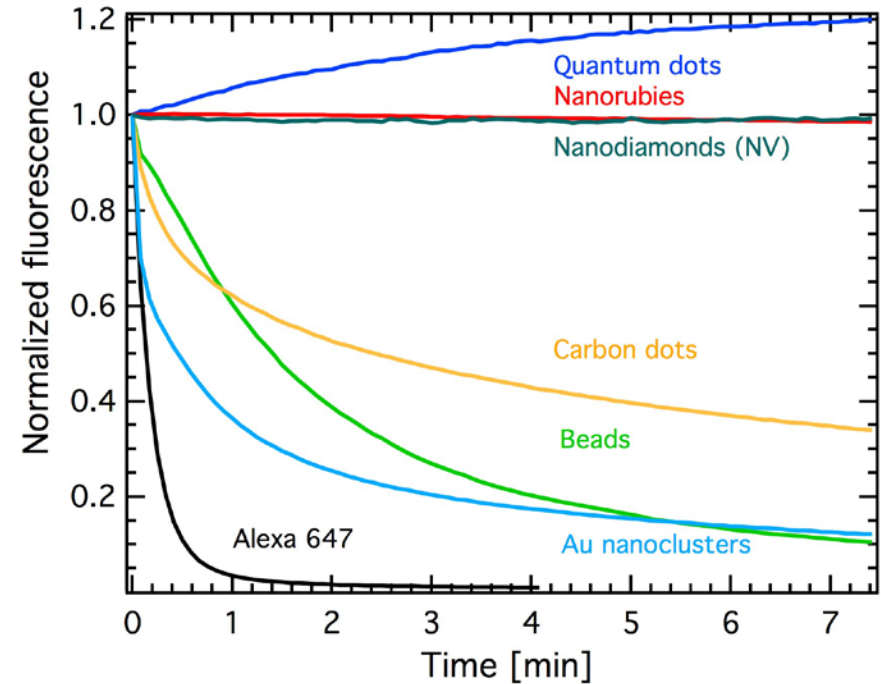
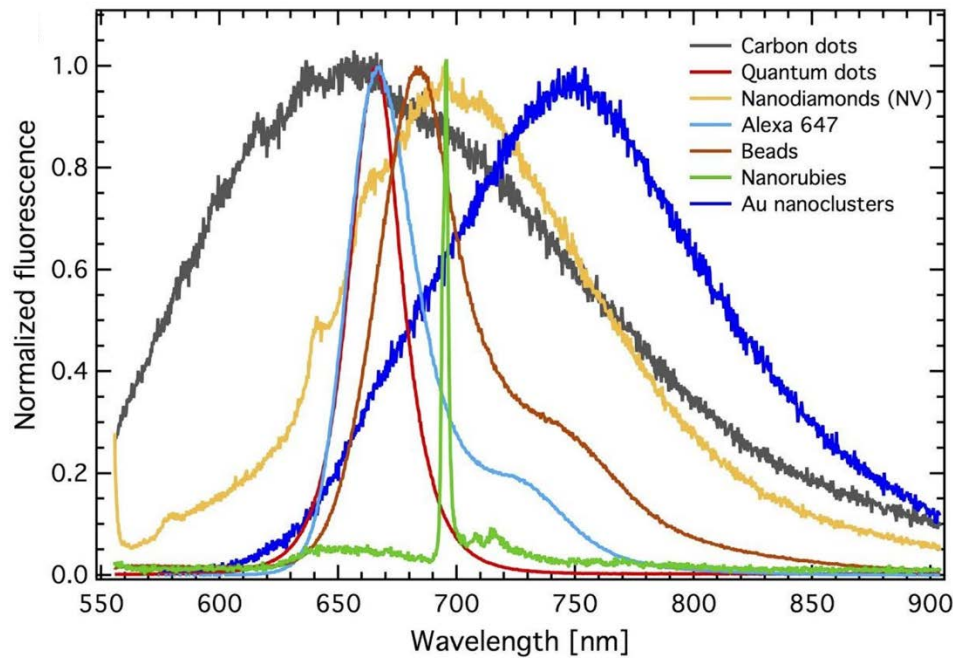
T. Wolf et al., Phys. Rev. X (2015)



B, E, T sensor

So how photostable?

Photostability comparison



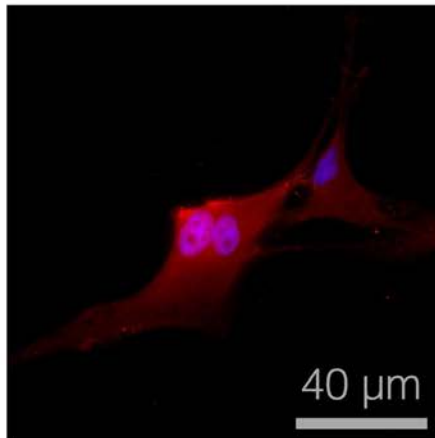
Bioimaging and Photobleaching

Fluorophore bleaching makes long term
imaging nearly impossible in fixed or live cells

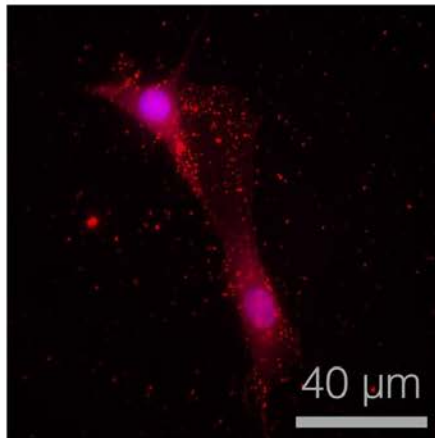
Astrocytes

0 sec

Alexa 647



Nano-
diamonds

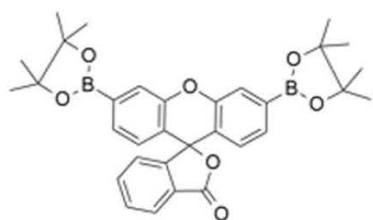


P. Reineck, et. al., Brightness and photostability of emerging red and near-IR
fluorescent nanomaterials for bioimaging, *Advanced Optical Materials* (2016)

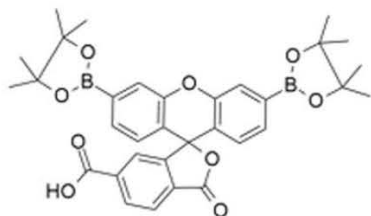
Hybrid Nanodiamond Materials and Sensing

Organic Fluorophore-Nanodiamond hybrid sensor

a) Fluorophores



Peroxyfluor-1
(PF1)



carboxy-Peroxyfluor-1
(carboxy-PF1)

b) PNS Imaging

Excitation  550 nm



Nanodiamond

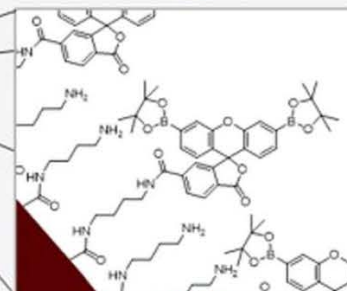
Emission  700 nm

c)

PNS Sensing

No H_2O_2

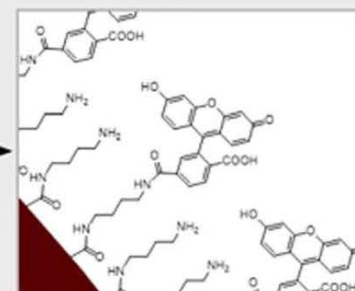
 490 nm




No Fluorescence

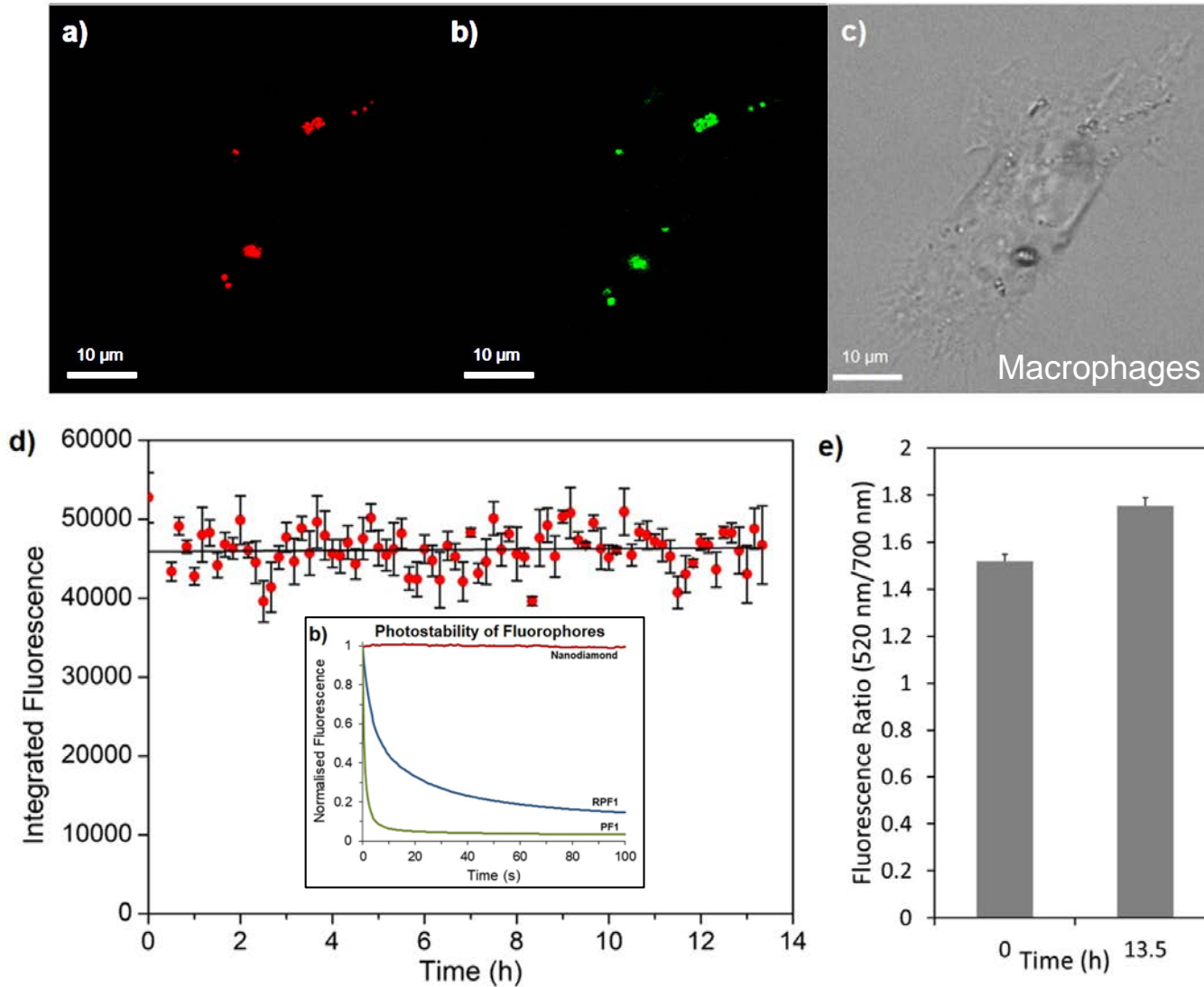
H_2O_2

 490 nm

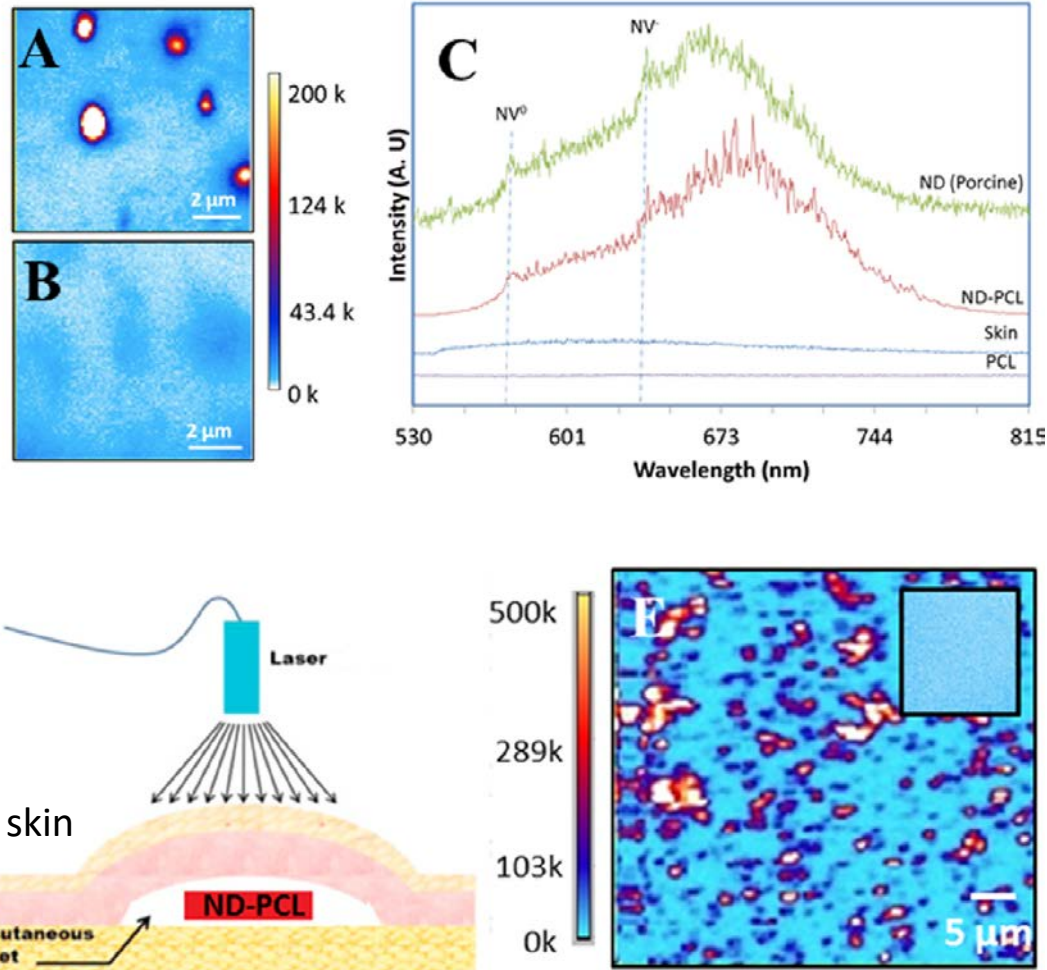


 520 nm

Organic Fluorophore-Nanodiamond hybrid sensor



Nanodiamond-polycaprolactone composite

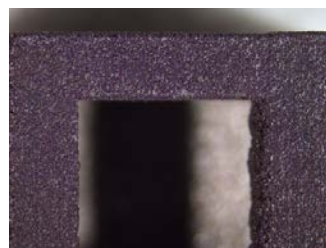
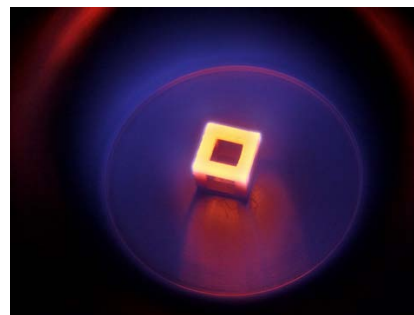
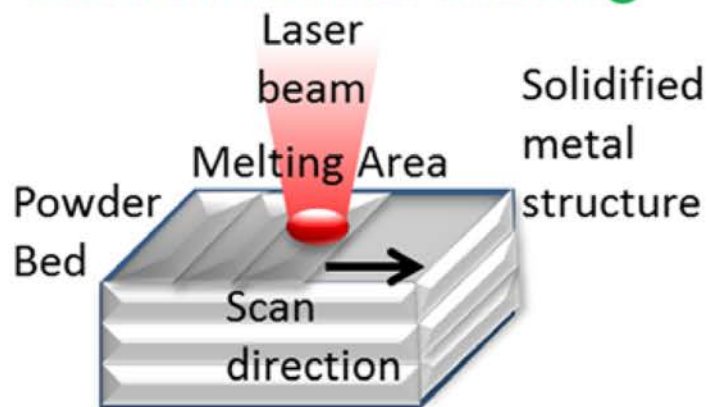


A new material for tissue engineering with
sub-dermal imaging capabilities

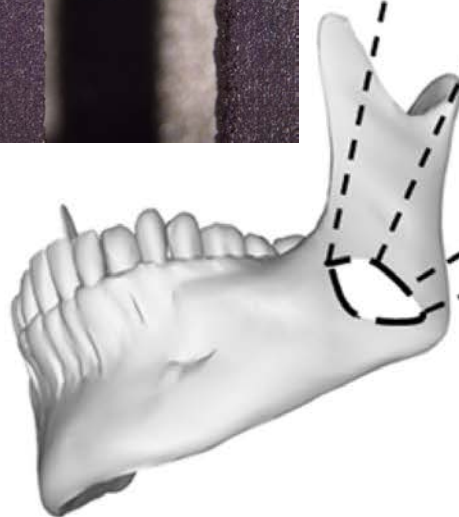
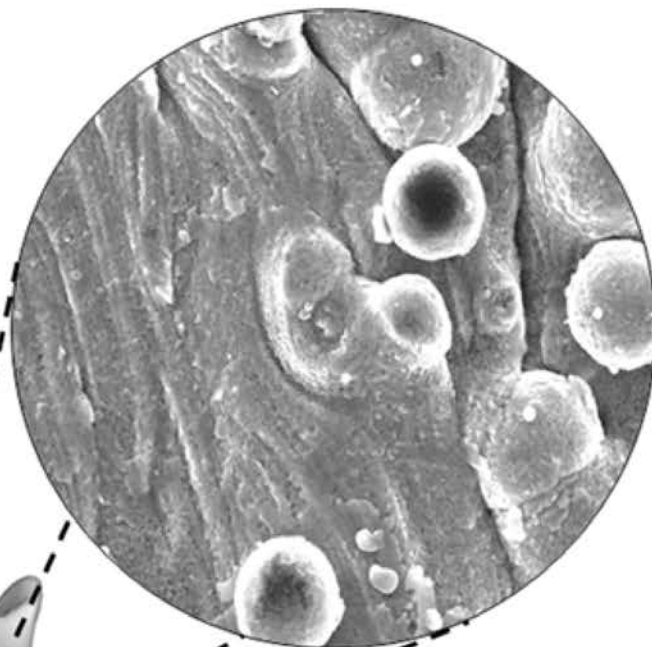
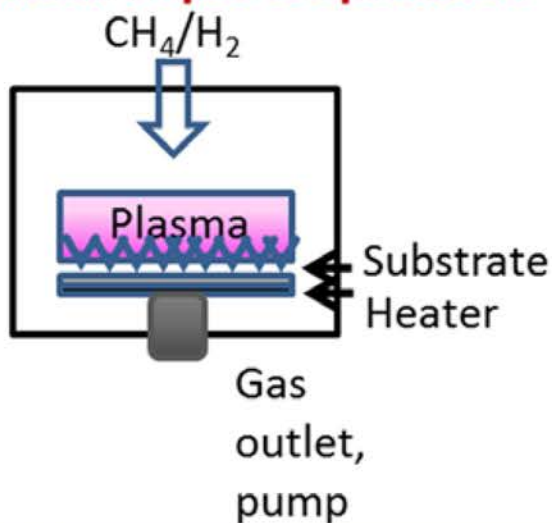
K. Fox, et. al., *Mat. Lett.* (2016)

Nanodiamond-titanium composite materials

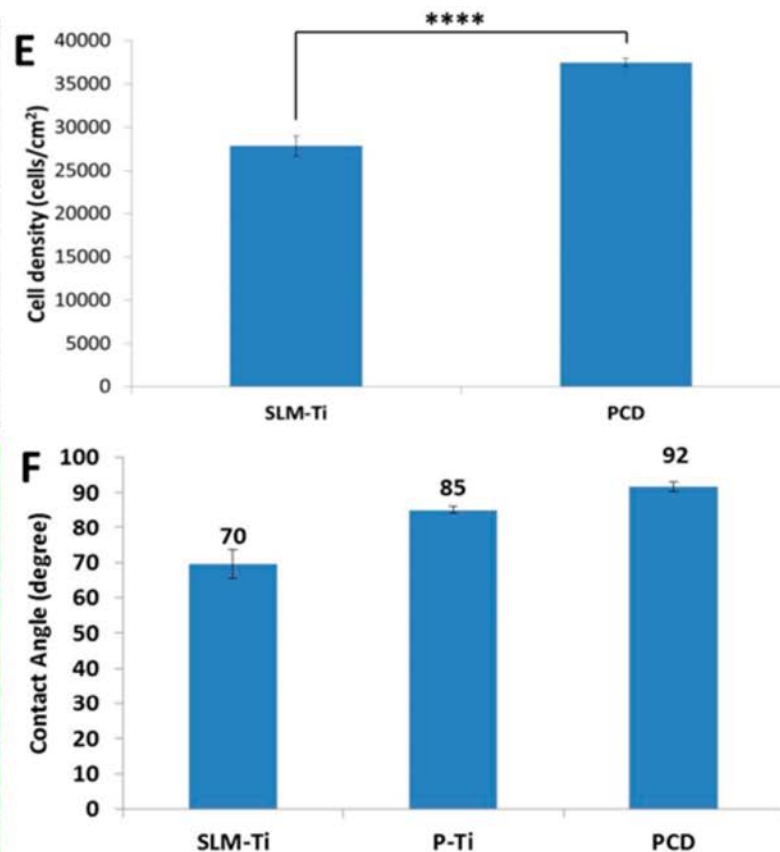
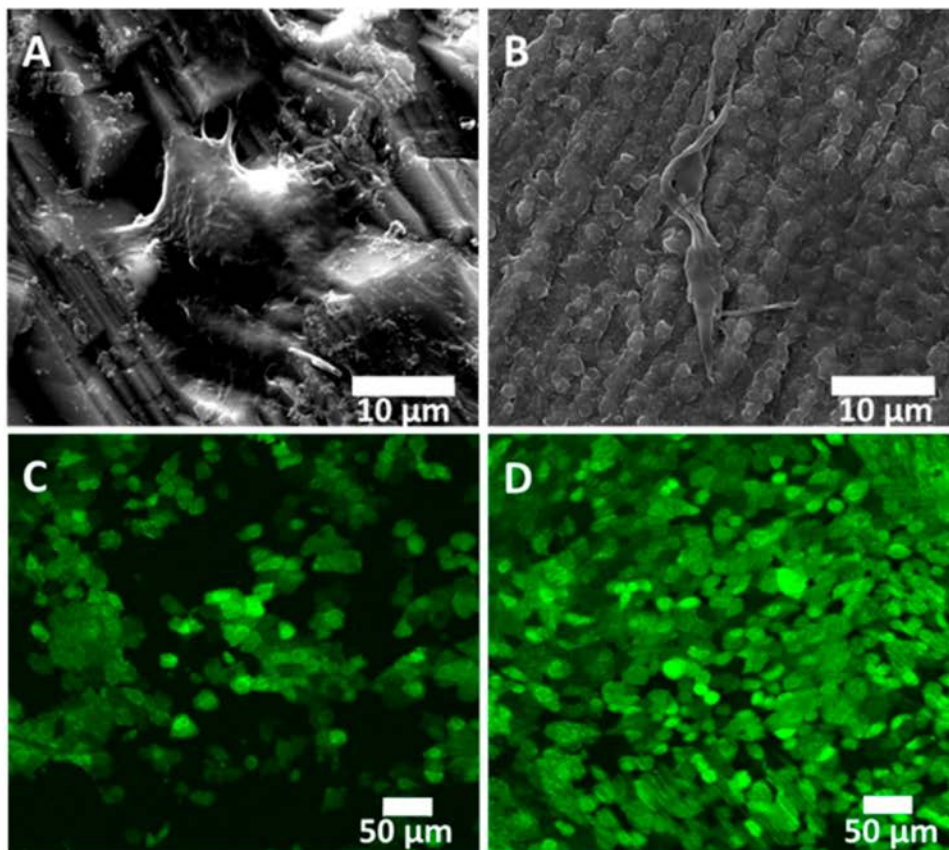
Selective Laser Melting



Chemical Vapor Deposition

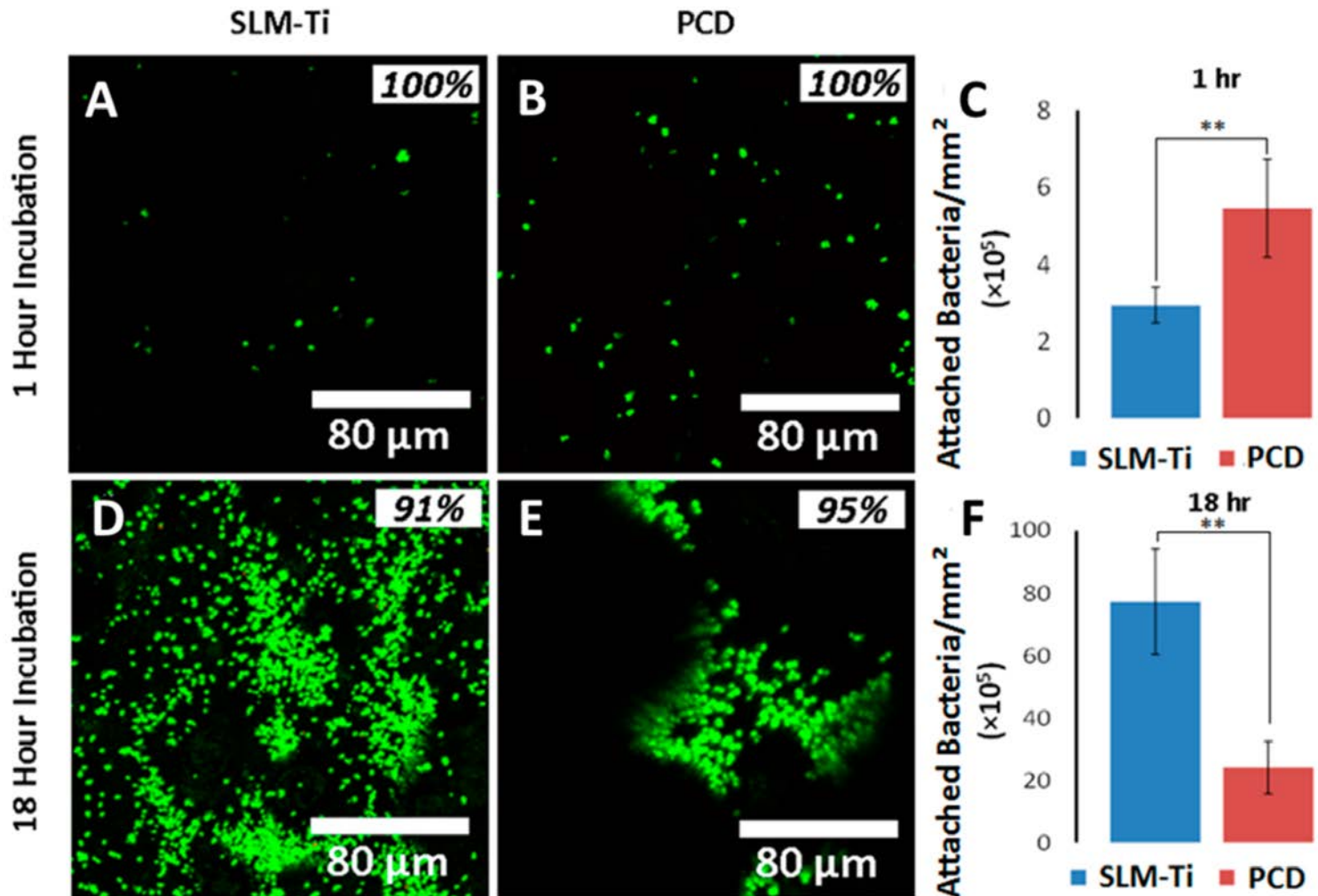


Nanodiamond-titanium composite materials – increased cell growth



Chinese Hamster Ovarian (CHO) cells

Nanodiamond-titanium composite materials - reduced microbial *S. aureus* activity.

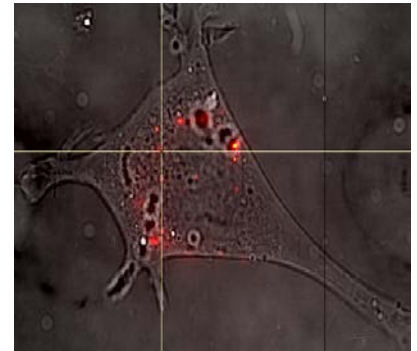
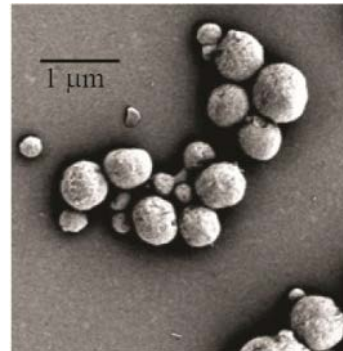


Nanodiamond-silk composite biomaterials

Silk cocoons

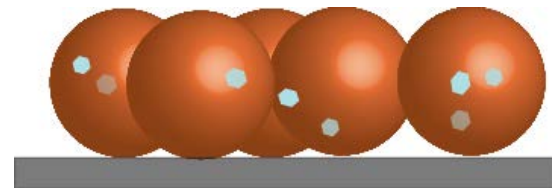


Silk biopolymer: tuneably biodegradable, biocompatible, optically transparent, $n=1.54$



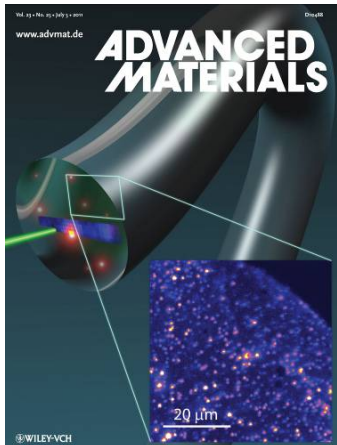
Implantable silk film

Drug loaded nanodiamond silk spheres



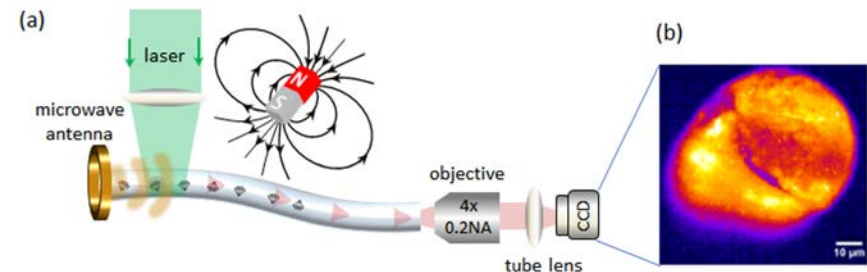
- A. Khalid, et al. *Biomed. Opt. Exp.* (2014)
- A. Khalid, et al. *ACS Biomater. Sci and Eng.* (2015)
- A. Khalid, et al. *Biomed. Opt. Exp.* (2015)
- A. Khalid, et al. *Nanoscale* (2016)

Magnetic field-sensitive optical fibres

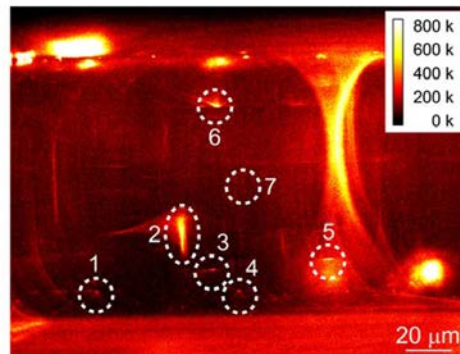
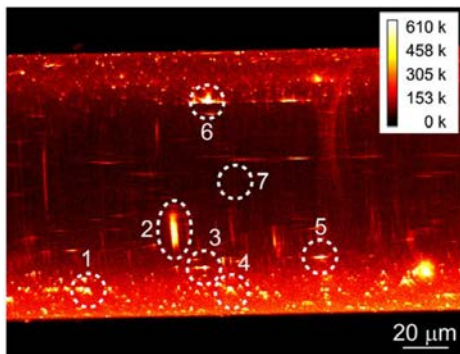


Fluorescent nanodiamond particles **embedded** in tellurite optical fibre – preserving quantum properties from diamond

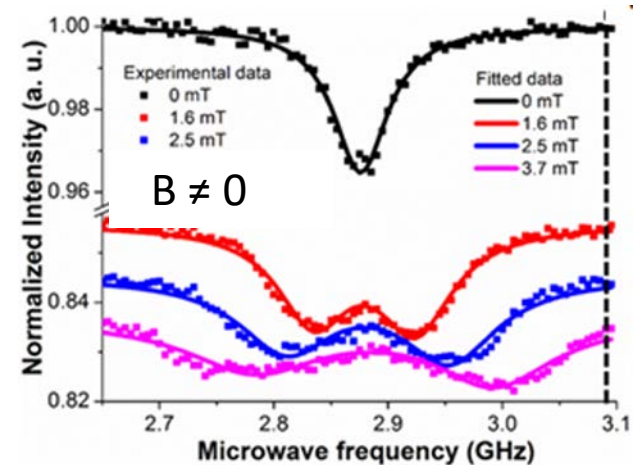
M. R. Henderson, B. C. Gibson, et al., Adv. Mat. **23**, 2806-2810, (2011).



Schematic of hybrid diamond-fibre sensing architecture

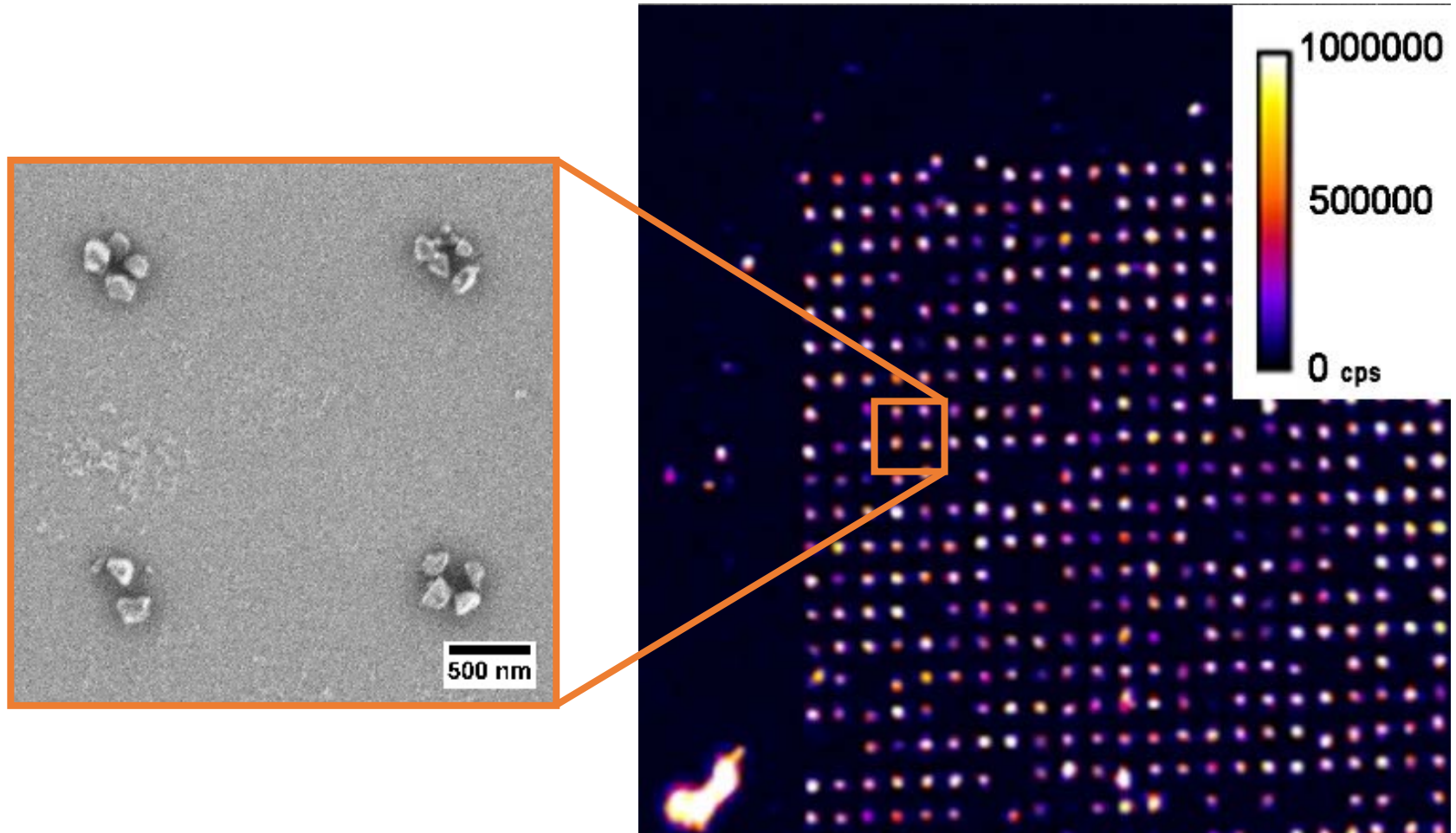


Diamond NV fluorescence from fibre side and end

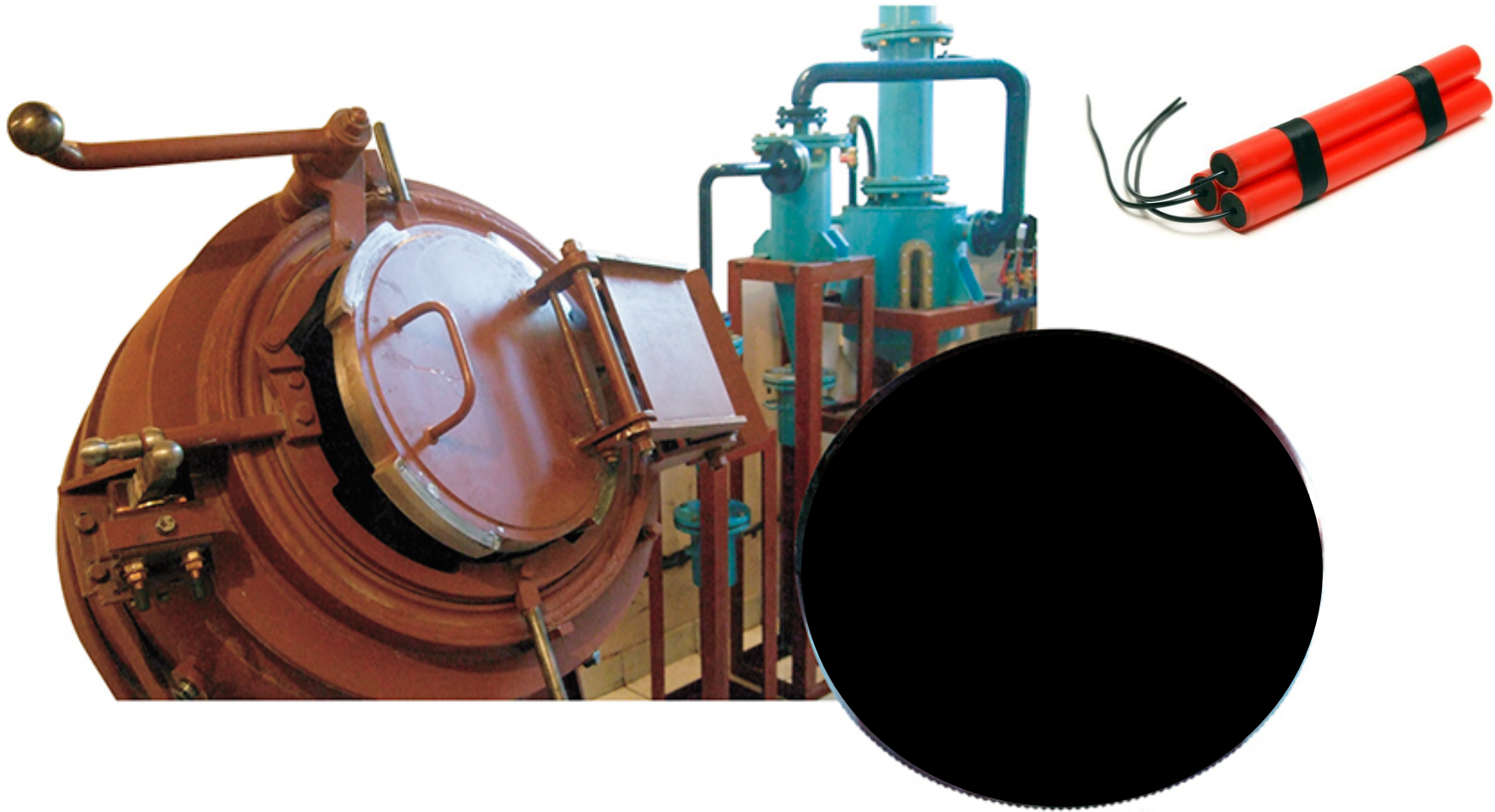


Magnetic sensitivity of 11 $\mu\text{T}/\sqrt{\text{Hz}}$ at room temperature.

Controlled positioning of nanodiamonds

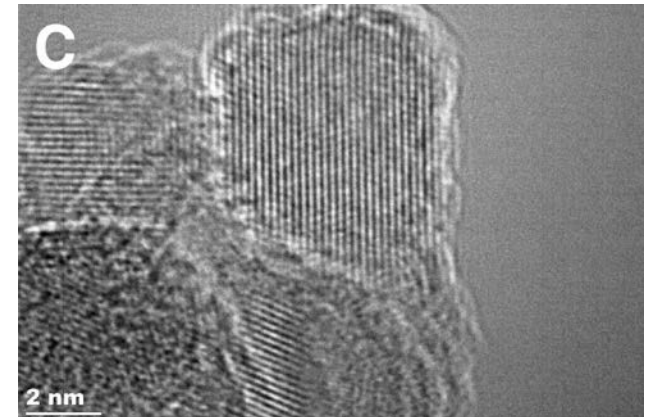
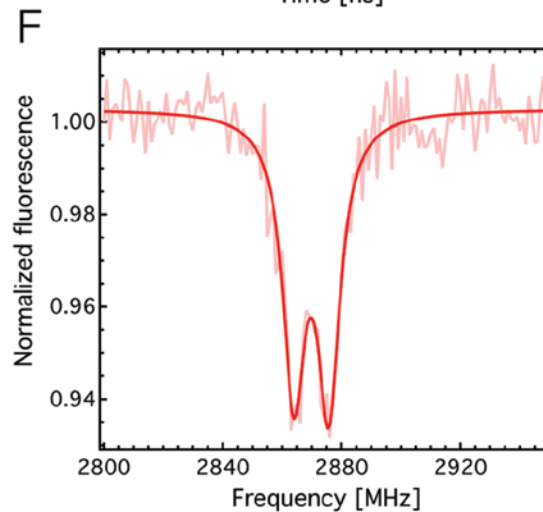
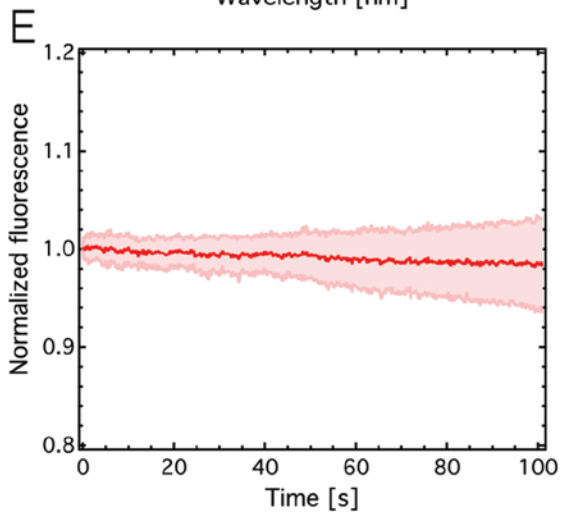
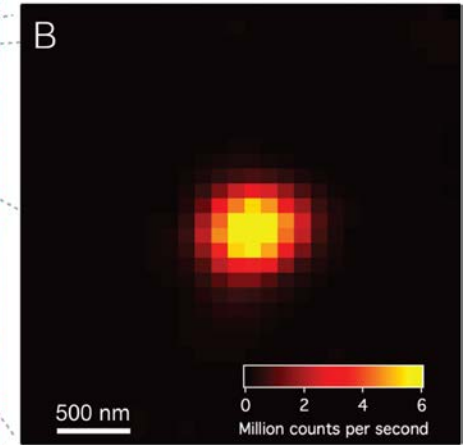
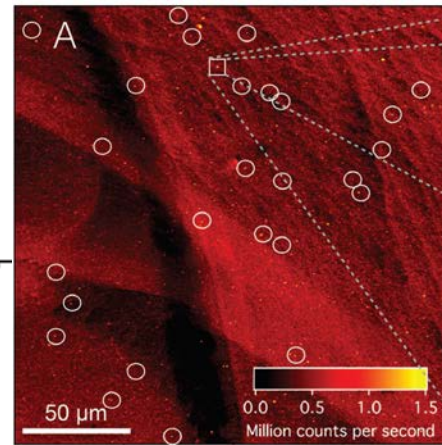
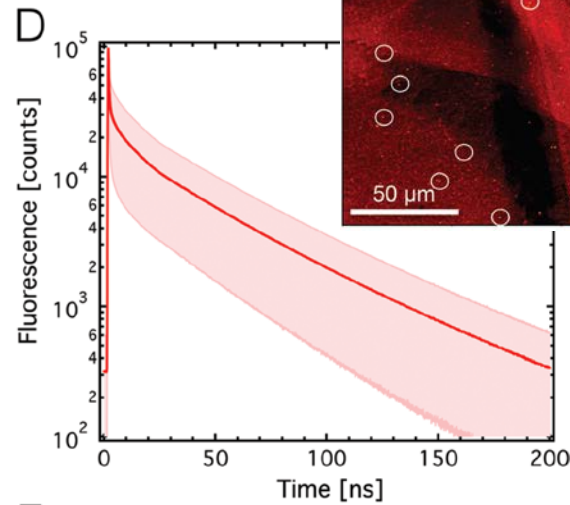
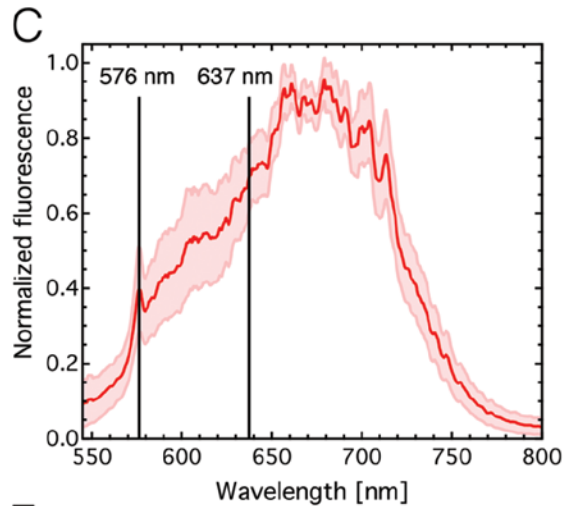


Detonation Nanodiamond (DNDs)



<https://scfh.ru/en/papers/diamonds-born-by-explosion/>

Fluorescent Detonation Nanodiamond



Effect of Surface Chemistry and pH on the Fluorescence of DNDs

