



**UNIVERSITY OF
TECHNOLOGY SYDNEY**

Diamond based nanoelectronics and imaging

A thesis submitted for the degree of Doctor of Philosophy at

University of Technology Sydney

Faculty of Science

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January 2019

Certificate of Original Authorship

I, Kerem Bray, certify that the work in this dissertation entitled, “Diamond based nanoelectronics and diagnostics”, has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also attest that the dissertation has been written by myself. Any help that I have received in my research work and the preparation of the dissertation itself has duly been acknowledged. In addition, I certify that all information sources and literature used are indicated in the dissertation.

This research is supported by an Australian Government Research Training Program Scholarship.

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Acknowledgments

Firstly, I would like to acknowledge and thank my supervisor, Prof. Igor Aharonovich, for allowing me to undertake my PhD and to be able to partake in the interesting fields of nanophotonics and material fabrication. I am thankful for your guidance and being available to lend aid with my academic difficulties. I have been able to learn a lot from your quick replies to many of my questions over the course of my candidature. Thanks to your mentorship, you have allowed me to grow as an experimental scientist and, for that I am grateful.

I would also like to thank my co-supervisors Dr. Olga Shimoni and Dr. Stella Valenzuela and, in addition Prof. Milos Toth. You have motivated me with your helpful comments and advice. You made time to offer valuable help and encouragement while also allowing me to pursue additional research that has arisen. I thank you for all of your support.

Additionally, I would like to thank Katie McBean for all her help in the lab, by training me on the various instruments around the Micro Analysis Unit (MAU), being available to answer my questions, as well as her invaluable help with the bureaucracy side of research. I also want to thank Geoff McCredie, Angus Gentle for their constant assistance around the MAU and vacuum labs. I am also thankful for Mark Berkahn for his assistance with the AFM and XRD machines.

I would like to acknowledge and thank the collaborators whom I have worked with over the years. I am grateful to Hiromitsu Kato and his group at the National Institute of Advanced Industrial Science and Technology (AIST), Japan for their invaluable help with diamond doping. Additionally, I would like to thank Dr. Kumaravelu Ganesan from the University of Melbourne for his help with diamond implantation. I would also like to thank Prof. Alexander Kubanek from the University of Ulm for hosting me at your lab and collaborating with us over the years. Furthermore, I also would like to thank Asst. Prof. Dirk Englund at the Massachusetts Institute of Technology (MIT) for our fruitful collaboration on a wide variety of research projects.

I would like to show my appreciation my fellow students at the MAU for their consistent support and creating a positive and enjoyable environment to work in. I would like to thank my fellow doctoral students for all the support and shared laughter, even in the most

stressful of times. To the Device & Development (D&D) group for the wonderful nights of imagination where I were able to explore many scenarios, I would like to show my appreciation.

To my partner Freya Whereat, thank you for all your patience through the past couple of years and supporting me through it all. You lifted me up through the stressful times.

Lastly, to my mother Munerva Bray, thank you for your unconditional love and support through all of the years.

List of Publications

Refereed journal publications

- 1) **K. Bray**, R. Previdi, B.C. Gibson, O. Shimoni and I. Aharonovich, “*Enhanced photoluminescence from single nitrogen-vacancy defects in nanodiamonds coated with phenol-ionic complexes*”, *Nanoscale*, Vol 11, issue 11, 4869-4874, 2015
- 2) **K. Bray**, R. Sandstrom, C. Elbadawi, M. Fischer, M. Schreck, O. Shimoni, C. Lobo, M. Toth, I. Aharonovich, “*Localization of narrowband single photon emitters in nanodiamonds*”, *ACS Applied Materials & Interfaces*, Vol 8, issue 11, 7590-7594, 2016. (Chapter 6)
- 3) **K. Bray**, H. Kato, R. Previdi, R. Sandstrom, K. Ganesan, M. Ogura, T. Makino, S. Yamasaki, A. P. Magyar, M. Toth, I. Aharonovich, “*Single crystal diamond membranes for nanoelectronics*”, *Nanoscale*, Vol. 10, 4028-4035, 2018. (Chapter 4 and Chapter 5)
- 4) **K. Bray**, A. Trycz, R. Previdi, B. Regan, G. Seniutinas, K. Ganesan, M. Kianinia, S. Kim, I. Aharonovich, “*Single crystal diamond membranes containing germanium vacancy centres*”, (arxiv)
- 5) **K. Bray**, L. Cheung, K. R. Hossain, I. Aharonovich, S. M. Valenzuela, O. Shimoni, “*Versatile Multicolor Nanodiamond Probes for Intracellular Imaging and Targeted Labeling*”, *Journal of Materials Chemistry B*, Vol. 6, 3078-3084, 2018 (Chapter 7)
- 6) T. T. Tran, J. Fang, H. Zhang, P. Rath, **K. Bray**, R. Sandstrom, O. Shimoni, M. Toth and I. Aharonovich, “*Facile Self-Assembly of Quantum Plasmonic Circuit Components*”, *Advanced Materials*, Vol. 27, issue 27, 4048-4053, 2015.
- 7) T. T. Tran, **K. Bray**, M. J. Ford, M. Toth and I. Aharonovich, “*Quantum Emission from Hexagonal Nitride Monolayers*”, *Nature Nanotechnology*, Vol. 11, Issue 1, 37, 2016.
- 8) T. T. Tran, C. Zachreson, A. M. Berhane, **K. Bray**, R. Sandstrom, L. H. Li, T. Taniguchi, K. Watanabe, I. Aharonovich, and M. Toth, “*Quantum Emission from Defects in Single-Crystalline Hexagonal Boron Nitride*”, *Physical Review Applied*, Vol 5, Issue 3, 034005, 2016

9) T. T. Tran, M. Kianinia, **K. Bray**, S. Kim, Z.-Q. Xu, A. Gentle, B. Sontheimer, C. Bradac, I. Aharonovich, “*Nanodiamonds with photostable, sub-gigahertz linewidth quantum emitters*”, APL Photonics, Vol. 2, Issue 11, 116103, 2017 (Chapter 6)

10) S. Häußler, J. Benedikter, **K. Bray**, B. Regan, A. Dietrich, J. Twamley, I. Aharonovich, D. Hunger, A. Kubanek, “*A Diamond-Photonics Platform Based on Silicon-Vacancy Centers in a Single Crystal Diamond Membrane and a Fiber-Cavity*”, ArXiv, 2018.

Conference presentations (Oral)

K. Bray et al., “*Localization of narrowband single photon emitters in nanodiamonds*”, Diamond and Carbon Related Materials (DCM), 2016, Montpellier, France.

Received Young Scholar Award for this presentation.

K. Bray et al., “*Localization of narrowband single photon emitters in nanodiamonds*”, Conference on Optoelectronic and Microelectroni Materials and Devices (COMMAD), 2016, Sydney, Australia.

K. Bray et al., “*Single crystal diamond membranes for nanoelectronics*”, International Conference of Nanoscience and Nanotechnology (ICONN), 2018, Wollongong, Australia.

Conference presentations (Poster)

K. Bray et al., “*Enhanced Photoluminescence from single nitrogen vacancy defects in nanodiamonds coated with phenol ionic complexes*”, Australian Nanotechnology Network (ANN), 2015, Queensland, Australia.

K. Bray et al., “*Enhanced Photoluminescence from single nitrogen vacancy defects in nanodiamonds coated with phenol ionic complexes*”, International Conference of Nanoscience and Nanotechnology (ICONN), 2016, Canberra, Australia.

K. Bray et al., “*Enhanced Photoluminescence from single nitrogen vacancy defects in nanodiamonds coated with phenol ionic complexes*”, Conference on Optoelectronic and Microelectroni Materials and Devices (COMMAD), 2016, Sydney, Australia.

K. Bray et al., “*Localization of narrowband single photon emitters in nanodiamonds*”, Conference on New Diamond and Nano-carbons (NDNC), 2016, Cairns, Australia.

K. Bray et al., “*Versatile Nanodiamond Probes for Intracellular Imaging*”, Conference on New Diamond and Nano-carbons (NDNC), 2016, Cairns, Australia.

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List of Abbreviations

Abbreviation	Meaning
AFM	Atomic Force Microscope
APD	Avalanche Photo Diode
BASD	Bead-Assisted Sonication Disintegration
CB	Conductance Band
CHO	Chinese Hamster Ovarian
CL	Cathodoluminescence
CPP	Cell Penetrating Peptide
CVD	Chemical Vapour Deposition
CW	Continuous Wavelength
EBIE	Electron Beam Induced Etching
EL	Electroluminescence
FIB	Focused Ion Beam
FWHM	Full Width at Half Maximum
GaN	Gallium Nitride
GeV	Germanium Vacancy
HBT	Hanbury Brown and Twiss
HPHT	High Pressure High Temperature
DW	Debye-Waller
ICP-RIE	Inductively Coupled Plasma - Reactive Ion Etching
IR	Infrared
LEDs	Light Emitting Diodes
MEM	Micro-Electromechanical System

MPCVD	Microwave Plasma Chemical Vapour Deposition
ND	Nanodiamond
NIR	Near Infra-Red
NV	Nitrogen Vacancy
PL	Photoluminescence
QDs	Quantum Dots
QE	Quantum Efficiency
SCR	Space Charge Region
SEM	Scanning Electron Microscopy
SiC	Silicon Carbide
SiV	Silicon Vacancy
SnV	Tin-Vacancy
SPE	Single Photon Emitter
SPS	Single Photon Source
SRIM	Stopping and Range of Ions in Matter
SIMS	Secondary Ion Mass Spectrometry
STED	Stimulated Emission Depletion
TEM	Transmission Electron Microscope
UV	Ultraviolet
VB	Valance Band
ZPL	Zero Phonon Line

Abstract

To investigate new pathways for numerous quantum technologies it is necessary to efficiently fabricate various interesting materials. Single photon sources that are optically and electrically triggerable are the fundamental building blocks required to push the boundaries of several applications, such as realising secure communication technologies. Accordingly, various platforms are being investigated for generation of single photon emitters (SPEs). Diamond is one platform of great interest, due to its ability to host several photostable, optically active SPE defects that can operate at room temperature. Numerous diamond defects have been studied extensively, including the Nitrogen vacancy (NV), Silicon vacancy (SiV) and, recently, the Germanium vacancy (GeV) colour centres. All were shown to be robust room temperature SPEs. Despite promising reports on quantification and applications of diamond-based defects, the search continues to find an emitter that can excel at most applications.

Another important factor for the utility of colour centres is the method of excitation. While optical pumping is common practice, the ability to electrically excite emitters is highly desired for optoelectronic applications. Several reports exist on the fabrication and characterisation of electrical device structures of various materials, including Gallium Nitride, Silicon Carbide, Zinc Oxide and diamond defects. The central part of the thesis delves into the fabrication of high aspect ratio, thin, nanoscale, conductive diamond membranes hosting SiV colour centres, which demonstrate key advantages, such as being easily transferrable to a variety of structures.

Secondly, I investigate unknown narrowband SPEs in diamond nanocrystals, which are preferable for nanophotonic, quantum communications and bio-imaging applications. The origin of the narrowband emission is determined to be point defects localised at extended morphological defects in individual nanodiamond particles. Furthermore, a highly polarised, narrowband, possessing sub GHz optical linewidths was observed at cryogenic temperatures.

Finally, I exploit the optimal fluorescent, chemical and biocompatibility properties for multi-colour tagging of CHO-K1 and U937 cell lines using both NV⁻ and, for the first time, SiV diamond colour centres, to investigate their intracellular properties. The non-toxic SiV diamond nanocrystals initially dispersed throughout the cell interior while tagged NV nanocrystals localised close to the nucleus.

Therefore, this work reports new findings in spectroscopic studies of diamond-based colour centres that can be excited optically and electrically. Furthermore, it provides detailed evidence

which forms the building blocks for future investigation into diamond-based devices and SPEs for a wide variety of applications. The results presented in this thesis therefore provide a new and interesting platform for applications using defect based nanophotonics.