Fluorescent nanodiamonds have disk-like shapes: implications for nanodiamond engineering and quantum sensing applications

Samir Eldemrdash[1*], Giannis Thalassinos,[2*] Amani Alzahrani,[1,3] Qiang Sun[1], Ella Walsh[4], Erin Grant[4], Hiroshi Abe[5], Tamar L. Greaves[1], Takeshi Ohshima[5], Petr Cigler[6], Pavel Matejicek[7], David Simpson[4], Andrew D. Greentree[2], Gary Bryant[1], Brant C. Gibson[2], Philipp Reineck[2]

[1] School of Science, RMIT University, Melbourne, VIC, 3000, Australia
[2] ARC Centre of Excellence for Nanoscale BioPhotonics, School of Science, RMIT University, Melbourne, VIC 3001, Australia
[3] Faculty Of Science and Arts in ALMandaq, Al Baha University, Saudi Arabia
[4] School of Physics, University of Melbourne Parkville, VIC 3052, Australia
[5] Quantum Beam Science Research Directorate and The Institute for Quantum Life Science, National Institutes for Quantum Science and Technology, Takasaki, Gunma 3701292, Japan
[6] Institute of Organic Chemistry and Biochemistry of the CAS, Prague, 166 10, Czech Republic
[7] Department of Physical and Macromolecular Chemistry, Faculty of Science, Charles University, 128 40 Prague 2, Czech Republic

Fluorescent nanodiamonds (FNDs) containing nitrogen-vacancy (NV) centers can be used as nanoscale sensors for temperature and electromagnetic fields and find increasing application in many areas of science and technology from biology to quantum metrology. Often, decreasing the separation between the NV centers and their sensing target strongly enhances the measurement sensitivity. For this reason, there is a significant effort in the manufacture of FNDs with sizes below 30 nm and bright fluorescence from negatively-charged NV centers (NV^-). Milled high-pressure high-temperature diamonds are commonly explored due to their low cost and ready availability. However, FND shape, which cannot practically be controlled in the milling process, strongly affects the distance from NV centers to the particle surface and therefore properties such as brightness and fluorescence spectrum; and can limit sensor applications.

Here, we demonstrate that FNDs made from high-pressure high-temperature diamond have predominantly disk-like shapes. Using single-particle atomic force microscopy (AFM) in combination with ensemble X-ray and light scattering techniques, we show that a typical FND in the 50 – 150 nm size range has an aspect ratio of three i.e. is three times thinner (e.g in z) than it is wide (e.g. in the x-y plane). This high aspect ratio of FNDs is important for many quantum sensing measurements as it will enable enhanced sensitivities compared to spherical or other isotropic particle geometries. We investigate FND shape, fluorescence properties, and T_1 spin relaxation time and T_1 fluorescence contrast as functions of particle size and discuss the implications of FND particle shape on quantum sensing applications.