RGC Ref.: N_CityU101/12
NSFC Ref. : 61261160498
(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

Electromigration and Thermomigration Studies in Nanostructured Composite Electronic Interconnects for Nanoelectronics Applications
用於納米電子應用的納米結構複合電子互連中的電遷移和熱遷移研究

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

	Hong Kong Team	Mainland Team
Name of Principal Investigator *(with title)*	Prof. Yan-cheong CHAN	Prof. Fengshun WU
Post	Chair Professor	Professor
Unit / Department / Institution	Department of Electronic Engineering/City University of Hong Kong	School of Materials Science and Engineering/Huazhong University of Science and Technology (HUST)
Contact Information	*eeycchan@cityu.edu.hk*	fengshunwu@hust.edu.cn
Co-investigator(s) *(with title and institution)*	Dr. Jonathan C. Y. Chu (Department of Physics and Materials Science/City University of Hong Kong) Prof. Christopher Bailey (The University of Greenwich, UK) Prof. King-Ning Tu (UCLA, USA) Mr. C. W. Cheung, (Compass Tech. Co. Ltd., Hong Kong)	

3. Project Duration

	Original	Revised	Date of RGC/ Institution Approval *(must be quoted)*
Project Start date	1st January 2013		1st January 2013
Project Completion date	31st December 2016		31st December 2016
Duration *(in month)*	48		48
Deadline for Submission of Completion Report	30th September 2017		30th September 2017

Part B: The Completion Report

5. Project Objectives

5.1 Objectives as per original application

1. To better understand the science of EM and TM- induced failure mechanisms of novel nanostructured composite electronic interconnects under different cumulative (electro-thermo-mechanical-chemical) stresses, temperature and high current stresses.

2. To establish a revolutionary scientific understanding on thermomechanical reliability and an integrated theoretical model to correlate EM and TM phenomena incorporating all the interacting loads (electro-thermo-mechanical-chemical) and failure analysis.

3. To explore the realistic optimization measures for mitigating EM and TM-induced failures in nanostructured composite electronic interconnects and interfaces and provide a total solution to prevent or mitigate the EM and TM-induced failures in interconnects under specific combinations of materials, processes, and loads for nanoelectronics applications on a wider scope.

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)

The first research findings and outcome are related to the reinforcement of nanoparticles doped low temperature solder micro-joint. Silver nanoparticles are deployed to investigate the drawbacks of low temperature solder joints in micro scale, with a view to improving the resistance to mechanical, thermal and electrical stresses. In this, various useful data and analyses have been performed for setting the foundation for better understanding of the science of EM and TM-induced failure mechanisms of novel nanostructured composite electronic interconnects.

The second research findings and outcome have derived from the benefits from the first, and basically yielded useful information on the distribution and solubility of nanoparticles in the solder joints, which are the key factors demining the effectiveness of reinforcement of the doped joints. In combination with the first set of research outcome, aimed at achieving the first and second project objectives, we have achieved better understanding of the EM and TM-induced failure mechanisms of novel nanostructured composite electronic interconnects, and such failure mechanisms are a lot clearer than before.

The third research findings and outcome lie in getting the realistic optimization measures for mitigating EM and TM-induced failures in nanostructured composite electronic interconnects and interfaces, and as a result, we have managed to obtain mitigation solutions to prevent or reduce the EM and TM-induced failures in interconnects, supported by theoretical models.

As said in the mid-term progress report, the following areas have been fully addressed

- Completed the research on nanoparticle refinement of EM/TM phenomena in micro-sized solder joint and the study of inhibition methods
- Completed the research on the behavior of nanoparticles (physical and chemical) in the solder joint during the process of fabrication and use
- Completed the study on the behavior of smaller sized solder joints (~50 micron), as applied in advanced packaging of through-silicon-via (TSV)
- Completed relevant research that would supplement the research findings and make the overall outcome coherent and have impact

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

A few key points for further development and possible course of action:

- Extend the current modeling for analyzing EM and TM-failure analyses to cover a wider spectrum of stresses and device dimensions & geometries
- Target for finer interconnect geometry to 50 to 100nm range for the more or less ultimate limit of challenge
- Overstress all the DUTs to the maximum possible to explore how the current theoretical models fit or not

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 significance of this research project really addresses a continuing trend of miniaturization in the evolution of electronics - towards higher packing densities for the components that form integrated circuits, circuit-boards and sub-systems. The research outcomes have set a good foundation for engineer to design higher component packing density with improved performance in terms of speed, power consumption and space occupied - together with lower cost. Armed with such new knowledge, engineers are able to adopt novel materials that can overcome the challenges of stability and robustness – and avoid the classic failure mechanisms of electromigration (EM) and thermomigration (TM) – hence, in a nutshell, the electronics will become more reliable, smaller, and cheaper.

The advances in nanoscience or nanotechnology are the backbone for inventing any novel nanostructured composite materials for use in electronic components. This is exactly where this project has achieved, adding new knowledge to this backbone, and yet produced research outcomes that have laid a strong foundation for a better scientific understanding of the capabilities and limitation of such physical phenomena in next generation advanced nanoelectronics applications, and numerous PhD students have benefited such journeys of research exploration.

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 Year of publication	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)*
2016	**Yi Li***, Adeline B.Y. Lim, Kaiming Luo, Zhong Chen, **Fengshun Wu**, **Y.C. Chan**	Phase segregation, interfacial intermetallic growth and electromigration-induced failure in Cu/In48Sn/Cu solder interconnects under current stressing /Journal of Alloys and Compounds vol:673 pp:372-382	No	Yes	Yes	No
2016	**Yi Li***, Kaiming Luo, Adeline B.Y. Lim, Zhong Chen, **Fengshun Wu**, **Y.C. Chan**	Improving the mechanical performance of Sn57.6Bi0.4Ag solder joints on Au/Ni/Cu pads during aging and electromigration through the addition of tungsten(W) nanoparticle reinforcement / Materials Science & Engineering A vol:669 pp:291–303	No	Yes	Yes	No

2016	**Ze Zhu*, Huayu Sun, Fengshun Wu, Yan-cheong Chan**	Comparative study of the microstructure and mechanical strength of tin-copper (Sn0.7Cu) solder modified with silver (Ag) by both alloying and doping methods / J Mater Sci: Mater Electron vol:27 pp: 6835–6844	No	Yes	Yes	No
2016	**Huayu Sun*, Y.C. Chan, Fengshun Wu**	Effect of CNTs and Ni coated CNTs on the mechanical performance of Sn57.6Bi0.4Ag BGA solder joints / Materials Science & Engineering A vol: 656 pp:249–255	No	Yes	Yes	No
2015	**Yi Li*, Fengshun Wu, Y. C. Chan**	Electromigration in eutectic In-48Sn ball grid array (BGA) solder interconnections with Au/Ni/Cu pads / J Mater Sci: Mater Electron vol: 26 pp: 8522–8533	No	Yes	Yes	No
2015	**Tianwei Hu*, Yi Li, Yan-Cheong Chan, Fengshun Wu**	Effect of nano Al2O3 particles doping on electromigration and mechanical properties of Sn–58Bi solder joints / Microelectronics Reliability vol:55 pp: 1226–1233	No	Yes	Yes	No
2015	**Huayu Sun*, Y. C. Chan, Fengshun Wu**	Influence of the aggregated Ag3Sn on the improvement of electromigration phenomenon in the doped Sn58Bi solder joints / J Mater Sci: Mater Electron vol: 26 pp: 5129–5134	No	Yes	Yes	No
2015	**Huayu Sun*, Y. C. Chan, Fengshun Wu**	The impact of reflow soldering induced dopant redistribution on the mechanical properties of CNTs doped Sn58Bi solder joints / J Mater Sci: Mater Electron vol: 26 pp: 5318–5325	No	Yes	Yes	No

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)*
Dec/2016/ Singapore	Failure mechanisms of solder interconnects under current stressing – a progress update from recent studies on novel interconnect materials	Electronics Packaging Technology Conference	No	Yes	Yes	No

Sep/2016/ Grenoble, France	Enhanced Electromigration (EM) Reliability of Sn58Bi Solder Due to the Incorporation of ZrO2 Nanoparticles	Electronics System-Integration Technology Conferences	No	Yes	Yes	No
Sep/2016/ Grenoble, France	Investigation in microstructure and mechanical properties of Ni-coated multi-wall carbon nanotubes doped Sn3.0Ag0.5Cu solder alloys	Electronics System-Integration Technology Conferences	No	Yes	Yes	No
Apr/2016/ Sapporo, Japan	A comparison study of electromigration in In-48Sn solder interconnects with Cu and Au/Ni/Cu pads	International Conference on Electronics Packaging	No	Yes	Yes	No
Dec/2015/ Singapore	Electromigration study of SnCu0.7 solder joints with Ag added by different methods	Electronics Packaging Technology Conference	No	Yes	Yes	No
Aug/2015/ Changsha, China	Effects of ZrO2 nanoparticles on the mechanical properties of Sn42Bi58 solder joint	International Conference on Electronic Packaging Technology	No	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
Qingqian LI	PhD	1 Jan 2010	Jun 2014/30 Jun 2014
Sha XU	PhD	1 Nov 2010	Sep 2014/31 Oct 2014
Yi LI	PhD	1 Sep 2013	July 2016/Nov 2016
Huayu SUN	PhD	1 Sep 2013	N/A
Ze ZHU	PhD	1 Sep 2014	N/A

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

Yi Li – CityU Outstanding Research Thesis award 2016