RGC Ref.: N_CityU123/15 NSFC Ref. : *(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

Synthesis and Optoelectronic Properties of the White Graphene
白石墨烯的制備與光電效應的研究

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

	Hong Kong Team	Mainland Team
Name of Principal Investigator *(with title)*	Prof ZHI Chunyi	Prof ZENG Haibo
Post	Professor	Professor
Unit / Department / Institution	Department of Materials Science and Engineering, City University	Nanjing University of Science and Technology
Contact Information	chunyzhi@cityu.edu.hk	ZengHaibo@noemail.com
Co-investigator(s) *(with title and institution)*		

3. Project Duration

	Original	Revised	Date of RGC/ Institution Approval *(must be quoted*)
Project Start date	01-Jan-2016	Nil.	Nil.
Project Completion date	31-Dec-2019	Nil.	Nil.
Duration *(in month)*	48	Nil.	Nil.
Deadline for Submission of Completion Report	31-Dec-2020	Nil.	Nil.

Part B: The Completion Report

5. Project Objectives

5.1 Objectives as per original application

1. To synthesize mono-dispersed white graphene (few-atomic layered boron nitride nanosheets) and white graphene quantum dots (few-atomic layered boron nitride nanosheets with nano-sized lateral sizes). Emphasis will be also placed on thickness and size control, as well as surface chemical modification of synthesized white graphene and its quantum dots.

2. To thoroughly investigate microstructures, optical properties and electronic structures of fabricated white graphene and white graphene quantum dots. Emphasis will be also placed on theoretical investigations on electronic structures.

3. To explore deep ultraviolet applications of the fabricated white graphene and white graphene quantum dots. Emphasis will be placed on deep ultraviolet detector and light emission devices (by Collaboration).

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)

Growth dynamics. This project systematically studied the growth thermodynamics of white graphene and developed an industrially compatible atmospheric pressure chemical vapor deposition growth method for large-area high-quality white graphene. This project systematically studied the effects of growth conditions such as growth temperature, reaction time, growth location, and gas flow on the white graphene product thickness, single crystal domain area, continuous film area, coverage and other parameters, and clarified the corresponding dependencies. we prepared ultra-small BN/BCNO quantum dots (QDs) with uniform sizes through a hydrothermal method by cutting white graphene provided by mainland partner and BCNO assisted by bases. The BN/BCNO QDs are water-soluble with uniform lateral size around 3.3 and 4.0 nm The paper was published on 2D Materials 2016, 3, 035007；RSC Advances, 2016, 6, 79090.

Optoelectronic properties. The photoluminescence excitation (PLE) spectra of BN/BCNO QDs both show main peaks at 320nm and weak peaks at 290 nm which is correlated with absorption spectra. Normalized PL spectra of both BN/BCNO QDs show an excitation-dependent effect, which means the PL spectra shift with varied excitation energies. We also developed the amino and silane surface functionalization technology of white graphene in response to the long-standing agglomeration problem in the field that is extremely unfavorable to the preparation of composite materials. Effectively inhibit the agglomeration in solvents and sols, greatly improve the dispersibility of dopants, and successfully develop a white graphene composite silicate gel glass with controllable content and uniform dispersion, with a content of 0.5 wt. % While still maintaining uniformity and transparency. Optical studies have shown that white graphene glass has a high light transmittance in the entire visible and near-infrared bands. For example, when the content is 0.01%, it has a light transmittance of up to 90% in the wide band of 300-1400 nm. It has excellent optical limiting effects in the wider band of 532-1570 nm, such as : 0.50% doped white graphene glass has a minimum limiting threshold of only 9 mJ/cm^2 for 1570 nm laser. The paper was published on 2D Materials 2018, 5, 035036.

Device. We developed the "graphene-white graphene-graphene" ultra-thin flexible capacitor. Through electrical studies, it is found that the vertical resistance of white graphene has a very good linear dependence on the number of atomic layers. The current density decreases from 40 pA/cm^2 to 0.8 pA/cm^2 as the number of layers increases. This linear resistance effect has laid a good foundation for the precise quantification of ultra-thin capacitors. The cooperative team in this project added boron nitride nanosheets with high thermal conductivity to the double-hinge polymerized polyacrylic hydrogel. This composite material exhibits excellent flexibility, self-healing and high thermal conductivity. The thermal conductivity increases nearly 10 times after compounding, reaching 3.5 W/(m·K). We also developed several flexible detectors based on two-dimensional materials, and explored optical and electrical enhancement strategies to achieve a significant improvement in optical detection performance. The detector has an optical opening ratio of up to 104, and the light response rise and fall times are 19μs and 25μs, respectively. The flexible device can be continuously bent. The current fluctuation is less than 3% after 10,000 times being, which is of great significance for flexible and wearable photodetectors. The paper was published on ACS Appl. Mater. Interfaces 2017, 9, 1007810084; Angew. Chem. 2017, 129, 5316.

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

Boron nitride has a large forbidden bandwidth and has special application prospects in photoelectric devices such as deep ultraviolet solar-blind detectors, the weakness of poor conductivity greatly limits practical applications. Two-dimensional electronic material system such as white graphene with higher conductivity and photoelectronic application prospects should be further studied. Materials with similar structure but more tunable electronic structure should be explored for constructing devices with better performance. The electronic structure characteristics of the two-dimensional heterojunction formed by white graphene and its isoelectronic body will be studied. White graphene and its isoelectronic two-dimensional superlattice may have the characteristics of adjustable semiconductor energy band, wide spectral response range, and adjustable conductivity, which can make up for the shortcomings of pure white graphene. This can extend applications of white graphene in the field of optoelectronics.

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)

The project aims to jointly develop the preparation method of 2D boron nitride white graphene and study its photoelectric effect. During the execution of this project, the planned research content was completed, and research progress was made in the growth thermodynamics of white graphene, optical and electrical properties, and device application exploration: (1) The growth thermodynamics of white graphene was systematically studied. We developed the atmospheric pressure chemical vapor deposition growth method of few layers of white graphene with a single crystal domain of 30 microns and a continuous film of 4 cm; (2), We found that white graphene has nonlinear optical limiting and blue luminescence characteristics. The white graphene composite glass was developed; (3), The quantum capacitance effect of ultra-thin white graphene was discovered. We also developed white graphene ultra-thin capacitors for wearable circuits and self-healing circuit heat dissipation materials with a thermal conductivity of 3.5 W/(m·K). In addition, a high-performance flexible two-dimensional photodetector prototype device with enhanced charge collection and enhanced light trapping was fabricated; (4) The design of white graphene and its isoelectronic two-dimensional superlattice reveals the characteristics of semiconductor band gap and adjustable mobility, and points out the development direction.

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) ***(bold** the authors belonging to the project teams and 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 this Joint Research Scheme *(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)*						
2016				**Song Xiufeng** ; Li Qiguang ; Ji Jianping; Yan Zhong; Gu Yu; Huo Chengxue; Zou Yousheng; **Zhi Chunyi; Zeng Haibo***	A comprehensive investigation on CVD growth thermokinetics of white graphene white graphene, 2D Materials 3, 035007 (2016)	2018	Yes	Yes	Yes
2016				**Zifeng Wang, Zijie Tang, Qi Xue, Yan Huang, Yang Huang, Minshen Zhu, Zengxia Pei, Hongfei Li, Hongbo Jiang, Chenxi Fu, and Chunyi Zhi***	Fabrication of Boron Nitride Nanosheets by Exfoliation, The Chemical Record 16, 1204 (2016)	2018	Yes	Yes	Yes

2018				Zhou Wenhan ; Liu Xuhai; Hu Xuemin; Zhang Shengli ; **Zhi Chunyi;** Cai Bo; Guo Shiying; Song Xiufeng; Li Zhi; **Zeng Haibo***	Band offsets in new BN/BX (X = P, As, Sb) lateral heterostructures based on bond-orbital theory, Nanoscale, 10, 15918 (2018)		Yes	Yes	Yes
2017				Jiang Hongbo ; Wang Zifeng ; Geng Huiyuan; Song Xiufeng; **Zeng Haibo*; Zhi Chunyi***	Highly Flexible and Self-Healable Thermal Interface Material Based on Boron Nitride Nanosheets and a Dual Cross-Linked Hydrogel ACS Applied Materials Interfaces, 9, 10078 (2017)	2018	Yes	Yes	Yes

2016				Xue Qi ; Zhang Huijie; Zhu Minshen; Wang Zifeng; Pei Zengxia; Huang Yang; Huang Yan; Song Xiufeng; **Zeng Haibo*; Zhi Chunyi***	Hydrothermal synthesis of blue-fluorescent monolayer BN and BCNO quantum dots for bio-imaging probes, RSC Advances 6, 79090 (2016)	2018	Yes	Yes	Yes
2019				Jiang Hongbo; Ma Longtao; Yang Qi; Tang Zijie; Song Xiufeng; **Zeng Haibo; Zhi Chunyi***	Three-dimensional porous boron nitride foam for effective CO2 adsorption, Solid State Communications 294, 1 (2019)		Yes	Yes	Yes
2019				Jiang Hongbo; Wang Zifeng, Ma Longtao; Yang Qi; Tang Zijie; Song Xiufeng; **Zeng Haibo; Zhi Chunyi***	Boron ink assisted in situ boron nitride coatings for anti-oxidation and anti-corrosion applications, Nanotechnology 30, 335704 (2019)		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)*
Aug/2017/Xi'an, China	BN nanosheet composite for electronic devices	21st International Conference on Composite Materials (ICCM-21)	No	No conference paper.	Yes	No conference paper.
April/2018/ Ningbo, China	Applications of 2D materials	2rd Novel Materials Synthesis and Application Symposium	No	No conference paper.	Yes	No conference paper.
July/2019/Qingdao, China	2D materials: synthesis and applications	中國材料大會	No	No conference paper.	Yes	No conference paper.

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
XUE Qi	PhD	2014	2017
WANG Zifeng	PhD	2015	2018

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

Currently, there is no industrial transformation of the project results. The white graphene composite optical glass and white graphene composite thermal conductive materials have good application prospects in laser windows and flexible circuit heat dissipation materials, which are expected to be realized through further engineering research.

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]	6	0	0	2	Nil.