RGC Reference **CUHK4/CRF/12G**
please insert ref. above

The Research Grants Council of Hong Kong
Collaborative Research Fund Group Research Projects
Completion Report

(*for completed projects only*)

Part A: The Project and Investigator(s)

1. Project Title

Multifunctional ultrasensitive sensing with hybrid gold-diamond nano-systems

基於金-鑽石複合納米系統的多功能超靈敏探測

2. Investigator(s) and Academic Department/Units Involved *(please highlight approved changes in the composition of the project team and quote the date when RGC granted approval of such changes)*

Research Team	Name/Post	Unit/Department/Institution	Average number of hours per week spent on this project in the current reporting period
Project Coordinator	Prof. Renbao LIU	Physics/CUHK	10
Co-Principal investigator(s)	Prof. Quan LI Prof. Jianfang WANG Prof. Xiaodong CUI Prof. Hongkai WU	Department of Physics/CUHK Department of Physics/CUHK Department of Physics/HKU Department of Chemistry/ HKUST	8 6 3 3
Collaborators/ Others			

3. Project Duration

	Original	Revised	Date of RGC Approval *(must be quoted)*
Project Start Date	15/06/2013		
Project Completion Date	14/06/2016		
Duration (*in month*)	36		
Deadline for Submission of Completion Report	14/06/2017		

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Part B: The Final Report

5. Project Objectives

5.1 Objectives as per original application

1. *Synthesis and characterization of hybrid gold-diamond nanosystems.* Gold nanoparticles, with controllable size and shape, have light emission and absorption greatly enhanced by plasmons whose modes and frequencies are tuneable. The nitrogen-vacancy (NV) defect centers in nanodiamonds are both optically and magnetically active. Gold nanoparticles have enhanced light efficiency but are not magnetically sensitive. Nanodiamonds are ideal for optical detection of magnetic resonance (ODMR) but have low optical efficiency. In this project we will synthesize hybrid gold-diamond nanosystems to exploit advantages of both systems for multifunctional sensing. Such synthesis is feasible due to the flexibility of surface engineering of both materials. We will characterize the optical and magnetic resonance properties of the hybrid systems and optimize the synthesis.

2. *Plasmon-enhanced ODMR using hybrid gold-diamond nanosystems, for monitoring local environments at nanoscales.* We will investigate the effects of surface engineering and integration with gold nanoparticles on ODMR of NV centers in nanodiamonds. The magnetic resonance frequency, spin coherence lifetime, and charge state (hence the fluorescence spectrum) of NV centers in nanodiamonds are sensitive to the temperature, magnetic, chemical, and charge environments as well as to the orientation of the nanodiamonds. Therefore we will develop the multifunctional of the environments. We will employ microfluidic circuits to provide controllable chemical, temperature, and fluidic environments for benchmark investigation on the sensitivity and efficiency of the nano-sensors. We will further optimize the design and synthesis of the hybrid nanosystems.

3. *Nanoscale ODMR study of plasmon-enhanced photothermal and photocatalytic effects of gold nanoparticles*. Gold nanoparticles have strong photothermal effects due to plasmon-enhanced absorption, which can in turn activate chemical reactions. Also, the plasmon-enhanced absorption can strongly improve the photocatalytic effect through generation of hot electrons. Both the photothermal and the photocatalytic effects have important applications in solar energy harvesting, artificial photosynthesis, and environment monitoring. The magnetic resonance frequency and width of NV centers in nanodiamonds depend sensitively on the local temperature and chemical environment (such as radical concentration), respectively. With the feasibility of *in situ* monitoring offered by the hybrid nanosystems, we will use the ODMR of the NV centers in nanodiamonds to study the microscopic mechanisms of the photothermal and photocatalytic processes in gold nanoparticles.

4. *In vitro investigation and functionalization of the hybrid gold-diamond nano-sensors.* The cytotoxicity and biodistribution of the hybrid nanoparticles are sensitive to their surface morphology, chemistry and charge states. Although both gold nanoparticles and nanodiamonds are suggested to have little cytotoxicity after proper surface cleaning, their biodistributions differ significantly. Functionalization of the hybrid gold-diamond nanosystem would be further carried out for biological and medical applications, such as controlled cellular uptake, drug delivery and activation, and generation of reactive oxygen species. The surface functionalization and the hybridization of the nanoparticles raise new questions on the cytotoxicity issue and also modify the biodistribution of the nanoprobes. An especially important question to be addressed is how the biodistribution and toxicity of the nanoparticles would be affected by the surface modification (which is necessary for forming the hybrid probe) and photo-activation (by optical excitation of plasmons in gold nanoparticles). This project will systematically study the cellular uptake of the hybrid nanosystems, functionalization of the hybrid nano-probe, and its biological consequences.

5.2 Revised objectives

Date of approval from the RGC: 3 March 2013

Reasons for the change: The objectives were adjusted according to available fund.

1. *Synthesis and characterization of hybrid gold-diamond nanosystems.* Gold nanoparticles, with controllable size and shape, have light emission and absorption greatly enhanced by plasmons whose modes and frequencies are tuneable. The nitrogen-vacancy (NV) defect centers in nanodiamonds are both optically and magnetically active. Gold nanoparticles have enhanced light efficiency but are not magnetically sensitive. Nanodiamonds are ideal for optical detection of magnetic resonance (ODMR) but have low optical efficiency. In this project we will synthesize hybrid gold-diamond nanosystems to exploit advantages of both systems for multifunctional sensing. Such synthesis is feasible due to the flexibility of surface engineering of both materials. We will characterize the optical and magnetic resonance properties of the hybrid systems and optimize the synthesis.

2. *Plasmon-enhanced ODMR using hybrid gold-diamond nanosystems, for monitoring local environments at nanoscales.* The magnetic resonance frequency and spin coherence lifetime of NV centers in nanodiamonds are sensitive to the temperature, magnetic, and chemical environments. We will use controllable chemical and temperature environments for benchmark investigation on the sensitivity and efficiency of the nano-sensors. We will further optimize the design and synthesis of the hybrid nanosystems.

3. *Nanoscale ODMR study of plasmon-enhanced photothermal effects of gold nanoparticles*. Gold nanoparticles have strong photothermal effects due to plasmon-enhanced absorption, which can in turn activate chemical reactions. The photothermal effects have important applications in solar energy harvesting, artificial photosynthesis, and environment monitoring. The magnetic resonance frequency of NV centers in nanodiamonds depends sensitively on the local temperature, respectively. With the feasibility of *in situ* monitoring offered by the hybrid nanosystems, we will use the ODMR of the NV centers in nanodiamonds to study the microscopic mechanisms of the photothermal processes in gold nanoparticles.

4. *In vitro investigation and functionalization of the hybrid gold-diamond nano-sensors.* The intracellular distribution and the interaction of the hybrid nanoparticles with cells are sensitive to a number of material parameters, including the particles' surface morphology, chemistry and charge states. These will be investigated in a systematic manner. Functionalization of the hybrid gold-diamond nanosystem would be further carried out for biological and medical applications, e.g. generation of reactive oxygen species. The surface functionalization and the hybridization of the nanoparticles raise new questions on the cell nanoparticle interaction. This project will systematically study the cellular uptake of the hybrid nanosystems, functionalization of the hybrid nano-probe, and its biological consequences.

6. Research Outcome

6.1 Major findings and research outcome

(maximum 1 page; please make reference to Part C where necessary)

TEM-ODMR correlation microscopy [Feng et al, paper in 2017 MRS Spring Meeting; N. Wang et al, submitted to Nat Comm]. Correlation between the morphological feature and the magnetic properties of single magnetic nanoparticles (size in the range of a few tens of nanometers) has been established by using bare ND sensors placed in the close vicinity of the MNPs. The shape, size, and chemical composition of MNPs and NDs can be individually measured using TEM with sub-nanometer spatial resolution. The confocal images of the carbon film on the TEM grid can be employed as a spatial pattern for identifying coupling between individual FNDs and MNPs with precise information about the size, shape, composition, and separation. The TEM-ODMR correlation method has been the basis for developing the ND-MNP hybrid nano-thermometer (see below).

Hybrid nano-thermometer [N. Wang et al, submitted to Nat Comm]. We designed and experimentally demonstrated a hybrid sensor composed of a nanodiamond and a magnetic nanoparticle. The NV center spin transitions in the ND are sensitive to the magnetization of the MNP. Near the ferromagnetic-paramagnetic phase transition temperature, a small temperature change would induce a large change of the magnetization and hence can be sensitively detected by the NV centers. The theoretical sensitivity can reach 2 $\mu K/Hz^{1/2}$ and the experimentally demonstrated sensitivity is **46 $mK/Hz^{1/2}$**, a *world record* of nano-thermometer under ambient conditions.

ND-Cell interaction and sensing in live cells [Chu et al, Sci Rep 2014, 4: 4495]. We developed surface functionalization methods for NDs, including surface charge and surface chemistry manipulation, and significantly improved their dispersity in biological environment. We have also realized preferential plasma membrane anchoring or internalization of the nanodiamond by controlling their morphologies. We have provided a complete picture on the intracellular translocation of the NDs, after their entering the cell interior. Shape of the ND has been identified as an independent parameter in determining the characteristics of their intracellular trafficking. These studies form the foundation of quantum sensing in live cells. We started the subcellular sensing experiments by measuring ODMR of bare NDs at different subcellular sites. We measured the temperature evolution of NDs at specific subcellular sites under external stimuli. In particular, we measured local temperature change of mitochrondria together with characterization of the physiology evolution of cells upon the introduction of chemical stimuli. The complicated intracellular environment and the rather insensitive nature of the bare ND sensor, however, lead to uncertainty in the measurement results.

Sensing algorithm development [Ma et al, Phys Rev Applied 2016]. We have designed new schemes, based on quantum coherence control of NV center spins in diamond, for atomic-scale magnetic resonance imaging of nuclear spins. Control pulse sequences were also designed to extract multi-dimensional correlations between nuclear spins. These schemes (published in a series of Physical Review Applied papers) may enable conformation analysis of bio-molecules as demonstrated by our numerical simulations. For sensor development experiments, we have also optimized the data acquisition methods [N. Wang et al, submitted to Nat Comm].

6.2 Potential for further development of the research and the proposed course of action *(maximum half a page)*

There are several directions along which the hybrid sensors developed in this CRF project can be applied and can be extended:

1) The hybridization of the magnetic nanoparticles and nanodiamonds can be generalized by introducing chemical transducers between the NDs and the MNPs (such as hydrogels) so that temperature and other parameters (such as pH and glucose concentration) can be sensitively measured by the ODMR of NV centers in diamonds;
2) The hybrid nano-sensors can be applied to study nano-plasmonics and the heating effects;
3) The hybrid nano-sensors can be applied to study heat-related biological processes such as the expression of heat-shock proteins;
4) It is critical to understand the critical behaviors of nano-magnetism. The hybrid sensor provide an ideal platform and method to investigate the critical fluctuations of magnetic nanoparticles (Q. Li and R. Liu have submitted a new proposal for the RGC/CRF).

6.3 Research collaboration achieved *(please give details on the achievement and its relevant impact)*

We have consolidated collaboration of the local research community in the field of quantum technology in general and quantum sensing in particular. In this collaboration, they have set up the first optically detected magnetic resonance (ODMR) system and realized the single spin detection capability in Hong Kong; they set up the integrated system of atomic force microscopy and ODMR; they synthesized, characterized and demonstrated the hybrid nanodiamond sensor with a world-record sensitivity (~40 mk/Hz$^{1/2}$).

The Hong Kong team has deepened their collaboration with Professor Wrachtrup's group in University of Stuttgart. Stuttgart's group has provided high-quality diamond samples to Hong Kong and has helped set up the ODMR system in CUHK. They have also worked closely in testing temperature measurement in live cells.

The state-of-the-art sensitivity achieved by the ND-MNP hybrid sensor make it extremely promising of temperature measurement in many solid state systems as well as biological systems. The work aroused much interest worldwide, leading to new collaboration with a French team on "new Nano thermometry development for plasmonic applications", and another collaboration with an Australia team led by Professor Hollenberg in University of Melbourne on "mapping the temperature of live systems using wide field ODMR". Now one PhD student is visiting University of Melbourne to help apply the hybrid sensor for wide-field measurement of temperature gradients in membranes of live cells.

7. The Layman's Summary

(describe <u>in layman's language</u> the nature, significance and value of the research project, in no more than 200 words)

Magnetic resonance spectroscopy has a broad range of applications such as NMR and MRI used in hospitals. A new opportunity in this field is the emergence of optically detected magnetic resonance using paramagnetic color centers in diamond, which has potential of monitoring chemical, biological and thermal processes with nanometer resolution. In this project, we developed nano-sensors based on hybrid systems of nanodiamonds and magnetic nanoparticles for enhanced optically detected magnetic resonance. The magnetic nanoparticles are designed to have a sharp transition from a magnetic phase to a paramagnetic one with changing temperature near the critical point. Therefore, the magnetic resonances of the color centres in the nanodiamonds shifts abruptly with temperature change. The hybrid nanodiamond sensor provides an ultrasensitive nano-thermometer, with sensitivity of 0.1 Celsius degree in less than 1 second. This hybrid nano-thermometer may find broad applications in biological studies.

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Part C: Research Output

8. Peer-reviewed journal publication(s) arising directly from this research project

(Please attach a copy of the publication and/or the letter of acceptance if not yet submitted in the previous progress report(s). All listed publications must acknowledge RGC's funding support by quoting the specific grant reference.)

The Latest Status of Publications				Author(s) *(denote the corresponding author with an asterisk*)*	Title and Journal/Book *(with the volume, pages and other necessary publishing details specified)*	Submitted to RGC *(indicate the year ending of the relevant progress report)*	Attached to this report *(Yes or No)*	Acknowledged the support of RGC *(Yes or No)*	Accessible from the institutional repository *(Yes or No)*
Year of publication	Year of Acceptance (For paper accepted but not yet published)	Under Review	Under Preparation (optional)						
		Under review in Nature Communications		Ning Wang, Gang-Qin Liu, Weng-Hang Leong, Hua-Ling Zeng, Xi Feng, Si-Hong Li, Florian Dolde, Helmut Fedder, Jörg Wrachtrup, Xiao-Dong Cui, Sen Yang, Quan Li* and Ren-Bao Liu*	Magnetic criticality enhanced hybrid nanodiamond-thermometer under ambient conditions	No	Yes	Yes	No
2017				Bokai Zhang, Xi Feng, Hang Yin, Zhenpeng Ge, Yanhuan Wang, Zhiqin Chu, Helena Raabova, Jan Vavra, Petr Cigler, Ren-Bao Liu, Yi Wang* & Quan Li*	*Scientific Reports* **7**, 46462 (2017). Anchored but not internalized: shape dependent endocytosis of nanodiamond. https://doi.org/10.1038/srep46462	No	Yes	Yes	No
2017				Gang-Qin Liu, Jian Xing, Wen-Long Ma, Ping Wang, Chang-Hao Li, Hoi Chun Po, Yu-Ran Zhang, Heng Fan, Ren-Bao Liu, and Xin-Yu Pan*	Phys. Rev. Lett. 118, 150504 – Published 12 April 2017). Single-Shot Readout of a Nuclear Spin Weakly Coupled to a Nitrogen-Vacancy Center at Room Temperature https://doi.org/10.1103/PhysRevLett.118.150504	No	Yes	Yes	No
2016				Wen-Long Ma and Ren-Bao Liu*	Physical Review Applied 6, 054012 (23 November 2016). Proposal for Quantum Sensing Based on Two-Dimensional Dynamical Decoupling:	No	Yes	Yes	No

					NMR Correlation Spectroscopy of Single Molecules. https://doi.org/10.1103/PhysRevApplied.6.054012				
2016				Wen-Long Ma and Ren-Bao Liu*	Phys. Rev. Applied 6, 024019 (26 August 2016). Angstrom-Resolution Magnetic Resonance Imaging of Single Molecules via Wave-Function Fingerprints of Nuclear Spins	No	Yes	Yes	No
2016				Wen-Long Ma, Shu-Shen Li, Geng-Yu Cao, and Ren-Bao Liu*	Physical Review Applied 5, 044016 (25 April 2016). Atomic-Scale Positioning of Single Spins via Multiple Nitrogen-Vacancy Centers	No	Yes	Yes	No
2015				J. E. Lang, R. B. Liu, and T. S. Monteiro*	Physical Review X 5, 041016 (30 Oct 2015). Dynamical-Decoupling-Based Quantum Sensing: Floquet Spectroscopy	No	Yes	Yes	No
2015				Wen-Long Ma, Gary Wolfowicz, Shu-Shen Li, John J. L. Morton*, and Ren-Bao Liu*	Physical Review B 92, 161403(R) (8 Oct 2015). Classical nature of nuclear spin noise near clock transitions of Bi donors in silicon	No	Yes	Yes	No
2014				Nan Zhao*, Jorg Wrachtrup and Ren-Bao Liu	Physical Review A 90, 032319 (2014). Dynamical decoupling design for identifying weakly coupled nuclear spins in a bath	No	Yes	Yes	No
2014				Zhenpeng Ge, Quan Li, Yi Wang*	"Free Energy Calculation of Nanodiamond -Membrane Association-The Effect of Shape and Surface Functionalization", Journal of Chemical Theory and Computation 2014, 10 (7), pp 2751–2758	2014	Yes	Yes	No
2014				Zhiqin Chu, Silu Zhang, Bokai Zhang,	Unambiguous observation of shape	2014	Yes	Yes	No

				Chunyuan Zhang, Chia-Yi Fang, Ivan Rehor, Petr Cigler, Huan-Cheng Chang, Ge Lin, Renbao Liu & Quan Li*	effects on cellular fate of nanoparticles", Scientific Reports 2014, 4 : 4495 | DOI: 10.1038/srep04495				
2016				Xingzhong Zhu, Xiaolu Zhuo, Qian Li, Zhi Yang*, Jianfang Wang*	Gold nanobipyramid-supported silver nanostructures with narrow plasmon linewidths and improved chemical stability, Advanced Functional Materials, 26, 341-352.	No	Yes	Yes	No
2016				Wei Gao, Yih Hong Lee, Ruibin Jiang, Jianfang Wang, Tianxi Liu*, Xing Yi Ling*	Localized and continuous tuning of monolayer MoS_2 photoluminescence using a single shape-controlled Ag nanoantenna, Advanced Materials, 28, 701-706.	No	Yes	Yes	No
2016				Ruibin Jiang, Feng Qin, Yejing Liu, Xing Yi Ling, Jun Guo, Minghua Tang, Si Cheng, Jianfang Wang*	Colloidal gold nanocups with orientation-dependent plasmonic properties, Advanced Materials, 28, 6322-6331.	No	Yes	Yes	No
2016				Feng Qin, Tian Zhao, Ruibin Jiang, Nina Jiang, Qifeng Ruan, Jianfang Wang*, Ling-Dong Sun*, Chun-Hua Yan*, Hai-Qing Lin	Thickness control produces gold nanoplates with their plasmon in the visible and near-infrared regions, Advanced Optical Materials, 4, 76-85.	No	Yes	Yes	No
2016				Feng Qin, Ximin Cui, Qifeng Ruan, Yunhe Lai, Jianfang Wang*, Hongge Ma, Hai-Qing Lin	Role of shape in substrate-induced plasmonic shift and mode uncovering on gold nanocrystals, Nanoscale, 8, 17645-17657.	No	Yes	Yes	No
2016				Yang Shen, Xizhe Cheng, Guozhen Li, Qiangzhong Zhu, Zhenguo Chi, Jianfang Wang*, Chongjun Jin*	Highly sensitive and uniform surface-enhanced Raman spectroscopy from grating-integrated plasmonic nanograss, Nanoscale Horizons, 1, 290-297.	No	Yes	Yes (typo in citing the project code: CUHK1/CRF/12G)	No
2016				Yijie Yang, Yih Hong Lee*, In Yee Phang, Ruibin Jiang, Howard Yi Fan Sim, Jianfang	A chemical approach to break the planar configuration of Ag nanocubes into tunable	No	Yes	Yes (typo in citing the	No

				Wang, Xing Yi Ling*	two-dimensional metasurfaces, Nano Letters, 16, 3872-3878.			project code: CUHK1/CRF/12G)	
2014				Xiao-Ming Zhu, Caihong Fang, Henglei Jia, Yu Huang, Christopher H. K. Cheng, Chun-Hay Ko, Zhiyi Chen, Jianfang Wang*, Yi-Xiang J. Wang*	Cellular uptake behavior, photothermal therapy performance, and cytotoxicity of gold nanorods with various coatings, Nanoscale 2014, 6, 11462-11472.	2014	Yes	Yes	No
2016				Yan Li, Xueqin Jiang, Huixiang Zhong, Wen Dai, Jianhua Zhou*, Hongkai Wu*	Hierarchical Patterning of Cells with a Microeraser and Electrospun Nanofibers, Small, 2016, 12, 1230-1239	No	Yes	Yes	Yes
2016				Xiaobin Liang, Xuetao Shi*, Serge Ostrovidov, Hongkai Wu*, Ken Nakajima	Probing stem cell differentiation using atomic force microscopy, Applied Surface Science, 2016, 366, 254-259	No	Yes	Yes	Yes
2016				Bo Shen, Hongkai Wu*	Aqueous and Nonaqueous Electrochemical Sensing on Whole-Teflon Chip ACS Sensors 2016, 1, 251-257	No	Yes	Yes	Yes
2015				Yin Chen, Junping Wang, Bo Shen, Camie WY Chan, Chaoyi Wang, Yihua Zhao, Ho N Chan, Qian Tian, Yangfan Chen, Chunlei Yao, I Hsing, Ronald A Li*, Hongkai Wu*	Engineering a freestanding biomimetic cardiac patch using biodegradable poly(lactic-co-glycolic acid) (PLGA) and human embryonic stem cell-derived ventricular cardiomyocytes (hESC-VCMs), Macromolecular Bioscience, 2015, 15, 426-436	No	Yes	Yes (HKUST internal project code was used)	Yes
2015				Xuetao Shi, Serge Ostrovidov, Yihua Zhao, Xiaobin Liang, Motohiro Kasuya, Kazue Kurihara, Ken Nakajima, Hojae Bae, Hongkai Wu*, Ali Khademhosseini*	Microfluidic Spinning of Cell-Responsive Grooved Microfibers, Advanced Functional Materials, 2015, 25, 2250-2259.	No	Yes	Yes (HKUST internal project code was used)	Yes
2015				Lu Huang, Yin Chen, Yangfan Chen, Hongkai Wu*	Centrifugation-Assisted Single-Cell Trapping in a Truncated Cone-Shaped Microwell	No	Yes	Yes	Yes

					Array Chip for the Real-Time Observation of Cellular Apoptosis Analytical Chemistry, 2015, 87, 12169-12176				
2015				Ho Nam Chan, Yangfan Chen, Yiwei Shu, Yin Chen, Qian Tian, Hongkai Wu*	Direct, one-step molding of 3D-printed structures for convenient fabrication of truly 3D PDMS microfluidic chips Microfluidics and Nanofluidics 2015, 19, 9-18	No	Yes	Yes	Yes
2015				Yin Chen, Wenbin Cao, Junli Zhou, Bidhari Pidhatika, Bin Xiong, Lu Huang, Qian Tian, Yiwei Shu, Weijia Wen, I-Ming Hsing, Hongkai Wu*	Poly (l-lysine)-graft-folic acid-coupled poly (2-methyl-2-oxazoline)(PLL-g-PMOXA-c-FA): A Bioactive Copolymer for Specific Targeting to Folate Receptor-Positive Cancer Cells ACS applied Materials & Interfaces, 2015, 7, 2919-2930	No	Yes	Yes	Yes
2014				Qifeng Ruan, Lei Shao, Yiwei Shu, Jianfang Wang*, Hongkai Wu*	Growth of Monodisperse Gold Nanospheres with Diameters from 20 nm to 220 nm and Their Core/Satellite Nanostructures. Advanced Optical Materials, 2014, 2, 65-73.	No	Yes	Yes (typo in citing the project code)	Yes
2014				Bin Xiong, Yin Chen, Yiwei Shu, Bo Shen, Ho Nam Chan, Yaozong Chen, Junli Zhou, Hongkai Wu*	Highly emissive and biocompatible dopamine-derived oligomers as fluorescent probes for chemical detection and targeted bioimaging, Chemical Communication, 2014, 50, 13578-13580.	2014	Yes	Yes (HKUST internal project code was used)	Yes

9. Recognized international conference(s) in which paper(s) related to this research project was/were delivered *(Please attach a copy of each conference abstract)*

Month/Year/ Place	Title	Conference Name	Submitted to RGC (indicate the year ending of the relevant progress report)	Attached to this report (Yes or No)	Acknowledged the support of RGC (Yes or No)	Accessible from the institutional repository (Yes or No)
17-21 Apr 2017, Phoenix, Arizona, USA	Hybrid nano-sensors composed of a nanodiamond and a magnetic nanoparticle	2017 MRS Spring Meeting & Exhibit	No	Yes	Yes	No
17-21 Apr 2017, Phoenix, Arizona, USA	Nanodiamond-hydrogel-magnetic nanoparticle sensors	2017 MRS Spring Meeting & Exhibit	No	Yes	Yes (verbal)	No
17-21 Apr 2017, Phoenix, Arizona, USA	Optically Narrowing of Nitrogen-Vacancy Center Spin Ensembles in Nanodiamonds	2017 MRS Spring Meeting & Exhibit	No	Yes	Yes	No
17-21 Apr 2017, Phoenix, Arizona, USA	Correlating Transmission Electron Microscopy and Nanomagnetometry	2017 MRS Spring Meeting & Exhibit	No	Yes	Yes	No
17-21 Apr 2017, Phoenix, Arizona, USA	Criticality-enhanced hybrid nanodiamond-thermometer	2017 MRS Spring Meeting & Exhibit	No	Yes	Yes	No
8-13 Jan 2017, Snowbird, Utah, USA	Hydrogel based nanodiamond quantum sensor	The 47th Winter Colloquium on the Physics of Quantum Electronics (PQE-2017)	No	Yes	Yes	No
8-13 Jan 2017, Snowbird, Utah, USA	Magnetic criticality enhanced diamond nanothermometer	The 47th Winter Colloquium on the Physics of Quantum Electronics (PQE-2017)	No	Yes	Yes	No
4-8 Dec 2016, Brisbane, Australia	Hybrid diamond nano-sensors - A tale of two particles	The Asia-Pacific Physics Conference	No	Yes	Yes	No
09/2016/Beijing, China	Developing nanodiamond based quantum sensor for biological applications	Chinese Physical Society Fall meeting	No	Yes	Yes	No
07/2016/ Hong Kong	Shape and Mechanical effect on nanoparticle-cell membrane interactions	Structural Nanomaterials Gordon Research Conference	No	Yes	Yes	No
24-30 Jul 2016, Casper, Wyoming, USA	Diamond Quantum sensing - To beat the T1 resolution limit	The TAMU-Princeton Summer Symposium on Quantum Bio Photonics	No	Yes	Yes	No
4-8 April 2016, Pilanesberg, South Africa	Wavefuntion fingerprint quantum sensing for atomic-scale MRI	Quantum Diamond 2016	No	Yes	Yes	No

03/2016/Hasselt, Belgium	Cellular interaction of nanodiamond—A preparation for subcellular sensing	Hasselt Diamond workshop 2016 SBDD XXI	No	Yes	Yes	No
3-8 Jan 2016, Snowbird, Utah, USA	Interaction of nanoparticles with cells: uptake, intracellular trafficking and excretion	The 46th Winter Colloquium on the Physics of Quantum Electronics (PQE-2016)	No	Yes	Yes	No
3-8 Jan 2016, Snowbird, Utah, USA	Quantum sensing for single-molecule NMR and MRI	The 46th Winter Colloquium on the Physics of Quantum Electronics (PQE-2016)	No	Yes	Yes	No
30 November – 04 December 2015, The University of Auckland, New Zealand	Dynamical decoupling based detection of nuclear spin correlations	Asia-Pacific Conference & Workshop on Quantum Information Science 2015 (APCWQIS'15)	No	Yes	Yes	No
August 21-24, 2015 Shanghai, China	Diamond quantum sensing toward single-molecule NMR	24th Annual International Laser Physics Workshop (LPHYS'15)	No	Yes	Yes	No
5-7 Aug 2015, Takamatsu, Japan	Quantum Sensing via Central Spin Decoherence	Diamond Quantum Sensing Workshop 2015	No	Yes	Yes	No
04/2015/Prague, Czech Republic	Interaction of nanodiamonds with cells –A preparation for intracellular sensing	Workshop of Tools for nanoscale imaging in cells and biological systems: nanodiamond and beyond	No	Yes	Yes (veral)	No
University of Chicago Center in Hong Kong, 30-31 Mar 2015	Single-nucleus NMR using dynamical-decoupling controlled spin decoherence in diamond	Workshop on Quantum Technology - A New Frontier in Engineering	No	Yes	Yes	No
18-22 Aug 2014, Brisbane, Australia	"Coupling of an ensemble of spins in diamond to a cavity for solid-state superradiant maser at room temperature"	2014 Workshop on Quantum Information using NV centres in Diamond (QDiamond 14)	No	Yes	Yes	No
July/2013/ Singapore	Cellular evolution of Nanoparticles and their biomedical implications	7th International conference on materials for advanced technologies	2014	Yes	Yes	No
Sep 16-20, 2013, Würzburg, Germany	Central spin decoherence as a probe to physics in environments	Sino-Germany Solid-State Quantum Information Symposium	2014	Yes	Yes (verbal)	No
15-17 Nov 2013, Daejeon, Korea	Nanomagnetometry and many-body physics probe via central spin decoherence	1st Nano-Scale Dynamics in Magnetism Workshop	2014	Yes	Yes (verbal)	No

10. ***Student(s) trained*** (please attach a copy of the title page of the thesis)

Name	Degree registered for	Date of registration	Date of thesis submission/ graduation
Zhang Bokai	PhD	July 2011	Dec 2016
Yin CHEN	PhD	2011-09-01	2015-07-01
Henglei JIA	PhD in MSE	August 2013	July 2016
Feng QIN	PhD in physics	August 2013	July 2016

11. **Other impact** *(e.g. award of patents or prizes, collaboration with other research institutions, technology transfer, etc.)*

1) An international workshop "Workshop on diamond - spintronics, photonic, bio-applications" was held on April 27-29, 2013, right before the start of the project. During this workshop, we established collaborations with Academia Sinica, Taiwan, University of Stuttgart, and Institute of Organic Chemistry and Biochemistry AS CR for supports in diamond samples and ODMR setup.

2) We have organized the first Quantum Sensing Gordon Research Conference to be held in The Chinese University of Hong Kong (2-7 Jul 2017), with R. B. Liu and Q. Li being the Chair and Vice Chair, respectively. This GRC is expected to be held in CUHK campus every other year and will contribute to increase the international visibility of the Hong Kong research community of quantum sensing.

Project Coordinator

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