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Nanoscale Magnetism of Novel Structures

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6. PI Name: Nguyen X. Phuc,
Nguyen T.K. Thanh, Srinivas Sridhar

7. Program Officer: Dr. Todd S. Rushing, AFOSR/AOARD
(Dr. Sheena Winder, L Lt Col., USAF)

8. Reporting Period Start Date: 10/2017
9. Reporting Period End Date: 9/2021

10. Report Abstract:

UCL-London:

Year 1: Continued working on 4 projects including “synthesis and measurements of Au nanorods to be used as the cheap biosensor dengue fever”, “synthesis and characterisation of anisotropic iron oxide nanoparticles for hyperthermia”, “synthesis of monodisperse ferrite nanoparticles for hyperthemia” and “multiferroic nanoparticles: synthesis and application”.

Year 2: The UCL group has been working on different project including “Gold nanorods for killing bacteria by generating reactive oxygen species”, “Growth Mechanism of the Co-Precipitation of Iron Oxide Nanoparticles”, “Hydroxypropylcellulose coating to improve graft-to-bone healing for anterior cruciate ligament reconstruction” “Size-Tuneable β-FeOOH Nanoellipsoids” and “multiferroic nanoparticles: synthesis and application”. For one year, we have managed with 4 publications in high impact factor peer review journals, 1 review published in Nano Today and 1 paper in preparation with IMS. The group organised and attended the conference entitled: “Nanomaterials for Healthcare” in Da Nang, Vietnam in July 2019 and then visited IMS, VAST in Hanoi to discuss about the project and future collaboration. During the visit Prof Thanh gave a seminar in VAST.

Year 3: The UCL group continued working on different project including “magnetic nanocomposite for thermo-chemotherapy ”, “Continuous Production of Magnetic Iron Oxide Nanoparticles *via* Fast and Economical High Temperature Synthesis”, “Synthesis of Stable High Magnetic Moment Fe_xC_y Nanoparticles for hyperthermia” and “Anisotropic Gold Nanoparticles on Plasmonic Coupling with a Photosensitizer for Antimicrobial Film”. For one year, we have managed with 4 publications in high impact factor peer review journals.

For the extended period: The UCL group has managed with 7 publications.

NEU-Boston:

Year 1: The Northeastern University (NEU) group carried out the first-in-human MRI scan in using the QUTE-CE MRI technique with magnetic nanoparticles that was developed partially under the previous AOARD award. The scans resulted in images of the blood vasculature with exceptional clarity and definition not available by any other technique. Quantitative analyses of the intensity data were carried out enabling segmentation of large, medium and small vessels. The cerebral blood volume

distribution was calculated in different regions of the brain for the first time using this technique.
Year 2: The Northeastern University (NEU) group carried out the first-in-human MRI scan in using the QUTE-CE MRI technique with magnetic nanoparticles that was developed partially under the previous AOARD award. The scans resulted in images of the blood vasculature with exceptional clarity and definition not available by any other technique. Quantitative analyses of the intensity data were carried out enabling segmentation of large, medium and small vessels. The cerebral blood volume distribution was calculated in different regions of the brain for the first time using this technique.
Year 3: Quantitative analyses of the MRI intensity data with magnetic nanoparticles as contrast agents were carried out enabling segmentation of large, medium and small vessels. The cerebral blood volume distribution was calculated in different regions of the brain and kidneys for the first time using this technique.

IMS@VAST-Hanoi:

Year 1:
The IMS@VAST group attempted to synthesize various structures of a metallic and an oxide component, such as Fe_3O_4@Au/Ag, CoFe@CoO/FeO. Dumbbell-like, hollow-like as well as core-shell nanostructures have been obtained. The magnetic and optical properties have been characterized and found to be dependent on the type of hybrid structure. An equipment has been established to measure simultaneously inductive heating generated by both magnetic and optical (plasmonic) effects. Regarding the former effect, the group continued to study the loss power (SLP) in various magnetic nanoparticles as affected by polymer coating (shell), as well as by magnetic intrinsic properties of the core particles for ferrite materials. By performing systematic calculation and analyses the group found interesting results on effect of magnetic anisotropy on the characteristics of SLP versus particle diameter.

Year 2: The IMS@VAST group has successfully synthesized hollow structures of a double-metallic and an oxide component, such as Fe_3O_4@Au/Ag whose morphology, optical and magnetic properties have been characterized by various techniques. The fabricated hybrid nanostructures benefit good heating performance as contributed by both magnetic (Fe3O4 component) and plasmonic (Ag/Au component) phenomena. After being coated with a copolymer, this magnetite-based structures showed also quite high MRI relaxivity of both T1 and T2 regimes. With the support by Dr. Sheena Winder (AOARD), the IMS group has organized the 5th International Workshop on Novel Magnetic and Multifunctional Materials (5^{th}IWNMMM) held in Hanoi, 9-12 Jan 2019.

Year 3: The IMS@VAST group has synthesized $CoFe_2O_4$ nanoparticles by thermal decomposition and characterized their morphology, size and magnetic properties. These nanoparticles benefit heating efficiency superior over those previously reported. The group has successfully developed different hollow structures of Ag/Au double-metallic and hybrid Fe_3O_4-Ag/Au NPs. Biotoxicity of the developed NPs has

been tested on different cell lines and on animal (rabbit). For one year, the group has published 1 paper and collected data and written two manuscripts.

For the extended period: The IMS group has synthesized several NPs of new structures including $MnFe_2O_4$ and its heteromeric hybrid with Ag, performed magnetic and photothermal heating generated by various nanostructures, and managed with 3 published papers and 2 manuscripts ready for publication.

Publications: 23

11. Archival publications published during reporting period, and other activities

11.1. Papers that we published, in press, in revision, submitted or in preparation that has acknowledgement of AFOSR

List of published papers:

1. Mourdikoudis, S., Pallares, R.M., and Thanh, N.T.K. "Characterization Techniques for Nanoparticles: Comparison and Complementarity upon Studying Nanoparticle Properties". Nanoscale. 10 (2018) 12871-12934. Gold open access.
2. F. Rossi, N.T.K. Thanh and X.D. Su (2019) Gold nanorods embedded in polymeric film for killing bacteria by generating reactive oxygen species with light. ACS Applied Bio Materials. 2 (2019) 3059-3067.
3. A.P. LaGrow, M.O. Besenhard, A. Hodzic, A. Sergides, L.K. Bogart, A. Gavriilidis and N.T.K. Thanh, Unraveling the Growth Mechanism of the Co-Precipitation of Iron Oxide Nanoparticles with the Aid of Synchrotron XRD in Solution. Nanoscale. 11 (2019) 6620-6628.
4. J. Yang, Y. Dong, J. Wang, J. Jiang, Y. Zhu, Y. Wu, F. Wan, P. Zhang, T. Chen, W. Zhou, P. Wu, N.T.K. Thanh, N.Q. Tran, J. Chen and S. Chen Hydroxypropylcellulose coating to improve graft-to-bone healing for anterior cruciate ligament reconstruction. ACS Biomaterials Science and Engineering 5 (2019) 1783-1803.
5. S.K. Sharma, N. Shrivastava, F. Rossi, L.D. Tung and N.T.K. Thanh, (2019) Nanoparticle-based magnetic and photo induced hyperthermia for cancer treatment. *Nano Today*. **29***:* Article 100795, pp 1-27. Green Open Access.
6. Wang, L., Hevault, A., Southern, P., Sandre, O., Couillaud, F., Thanh, N. T. K***** In vitro exploration of the synergistic effect of alternating magnetic field mediated thermo-chemotherapy with doxorubicin loaded dual pH- and thermo-responsive magnetic nanocomposite carriers. *Journal of Materials Chemistry B. Royal Society of Chemistry 8* (2020) *10.1039/D0TB01983F*. *Gold open access*. FRONT COVER.
7. Besenhard, M.O., Famiani, S., LaGrow A.P., Pucciarelli, M., Lettieri, P., Thanh, N. T. K* and Gavriilidis, A., Continuous Production of Magnetic Iron Oxide Nanoparticles *via* Fast and Economical High Temperature Synthesis. *Reaction Chemistry & Engineering*. **5** (2020) 1474-1483. Gold Open Access.
8. Loizou, K., Mourdikoudis, S., Sergides, A., Besenhard, M.O., Sarafidis, C., Higashimine, K., Kalorigrou, O., Maenosono, S., Gavriilidis, A., and Thanh, N. T.

K.*. Rapid Millifluidic Synthesis of Stable High Magnetic Moment Fe_xC_y Nanoparticles for hyperthermia. *ACS Applied Materials and Interfaces.* **20** (2020) 28520-28531. *Gold Open Access.* ACS Live Slide

9. Rossi, F., Huat, K. E., Thanh, N. T. K* and Su X. D.. Study of the Effect of Anisotropic Gold Nanoparticles on Plasmonic Coupling with a Photosensitizer for Antimicrobial Film. *ACS Applied Bio Materials.* **3** (2020) 315-326. Green Open Access.

10. Storozhuk, L., Besenhard M. O., Mourdikoudis, S., LaGrow, A. P., Lees, M.R., Tung, L. D., Gavriilidis, A., **Thanh, N. T. K*** (2021) Simple and Fast Polyol Synthesis of Stable Iron Oxide Nanoflowers with Exceptional Heating Efficiency. *Journal of Applied Materials and Interface. In Press. Green Open Access-Click on this link: am-2021-123235.R1_Proof_hi*

11. Çitoğlu, S., Coşkun, Ö. D., Tung, L. D., Onur, A and **Thanh, N. T. K**,* (2021) DMSA coated cubic iron oxide nanoparticles as potential therapeutic agents. *Nanomedicine*. **16**: 925–641. Gold Open Access.

12. Besenhard M. O., Panariello, L., Kiefer, C., LaGrow, A. P., Storozhuk, L., Perton F., Begin, S., Damien Mertz, D., **Thanh, N. T. K**.* and Gavriilidis, A. (2021) Small Iron Oxide Nanoparticles as MRI T_1 Contrast Agent: Scalable Inexpensive Water-Based Synthesis Using a Flow Reactor. *Nanoscale.* **13**: 8795-8805. Gold Open Access. FRONT COVER PAGE

13. Talib N. A., LaGrow, A. P., Besenhard, M. O., Sergides, A., Famiani, S., Ferreira, L. P., Cruz, M. M., Gavriilidis, A., and **Thanh, N. T. K.*** (2021) Shape controlled iron oxide nanoparticles: inducing branching and controlling particle crystallinity. *CrystEngComm.* **23:** 550 – 561. *Gold Open Access. BACK COVER*

14. Deeprasert S., Wang, L., Simeonidis, K., **Thanh, N. T. K.*,** Duguet, E., and Mourdikoudis, S. (2021) Dimpled SiO_2@γ-Fe_2O_3nanocomposites – Fabrication and Use for Arsenic Adsorption in Aqueous Medium. *RSC Advances.* **11***:* 1343-1353. *Gold Open Access.*

15. Deeprasert S., Wang, L., Simeonidis, K., **Thanh, N. T. K.*,** Duguet, E., and Mourdikoudis, S. (2021) Dimpled SiO_2@γ-Fe_2O_3nanocomposites – Fabrication and Use for Arsenic Adsorption in Aqueous Medium. *RSC Advances.* **11***:* 1343-1353. *Gold Open Access.*

16. Hildebrand, S., Löwa, N., Paysen, H., Fratila R.M., Salisa, L. R., Trakoolwilaiwan, T., Niu, Z., Kasparis, G., Preuss, S F., Kosch, O., de la Fuente, J. M., **Thanh, N. T. K.,** Wiekhorst, F., and Pfeifer, A. (2021) Quantification of lipoprotein uptake in vivo using magnetic particle imaging and spectroscopy. *ACS Nano.***15**: 434-446. *Green Open Access*.

17. Ronodeep Mitra, Ju Qiao, Gerard L. O'Neil, Bailey Ritchie, Praveen Kulkarni, Srinivas Sridhar, Anne L. van de Ven, Craig Ferris, James A Hamilton, Eno E. Ebong, The Comparative Effects of High Fat Diet or Disturbed Blood Flow on Glycocalyx Integrity and Vascular Inflammation, Transl Med Commun. 2018;3. pii: 10. doi: 19.1186/s41231-018-0029-9. Epub 2018 Nov 22.

18. P.H. Nam, L.T. Lu, P.H. Linh, D.H. Manh, Le. T.T. Tam, N.X. Phuc, P.T. Phong, In-Ja Lee, "Polymer-coated cobalt ferrite nanoparticles: synthesis,

characterization, and toxicity for hyperthermia applications", New J. Chem 42. (2018) 12430

19. P.H. Nam, N.X. Phuc, P.H. Linh, L.T. Lu, D.H. Manh, P.T. Phong, In-Ja Lee, "Effect of zinc on structure, optical and magnetic properties and magnetic heating efficiency of $Mn_{1-x}Zn_xFe_2O_4$ nanoparticles", Physica B: Physics of Condensed Matter 550 (2018) 428-435.

20. Thi Hong Phong Le, Do Hung Manh, Hong Nam Pham, Thanh Phong Pham, J Kováčˇ, I Skorvanek, The Long Phan, Manh Huong Phan, and Xuan Phuc Nguyen, High heating efficiency of interactive cobalt ferrite nanoparticles, Adv. Nat. Sci.: Nanosci. Nanotechnol. 11 (2020) 045005.

21. Ngo T Dung, Nguyen T.N. Linh, Dinh L. Chi, Nguyen T.H. Hoa, Nguyen P Hung, Ngo T Ha, Pham H Nam, Nguyen X Phuc, Le T Tam, Optical properties and stability of small hollow gold nanoparticles, RSC Adv. 11 (2021) 13458.

22. Luu Huu Nguyen, Pham Thanh Phong, Pham Hong Nam, Do Hung Manh, Nguyen Thi Kim Thanh, Le Duc Tung, Nguyen Xuan Phuc, The role of anisotropy in distinguishing domination of Neel or Brownian relaxation contribution to magnetic inductive heating: Orientations for biomedical applications, Materials, 14 (2021) 1875.

23. T.T.N. Nha, P.H. Nam, N.X.Phuc, V.Q. Nguyen, N.H. Nam, D.H. Manh, L.T.Tam, N.T.N. Linh, B.T.V. Khanh, L.T.Lu, L.H.Nguyen, P.T. Phong, Sensitive $MnFe_2O_4$-Ag hybrid nanoparticles with photothermal and magnetothermal properties for hyperthermia applications, RSC Adv. 11 (2021) 30054-30068.

Ready for submission:

- Le Thi Thu Huong, Phan Quoc Thong, Nguyen Dac Tu, Hoang Thi My Nhung, Lam Khanh, Do Hung Manh, Pham Hong Nam, Nguyen Xuan Phuc, Javier Alonso, Ju Qiao, Srinivas Sridhar, Ha Phuong Thu, Nguyen Thi Kim Thanh, and Manh Huong Phan, Multifunctional nanocarriers of Fe_3O_4@PLA-PEG for MRI, magnetic hyperthermia and drug delivery, to be submitted in Oct. 2021.
- Nguyen T. N. Linh, Ngo T. Dung, Le T. T. Tam, Le T. Tam, Doan T. Tung, Nguyen D. Vinh, Nguyen P. Hung, Ngo T. Ha, Pham. H. Nam, Nguyen V. Dang, Nguyen X. Phuc, Nguyen T. K. Thanh and Le T. Lu, New insight into the Synthesis and Property of Hollow Fe_3O_4-Ag/Au Hybrid Nanostructures for T1-T2 dual mode MRI Imaging and Combined Magnetic/Photo Heating, to be submitted in Oct. 2021.

11.2 Conference/meeting Presentations.

- Invited Presentation by Prof Sridhar
    - “Nanotherapies and Quantitative Imaging for Radiation Oncology”, Dana-Farber Cancer Institute, Boston, June 14, 2018,
- Ju Qiao, Codi Gharagouzloo, Liam Timms, Praveen Kulkarni, Craig Ferris, Anne van de Ven, Sagar Kamarthi, Srinivas Sridhar, “Machine Learning Methods to Segment Blood Vessels in QUTE-CE MRI”
    - ISMRM Machine Learning Workshop, San Francisco, March 2018

- Ju Qiao, Codi Gharagouzloo , Liam Timms, Zihang Fang, Paige Baldwin, Praveen Kulkarni, Craig Ferris, Sagar Kamarthi, Srinivas Sridhar, Anne van de Ven. “A Novel Imaging Modality Reveals Nanoparticle in Tumors.” Poster. 4th Annual CaNCURE Nanomedicine Day. Boston, MA. June 20, 2018.

- Anick Mallette, Ju Qiao, Codi Amir Gharagouzloo, Anne van de Ven, Praveen Kulkarni, Craig Ferris, Srinivas Sridhar. “Early Diagnosis of Neuropathy with QUTE-CE MRI.” Poster. 4th Annual CaNCURE Nanomedicine Day. Boston, MA. June 20, 2018.

- Ju Qiao, Codi Gharagouzloo, Liam Timms, Anne L van de Ven, Paige Baldwin, Zihang Zhang, Shifalika Tangutoori, Praveen Kulkarni, Sagar Kamarthi, Craig Ferris, Srinivas Sridhar, “A novel imaging modality reveals nanoparticle accumulation in tumors”, RISE Conference, Boston, April 25, 2018

- Nguyen T.K. Thanh, Oct 2017: Plenary lecture in “Nanoparticle synthesis, structure, properties, safer-by-design” Section of 7th biannual International Meeting of The Institute of Metals in Biology of Grenoble (IMBG) "Metallic nanoparticles: health, environment, applications and safer-by-design", Grenoble, France. Invited by Dr. Géraldine Sarret
- Nguyen T.K. Thanh, Mar 2018: EU COST TD142 Multifunctional Nanoparticles for Magnetic Hyperthermia and Indirect Radiation Therapy (Radiomag), Annual Action Progress Conference, Timisoara, Romania
- Nguyen T.K. Thanh, Jun 2018: Mentor for Vietnam-UK Workshop on Microfluidics, Nanomaterials, and Point-of-Care in Healthcare for developing countries, Ho Chi Minh City, Vietnam. Invited by Dr Huynh Chan Khon
- Nguyen T.K. Thanh, Jun 2018: Plenary talk at the 7th International Conference in Vietnam on the Development of Biomedical Engineering, Ho Chi Minh City, Vietnam. Invited by Prof Vo Van Toi

- Srinivas Sridhar, Nanotechnologies for precision medicine, 9th International Workshop on Advanced Materials Science and Nanotechnology, IWAMSN 2018, Ninh Binh, November 8, 2018.
- Liam Timms, Magnetic relaxation dynamics in biocompatible magnetic nanoparticles, The 5th International Workshop On Novel Magnetic And Multifunctional Materials, Jan. 2019, Hanoi, January 10, 2019.
- Nguyen TK Thanh, 5th International Workshop on Novel Magnetism and Multifunctional Materials, Jan. 2019, Hanoi, Vietnam.
- Le T. H. Phong, Magnetic properties of $CoFe_2O_4/Fe_3O_4$ nanoparticles synthesized by thermal decomposition combined with seeded growth method, 5th International Workshop on Novel Magnetism and Multifunctional Materials, Jan. 2019, Hanoi, Vietnam.
- Stefanos Mourkikoudis, Decoration of Dimpled Silica Nanostructures with Magnetic Iron Oxide Nanoparticles for Arsenic Detection and Removal in water, 5th International Workshop on Novel Magnetism and Multifunctional Materials, Jan. 2019, Hanoi, Vietnam
- Nguyen Xuan Phuc, Decisive role of nanoparticle anisotropy for power characteristics of magnetic inductive heating, International conference on 'Nanomaterials for Health Care' Danang, Vietnam, 29-31 July 2019.
- Nguyen TK Thanh, EU COST TD142 Multifunctional Nanoparticles for Magnetic Hyperthermia and Indirect Radiation Therapy (Radiomag), Annual Action Progress Conference, Florence, Italy.
- Nguyen TK Thanh, International Conference on Advances in Materials Science & Applied Biology (AMSAB): Nano-drug delivery and Therapeutics, in Mumbai, India. Invited by Associate Professor Sudeshna Chandra.
- Nguyen TK Thanh, Keynote, 2019 Hanoi International Symposium on Advanced Materials and Devices (HISAMD2019) Hanoi, Vietnam.
- Nguyen TK Thanh, UK Magnetics Society seminar on MRI and Magnetic Particles for MRI Diagnostics, University of Oxford, UK.
- Nguyen TK Thanh, ACS Applied Materials & Interfaces, to be held at the Spring ACS National Meeting (March 31 - April 4, 2019) in Orlando, Florida.
- Nguyen TK Thanh, Micro/Nanotechnologies for Diagnostics and Therapeutics workshop organised by Royal Society Chemistry Biotechnology Group.
- Nguyen TK Thanh, The 3rd Overseas Academicians Qingdao Tour & Qingdao International Academicians Conference, China.
- Nguyen TK Thanh, 10th International Conference on Materials for Advanced Technologies (ICMAT 2019) Symposium J "Micro/nano-technology for Drug Delivery and Imaging", Singapore.
- Nguyen TK Thanh, 10th International Conference on Materials for Advanced Technologies (ICMAT 2019) Symposium Y: "Colloidal

Nanoparticle-Based Probes and Sensors" (Jointly organized with MRS Japan), Singapore.

- Nguyen TK Thanh, Worldwide Meeting of Young Academy and Nanomaterial for Health jointly organized with Global Young Academy and Vietnam Young Academy, Da nang, Vietnam.
- Nguyen TK Thanh, Northeast International Conference on Progress in Nanoscience, nanotechnology and nanobiotechnology. San Luiz, Brasil.
- Nguyen TK Thanh, Institute of Nanosystem, National University of San Martin, Argentina.
- Nguyen TK Thanh, The Institute for the Chemistry of OrganoMetallic Compounds of the Italian National Council for Research, Argentina.
- Nguyen TK Thanh, Department of Materials Science & Engineering, College of Engineering, Peking University, China.
- Nguyen TK Thanh, Institute of Chemistry, Chinese Academy of Sciences, Beijing, China.
- Nguyen TK Thanh, College of Science and Engineering, City University of Hongkong, China.
- Nguyen TK Thanh, Nano Agricultural Chemistry and Processing Research, National Nanotechnology Centre (Nanotec), Bangkok, Thailand.
- Nguyen TK Thanh, Advanced Imaging Research Centre, Department of Biomedical Engineering, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang (KMITL), Thailand.
- Nguyen TK Thanh, Biomedical Engineering Department, Mahidol University, Thailand.
- Nguyen TK Thanh, Institute for Bioengineering and Cancer Research UK Edinburgh Centre, University of Edinburgh, UK.
- Nguyen TK Thanh, Recent trends in Nanoscience and Nanotechnology, Online Conference Hosted by Haldia Institute of Technology, India. *Invited by Dr Arka Chaudhuri.* Sep 2020.
- Nguyen TK Thanh, Panel member for Webinar "Can Materials Science Counter the COVID-19 Pandemic? A Discussion with materials researchers at the frontlines of battling coronavirus". Co presented by Material Research Society and The Society for Biomaterials. https://mrs.digitellinc.com/mrs/live/503/page/2328, Apr 2020

11.3 People involved in the project & Students completing degrees:

1. Srinivas Sridhar, PI, NEU-Boston
2. Anne van de Ven, Assistant Professor, NEU-Boston
3. Ju Qiao, Graduate Student, NEU-Boston
4. Liam Timms, Graduate Student, NEU-Boston
5. Seyed Ali Banijamali NEU-Boston
6. Nguyen T K Thanh, PI, UCL-London
7. Le D Tung, Dr. UCL-London
8. Lilin Wang, PhD student UCL-London

9. Simone Famiani, PhD Student UCL-London
10. Stefanos Mourdikoudis, Dr. UCL-London
11. Alec La Grow, Dr. UCL-London
12. Andreas Sergides, PhD Student UCL-London
13. Liudmyla Storozhuk, Dr. UCL-London
14. Thithawat Trakoolwilaiwan, PhD student UCL-London
15. Nguyen X Phuc, PI, IMS@VAST-Hanoi
16. Do H Manh, Assistant Professor IMS@VAST-Hanoi
17. Le T Lu, Dr. IMS@VAST-Hanoi
18. Pham H Nam, Dr. IMS@VAST-Hanoi
19. Le T H Phong, PhD student IMS@VAST-Hanoi
20. Dung T Ngo, PhD IMS@VAST-Hanoi.
21. Nguyen T.N. Linh, PhD student IMS@VAST-Hanoi.

Students completing degrees:

- Pham Hong Nam, IMS@VAST, completed PhD thesis in Jun. 2018
- Nguyen Thi Ngoc Linh, IMS@VAST, completed PhD thesis in Jan. 2021.

11.4 The visits have taken in place between different sites (date, discussion).

- Prof Nguyen TK Thanh (UCL) visited Hanoi and discussed with Prof Phuc (IMS) in Dec 2017 and Jun 2018.
- Liam Timms (NEU), visited to UCL to discuss magnetic nanoparticle dynamics, June 22, 2018.
- Pham Hong Nam (IMS), visited to UCL to carry out the magnetic hyperthermia measurements on the iron oxide nanoparticles synthesized in Vietnam, for 1 month in May 2018, to discuss on hyperthermia measurements.
- Le T.H. Phong (IMS), visited to UCL involved in synthesis and application of multiferroic materials, for 4 months since May 2018, to discuss on synthesis of magnetic nanoparticles.
- Nguyen X Phuc (IMS), visited to UCL giving a seminar and discussing on collaborative plan, 2 days in August 2018.

- Dr. Srinivas Sridhar visited VAST in Nov 2019 to attend international conference.
- Graduate Student Liam Timms visited VAST, Hanoi in Jan 2019 to attend workshop.
- Postdoctoral research Stefanos Mourdikoudis visited VAST, Hanoi in Jan 2019 to attend workshop
- Dr. LD Tung and Prof NTK Thanh visited IMS in Jan 2019 to discuss on writing a common paper.

- Dr. LD Tung and Prof NTK Thanh visited IMS in July 2019 to give invited talk.

11.5 Special awards received, other outcomes & good news stories:

- Prof Nguyen TK Thanh received Royal Society Rosalind Franklin Award Public lecture on the 29th Oct 2019: https://royalsociety.org/science-events-and-lectures/2019/10/rosalind-franklin-lecture/
- Nguyen TK Thanh was also appointed as Editor-in-chief of the Royal Society of Chemistry book Series, Nanoscience and Nanotechnology: https://tinyurl.com/y44sybqr.

12. **Change In Research Objectives:** Several exchange visits have been cut off due to the coronavirus.
13. **Change in Program Officer:** In Sept 2020 Dr. Sheena Winder was replaced by Dr. Todd S. Rushing.
14. **Extensions Granted/Milestones Slipped:** A NCE P00004 Modification was released to extend the period of performance of Option 2 through 27 Sept 2021.

Hanoi, date October 28, 2021

Prepared by

Prof. Nguyen Xuan Phuc,
Project PI
Science

Managed by

VIỆN KHOA HỌC VÀ CÔNG NGHỆ VIỆT NAM
VIỆN KHOA HỌC VẬT LIỆU

Prof. Doan Dinh Phuong,
Director of Inst. of Materials