RGC Ref.: N_HKUST605/16
NSFC Ref. : 61631166004
(please insert ref. above)

The Research Grants Council of Hong Kong
NSFC/RGC Joint Research Scheme
Joint Completion Report

(Please attach a copy of the completion report submitted to the NSFC by the Mainland researcher)

Part A: The Project and Investigator(s)

1. Project Title

Hybrid structures of low-dimensional functional oxide thin films and 2D semiconductors: design, fabrication, and interface control
低維功能氧化物薄膜與二維半導體材料復合結構的設計制備與界面調控研究

2. Investigator(s) and Academic Department/Units Involved

	Hong Kong Team	Mainland Team
Name of Principal Investigator *(with title)*	Prof Jiannong WANG	Prof Hong WANG
Post	Professor	Professor
Unit / Department / Institution	Department of Physics/HKUST	School of Electronic and Information Engineering / Xi'an Jiaotong University
Contact Information	phjwang@ust.hk	hwang@xjtu.edu.cn , wangh6@sustech.edu.cn
Co-investigator(s) *(with title and institution)*		Dr. Chunrui MA / Xi'an Jiaotong University

3. Project Duration

	Original	Revised	Date of RGC/ Institution Approval *(must be quoted)*
Project Start date	1 Jan 2017		
Project Completion date	31 Dec 2020		
Duration *(in month)*	48		
Deadline for Submission of Completion Report	31 Dec 2021		

Part B: The Completion Report

5. Project Objectives

5.1 Objectives as per original application

1. Based on ferromagnetic ($La_{0.7}Sr_{0.3}MnO_3$, YIG, Fe_3O_4) thin films, we will form hybrid structures with new 2D materials such as topological insulators (Bi_2Se_3, Bi_2Te_3), layered semimetal/metal (graphene, WTe_2, $NiCo_2O_4$, etc.) and semiconducting TMDCs (MoS_2, $MoSe_2$, WS_2, WSe_2) using the chemical vapor deposition (CVD) over-growth or mechanical transfer method. Our goal is to achieve high spin injection and we will explore the spin Hall or inverse spin Hall effect in these structures.

2. We will grow ferroelectric ($BaTiO_3$, etc.) and piezoelectric (PZT, etc.) thin films and then form hybrid structures with new 2D materials such as graphene, semiconducting TMDCs (MoS_2, $MoSe_2$, WS_2, WSe_2), and topological insulators (Bi_2Se_3, Bi_2Te_3) using the CVD over-growth or mechanical transfer method. We will explore the new physical properties and functionalities of these unconventional hybrid structures.

3. For all fabricated hybrid structures we will investigate the influence of interface and defect. We will find ways to improve the controllability of these hybrid structures. We aim to explore potential new device applications of these multifunctional hybrid structures.

5.2 Revised Objectives

Date of approval from the RGC: _____

Reasons for the change: _____

_____

1.
2.
3. ....

6. Research Outcome

Major findings and research outcome
(maximum 1 page; please make reference to Part C where necessary)

We have studied a flexible microwave magnetic $CuFe_2O_4$ (CuFO) epitaxial thin film with tunable ferromagnetic resonance spectra using purely mechanical strains, including tensile and compressive strains, on flexible fluorophlogopite (Mica) substrates. It can be used for flexible tunable resonators and filters and has great potential for flexible mechanics-magnetic deformation sensors. Furthermore, we observe a superior microwave magnetic stability and mechanical antifatigue character in the CuFO/Mica thin films. These flexible epitaxial CuFO thin films with tunable microwave magnetism and excellent mechanical durability are promising for the applications in flexible spintronics, microwave detectors, and oscillators. The results have been published in *Adv. Funct. Mater.*

We have prepared solid-solutions $(1-y)(Mg_{0.95}Zn_{0.05})_2TiO_4$-$yMg_{0.95}Zn_{0.05}Fe_2O_4$ (y = 0, 0.1, 0.3, 0.5, 0.7, 0.9, 1) by traditional solid-state reaction and systematically study their phases, morphologies, and magnetodielectric properties. The giant dielectric constants are observed at low frequency in the ceramics, with y>0.5 when the sintering temperature exceeds 1200 ℃. All the results indicate that our

solid-solutions with y>0.5 can considerably improve the dielectric and magnetic properties, providing more advantages than the simple bi-phasic compounds in the applications for novel electronic devices. The results have been published in *Journal of the European Ceramic Society*.

We have realized quasi-zero-dimensional (0D) photon emission of WS_2 in a coupled hybrid structure of monolayer WS_2 and InGaN quantum dots (QDs). An interfacial bound exciton, i.e., the coupling between the excitons in WS_2 and the electrons in QDs has been identified. The emission of this interfacial bound exciton inherits the 0-D confinement of QDs as well as the spin-valley physics of excitons in monolayer WS_2. The results have been published in *Nano Letter*. We have observed the enhancement of the PL intensity of ML-WS_2 in a van der Waals heterostructure of ML-WS_2/InGaN-QDs. The mechanism of this PL enhancement is due to the aggregation of excitons in WS_2 ML toward the QD sites to form an interfacial bound state, which effectively mitigates the influence of defects. The results have been published in *Applied Physics Letters*.

We have obtained the laminated $Co_{1.1}Fe_{1.9}O_4$ (CFO) spinel ferrites with different thicknesses by tape-casting method. All these samples have high relative density larger than 95%. Besides, comparing with the CFO sample sintered via traditional solid-state reaction method, the samples fabricated with tape-casting method own more uniform grain distribution and stronger magnetic anisotropies, and their magnetic anisotropies can be considerably enhanced by reducing the thickness, which may be caused by the gradually changed grain orientation, smaller grain sizes and uniform grain distribution. This valuable method provides a new approach to improve magnetic anisotropy of not only CFO but probably also other ferrites. The results have been published in *Ceramics International*.

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

The successful collaborations between the two teams will continue in the direction of studying functional and quantum materials, and their hybrid structures. Future development will focus on design and demonstration of various devices. We are co-supervising two PhD students currently working in these directions.

7. The Layman's Summary

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

Functional materials, layered 2D materials, and their hybrid structures have potential applications in flexible spintronics, microwave detectors and oscillators, electronics, and optoelectronics. In this research project, we have explored functional materials and obtained their improved properties by using new fabrication methods. We have fabricated 2D-0D hybrid structures and observed enhanced light emission. These results are valuable for further development of designing new devices.

Part C: Research Output

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

(Please attach a copy of each 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)	Title and Journal/ Book	Submitted to RGC	Attached to this report	Acknowledged the support of this Joint Research Scheme	Accessible from the institutional repository
Year of publication	Year of Acceptance *(For paper accepted but not yet published)*	Under Review	Under Preparation *(optional)*	***(bold** the authors belonging to the project teams and denote the corresponding author with an asterisk*)*	*(with the volume, pages and other necessary publishing details specified)*	*(indicate the year ending of the relevant progress report)*	*(Yes or No)*	*(Yes or No)*	*(Yes or No)*
2018				**Wenlong Liu**, Ming Liu, **Rong Ma**, Ruyi Zhang, Wenqing Zhang, Dapeng Yu, Qing Wang, **Jiannong Wang**, and **Hong Wang***	"Mechanical Strain-Tunable Microwave Magnetism in Flexible $CuFe_2O_4$ Epitaxial Thin Film for Wearable Sensors" *Adv. Funct. Mater.* **28**, 1705928	2019	No	Yes	Yes
2018				**Rong. Ma**, Yatong. Cheng, **W.enlong Liu**, Liangliang Wu, Qibin Yuan, Huachen Zhang, Huajing Fang, **Jiannong Wang***, and **Hong Wang***	"Enhanced permittivity and permeability of (1-y) $(Mg_{0.95}Zn_{0.05})_2TiO_4$ $Mg_{0.95}Zn_{0.05}Fe_2O_4$ ceramics" *Journal of the European Ceramic Society,* **38**, 5367–5374	2019	No	Yes	Yes
2018				**Guanghui Cheng**, Baikui Li*, Chunyu Zhao, Xin Yan, **Hong Wang,** Kei May Lau, and **Jiannong Wang***	"Interfacially Bound Exciton State in a Hybrid Structure of Monolayer WS_2 and InGaN Quantum Dots" *Nano Lett.* **18**, 5640−5645	2019	No	Yes	Yes

2019				**Guanghui Cheng**, Baikui Li, Chunyu Zhao, Zijing Jin, Hui Li, Kei May Lau and **Jiannong Wang***	"Exciton aggregation induced photolumines cence enhancement of monolayer WS_2" *Appl. Phys. Lett.* **114**, 232101	2021	Yes	Yes	Yes
2019				**Rong Ma, Wenlong Liu,** Qibin Yuan, Huajing Fang, **Jiannong Wang**,* and **Hong Wang***	"Thickness - dependent magnetic anisotropy in laminated $Co_{1.1}Fe_{1.9}O_4$ ceramics" *Ceramics International* **45** 23734–23739	2021	Yes	Yes	Yes

9. Recognized international conference(s) in which paper(s) related to this research project was/were delivered

(Please attach a copy of each delivered paper. All listed papers must acknowledge RGC's funding support by quoting the specific grant reference.)

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 this Joint Research Scheme *(Yes or No)*	Accessible from the institutional repository *(Yes or No)*
July 29 to August 3 2018, Monpellier, France	"Observation of Interfacial Bound Exciton State in a Hybrid Structure of Monolayer WS_2 and InGaN Quantum Dots"	the 34th International Conference on the Physics of Semiconductors	2019	No	Yes	Yes
July 14 - 19, 2019 Nara, Japan	"Exciton Aggregation Induced Photoluminescenc e Enhancement of Monolayer WS_2"	the 21st International Conference on Electron Dynamics in Semiconductors, Optoelectronics and Nanostructures (EDISON 21)	2021	Yes	Yes	No
Dec 12-15, 2019 Shenzhen, China	"Interfacial excitonic states in monolayer WS_2 based vdW heterostructures"	the 2nd International Symposium on Low Dimensional Materials for Optoelectronics	2021	Yes	Yes	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
Rong Ma	PhD	August 2016	June 2019
Rui Gong	PhD	August 2018	August 2022 (Expected)

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

N.A.

12. Statistics on Research Outputs *(Please ensure the summary statistics below are consistent with the information presented in other parts of this report.)*

	Peer-reviewed journal publications	Conference papers	Scholarly books, monographs and chapters	Patents awarded	Other research outputs (Please specify)
No. of outputs arising directly from this research project [or conference]	5	3	0	0	0