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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

Processing and Characterization of 3D Graphene Based Thermal Interface Materials

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

	Hong Kong Team	Mainland Team
Name of Principal Investigator *(with title)*	Prof. WONG Ching Ping	Prof. BAI Shulin
Post	Dean of Faculty of Engineering	Executive Director of the Advanced Technology Institute
Unit / Department / Institution	Electronic Engineering/The Chinese University of Hong Kong	Materials Science and Engineering/College of Engineering/Peking University
Co-investigator(s) *(with title)*	Prof. XU Dongyan Prof. ZHAO Ni	Prof. Huang Zhuping Ms. ZHOU Wenling Mr. ZHANG Yangfei

3. Project Duration

	Original	Revised	Date of RGC/ Institution Approval *(must be quoted)*
Project Start date	01-01-2014		
Project Completion date	31-12-2017		
Duration *(in month)*	48		
Deadline for Submission of Completion Report	31-12-2018		

Part B: The Completion Report

5. Project Objectives

5.1 Objectives as per original application

1. To design and develop a new thermal interface material (TIM) based on 3D graphene network filled with graphene nanosheets/polymer blend.
2. To experimentally characterize thermal properties of the new TIM and to understand thermal transport mechanism in the complex composite materials.
3. To experimentally characterize mechanical properties of the new TIM and to develop microscopic component assembly models to understand the deformation and failure behavior of the material.

4. To establish a correlation between processing, microstructure, thermal and mechanical properties of 3D graphene based TIMs.
5. To optimize the performance of graphene/polymer composite TIMs and to explore their applications in thermal management systems of microelectronic devices.

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 systematically studied thermal interface materials (TIMs) consisting of 3D graphene or boron nitride (BN) network in a polymer matrix. The project revealed that a properly designed 3D graphene or BN skeleton can could provide effective thermal transport pathways, endowing the TIMs with both high mechanical compliance and high thermal conductivity, all achieved at a low loading of fillers. (Publications #1, 2, 4, 5)

After verifying the importance of forming 3D thermal transport network, we focused specifically on low-cost fabrication methods to produce high performance TIM network. We developed a direct foaming method to fabricate a three dimensionally interconnected hierarchical porous BN/epoxy composite for thermal interface material applications. The foam-templated approach allows for construction of an isotropic porous structure with low loading of fillers and is a versatile method that can be applied to various high-thermal conductivity fillers. Based on this method, we performed a comparative study on micron-size and submicron-size BN based thermal interface materials through combining structural, morphological and thermal property characterizations as well as defect analysis. The results demonstrate that, as compared to the submicron BN fillers, the micron BN fillers can form a better aligned distribution along the three dimensional network while introducing less defects and grain boundaries, resulting in high thermal conductivity both in-plane and out-of-plane at a low filler concentration. This study provides guidelines on the design, fabrication and optimization of composite-based thermal interface materials. (Publications # 2)

Furthermore, inspired by the process of making 3D graphene/polymer composite, we developed a new fabrication process to make wood derived carbon composites that can potentially be used as TIMs, battery electrodes, and active materials for mechanical sensors. Natural wood possesses a unique 3D microstructure containing hierarchical interconnected channels along its growth direction. We reported a facile processing strategy to utilize such structure to fabricate carbon/silicone composite based flexible pressure sensors. The unique contribution of the multichannel structure on the sensor performance is analyzed by comparing the pressure response of the vertically cut and horizontally cut composite structures. The results show that the horizontally cut composite based sensors exhibit much higher sensitivity and wider linear region, due to their rough surface and largely deformable microstructure. Besides, the sensors also show little hysteresis and good cycle stability. (Publication #3) We have also explored other applications of 3D graphene such as energy storage devices. (Publication #6)

Potential for further development of the research and the proposed course of action

(maximum half a page)

The success of the project shows that the vertically aligned graphene/polymer composites and 3D graphene or boron nitride/epoxy composites are two effective way for preparation of thermal interface material with high thermal conductivity. Fillers with larger size, less defects is benefit for achieving high thermal conductivity. We planned to develop hydrothermal method to get graphene to self-assemble into a 3D graphene foam with small pore size and less defects. Which can act as the thermal condition pathway of thermal interface material. In addition, we will further introduce carbon nanotube, metal nanowire and boron nitride into the 3D graphene foam to synergically enhance the thermal conductivity.

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)

Thermal management is critical for operation of various high power electronic devices. A key component of a thermal management system is the thermal interface material (TIM), which is used to improve the thermal contact between two dissimilar surfaces, e.g. the interface between the heat spreader and the microprocessor chip. Traditional TIMs, such as thermal grease, are easy to assemble and possess long-term reliability; however, with the ever increasing power density of microelectronics, these TIMs will soon become insufficient in dissipating the ultrahigh-heat-flux.

Through this proposal we have developed new TIMs with both high mechanical compliance and high thermal conductivity. The materials can be fabricated in large scale, and at low cost. Furthermore, we have combined the experimental and theoretical approaches to study the correlations among the material structures, processing conditions and thermal properties. The findings also provide guidelines to design of new high performance TIMs. The new composite TIMs developed in this project can be readily implemented into various thermal management systems, which will benefit next generation microelectronics and other high-power electronic 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) (**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				**Haoming Fang, Shu-Lin Bai*, Ching Ping Wong**	“White graphene” – hexagonal boron nitride based polymeric composites and their application in thermal management, Composites Communications, 2 (2016) 19-24.	N.A.	Yes	Yes	Yes
2018				**Zhilin Tian, Jiajia Sun, Shaogang Wang,Xiaoliang Zeng, Shuang Zhou, Shulin Bai, Ni Zhao* and Ching-Ping Wong*,**	A thermal interface material based on foam templated three-dimensional hierarchical porous boron nitride, Journal of the Material Chemistry A, 6 (2018) 17540	N.A.	Yes	Yes	Yes

2018				**Yan Huang, Yun Chen, Xiangyu Fan, Ningqi Luo, Shuang Zhou, Shih-Chi Chen, Ni Zhao*, Ching Ping Wong***	Wood Derived Composites for High Sensitivity and Wide Linear-Range Pressure Sensing, Small, 14 (2018), 1801520	N.A.	Yes	Yes	Yes
2017				**Haoming Fang, Shu-Lin Bai*, Ching Ping Wong**	Thermal, mechanical and dielectric properties of flexible BN foam and BN nanosheets reinforced polymer composites for electronic packaging application, Composites: Part A, 100 (2017) 71-80.	N.A.	Yes	Yes	Yes
2016				**Dong Han, Yun-Hong Zhao, Shu-Lin Bai* and Wong Ching Ping**	High shielding effectiveness of multilayer graphene oxide aerogel film/polymer composites, RSC Advances, 6 (2016), 92168.	N.A.	Yes	Yes	Yes

2015				**Zhen-Kun Wu, Ziyin Linb, Liyi Li, Bo Song, Chia-Chi Tuan, Zhuo Li, Kyoung-sik Moon, Shu-Lin Bai* and Ching-Ping Wong***	"Capacitance enhancement by electrochemically active benzene derivatives for graphene-based supercapacitors"	2016	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)*
06/2018	Wearable sensor system based on composite materials for cardiopulmonary monitoring	2018 European Material Research Society Spring Meeting	N.A.	Yes	Yes	No
04/2017	Bioinspired anisotropic carbon network for highly selective pressure sensing	2017 Material Research Society Spring Meeting	N.A.	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
Yan Huang	PhD	01/08/2015	31/07/2019

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

N.A.