Surface engineering of diamond for quantum applications: Understanding the surface and its effect on band-bending

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1. Introduction

Defect centres in diamond – specifically the NV defect - are driving an ever-increasing range of advanced sensing applications,(*1, 2*) able to interrogate a wide range of targets from the biological(*3*) to exotic materials.(*4*) Real-world applications include the creation of wide-field magnetic imaging systems(*5*), nano-scale MRI(*6*) and nuclear hyper-polarization systems.(*7*) These real-world applications do however required optically active defects to be increasingly located within micrometers or even nanometres of the diamond surface,(*8*) where their quantum properties such as coherence time, charge state stability and spectral width can suffer significant degradation.(*9*) I will detail our efforts to explore the origins of these surface noise and band-bending effects, through a novel combination of surface spectroscopy(*10*) and defect-based electro-magnetic measurements(*11*).

2. Surface noise as a function of surface chemistry and electron traps

By combining surface chemical and morphological characterisation (surface science) with NV-based noise spectroscopy measurements we find that smoother more highly ordered oxygen-terminated surfaces can be created which significantly suppress noise for implanted NV centres within 10nm of the surface(*11*). We have also identified a ubiquitous electron trap associated with single-vacancy defects at the diamond surface(*10*) and discuss the evidence for this being the primary electro-magnetic noise source in these systems, including a direct comparison of electronic and magnetic components of this noise. Finally, we will present a synchrotron-science experiment used to quantify the concentration of specific oxygen states on the diamond surface.

3. Imaging of band-bending and NV charge state instability

Finally, we will describe how these electron traps are likely to be the cause of band-bending and Fermi-pinning at the diamond surface, in a range of devices. We will present data from NV-based measurements which directly confirms this band-bending(*12*) and contrast different electrostatic environments caused by different surface treatments.

1. L. Rondin *et al.*, *Rep. Prog. Phys.* **77**, 056503 (2014).
2. R. Schirhagl, K. Chang, M. Loretz, C. L. Degen, *Annu. Rev. Phys. Chem.* **65**, 83-105 (2014).
3. L. McGuinness *et al.*, *Nature nanotechnology* **6**, 358-363 (2011).
4. F. Casola, T. van der Sar, A. Yacoby, *Nature Reviews Materials* **3**, 17088 (2018).
5. D. Le Sage *et al.*, *Nature* **496**, 486-489 (2013).
6. T. Häberle, D. Schmid-Lorch, F. Reinhard, J. Wrachtrup, *Nature Nanotechnology* **10**, 125-128 (2015).
7. D. A. Broadway *et al.*, *Nat. Commun.* **9**, 1246 (2018).
8. T. Rosskopf *et al.*, *Phys. Rev. Lett.* **112**, 147602 (2014).
9. J. Wrachtrup, F. Jelezko, B. Grotz, L. McGuinness, *MRS Bulletin* **38**, 149-154 (2013).
10. A. Stacey *et al.*, *Advanced Materials Interfaces* **6**, 1801449 (2019).
11. S. Sangtawesin *et al.*, *Physical Review X* **9**, 031052 (2019).
12. D. A. Broadway *et al.*, *Nature Electronics* **1**, 502-507 (2018).