RGC Ref.: M-HKBU209/12
(please insert ref. above)

The Research Grants Council of Hong Kong
SRFDP & RGC ERG Joint Research Scheme
Completion Report

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

Part A: The Project and Investigator(s)

1. Project Title

Fiber-shaped Photovoltaic Cells (纖維態光伏電池)

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

	Hong Kong Team	Mainland Team
Name of Principal Investigator *(with title)*	Zhu Furong (Prof.)	Zou Dechun (Prof.)
Post	Professor	Professor
Unit / Department / Institution	Department of Physics Hong Kong Baptist University	College of Chemistry and Molecular Engineering, Peking University
Contact Information	(852) 3411-5867 frzhu@hkbu.edu.hk	010-62759799 dczou@pku.edu.cn
Co-investigator(s) *(with title and Institution)*	Wu Bo (Dr. HKBU)	
PhD student(s) (with period of involvement)	Name: Yang Qingyi Wu Zhenghui Lee Min-Hsuan Lan Weixia Institution: Hong Kong Baptist University Period from 1 March 2013 to 28 February, 2016	Name: Hongwei Wu Shaocong Hou Kafafy Hany Institution: Peking University Period from 1 March 2013 to 28 February, 2016

Note: The Hong Kong project team must involve at least one research postgraduate student pursuing a Doctor of Philosophy degree at the UGC-funded university (PhD student) at any time throughout the project period.

3. Project Duration

	Original	Revised	Date of RGC/ Institution Approval *(must be quoted)*

Project Start date	1 Mar, 2013		19 December 2012
Project Completion date	28 Feb, 2016		
Duration *(in month)*	36		
Deadline for Submission of Completion Report	28 Aug, 2016		

Part B: The Completion Report

5. Project Objectives

5.1 Objectives as per original application

1. *Synthesize new disulfide redox, alternative hole conductor and process optimization for application in solid state fiber-shaped DSSCs.*
2. *Understand the plasmonic effect of Ag nanoparticles on spectral response of fiber-shaped OSCs.*
3. *Develop high performance fiber-shaped photovoltaic cells using surface-modified Ti metal wires and optical fibers.*
4. *Promote research collaboration and jointly train 4-6 PhD students in materials science, theoretical modelling, device physics and engineering.*

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)

1. Spectral response of fiber-shaped OSCs with Ag nanoparticles.

The distribution of the electromagnetic field on the surface of the Ti wires, under the illumination of AM1.5G condition, was calculated by FDTD numerical simulation. Theoretical calculation reveals the intensity of incident light on the Ti surface in different position varies due to the interference effect, assuming the first half of a Ti wire is exposed to the solar radiation. For simplicity, a model of planar OSCs with Ag nanoparticles was used in the optical simulation, the fiber-shaped cells are irradiated

either with the vertical or oblique incidence, having different intensities of incident light. The effect of the plasma-polymerized fluorocarbon (CFx)-modified Ag nanoparticles (NPs) on absorption enhancement of the cells, using a model organic photoactive system of zinc phthalocyanine:fullerene, is analyzed. Both FDTD simulation and experimental results indicate that the coalescent of Ag NPs influences the localized surface plasmon resonance, contributing to the broadband light absorption enhancement in the active layer. More than 10% enhancement in the short circuit current density was achieved due to the absorption enhancement, caused by the plasmonic effect of Ag NPs. The size distribution of the Ag NPs, formed by the thermal evaporation, is over the range from 2.0 nm to 10 nm. It is found that localized surface plasmon resonance is strongly influenced by the size of Ag NPs and the dielectric constant of the surrounding medium.

2. Surface-modified Ti metal wires for fiber-shaped DSSCs

Bilayer TiO_2 modified Ti wires were prepared for fiber-shaped DSSCs with a power conversion efficiency of >4%. The inner layer TiO_2, made from the sintering process, acts as the compact layer to separate the electrolyte from the metal wire contact. The thinner outer TiO_2 layer is made from the electrical heating process. The uniform layer of TiO_2 nanoparticles covers the inner layer and forms curved smooth surface. One-dimensional semiconductor TiO_2 nanowires were also synthesized using controllable solution process at a low temperature. Fiber-shaped DSSCs with an integrated groove luminescent solar concentrator was also demonstrated, revealing an obvious improvement in the output power of the cells. The improvement in the cell performance is caused by the efficient light harvesting due to the reflection by the groove, simple but effective for high performance fiber-shaped solar cells at a low cost. The outcomes of the work provide an intriguing avenue for attaining lightweight, cost-effective and high performance flexible/wearable solar cells. Details of the technical results are summarized in the attached publication, Ming Peng, Shaocong Hou, Hongwei Wu, Qingyi Yang, Xin Cai, Xiao Yu, Kai Yan, Hsienwei Hu, Furong Zhu* and Dechun Zou*, Integration of fiber dye-sensitized solar cells with luminescent solar concentrators for high power output, J. Mater. Chem. A, 2 (2014) 926–932.

3. Waveguide fiber-shaped DSSCs

The performance of lightweight fiber-shaped DSSCs with a built-in luminescent solar concentrator was analyzed. The effect of different configurations of the built-in luminescent solar concentrator on the photovoltaic performance of fiber-shaped DSSCs was examined. An enhancement factor of >5.0 in the maximum output power of fiber-shaped DSSCs was realized through omnidirectional absorption enhancement over a large area. The improvement in the output power of the fiber-shaped DSSCs was also achieved over a range of large incident angle ranges of incident light from 0° to 80° and 100° to 180°. Fiber-shaped DSSCs show reasonable photovoltaic performance under natural sunlight with a highly oblique angle and even under the shade. The results are summarized in the attached journal publication, Ming Peng, Xiao Yu, Xin Cai, Qingyi Yang, Hsienwei Hu, Kai Yan, Hui Wang, Bin Dong, Furong Zhu* and Dechun Zou*, Waveguide fiber dye-sensitized solar cells, Nano Energy, 10 (2014) 117-124.

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

Further effort is needed for realizing all solution processable solid fiber-shaped solar cells, e.g., extending the work to develop polymer and perovskite-based fiber-shaped solar cells. For fiber-shaped OSCs, the uniform coverage of an organic active layer with a thickness of > 300 nm on the fiber is a prerequisite for achieving high device performance. Although some progresses have been made in this work, forming a thin layer of organic active layer on the surface of fiber-shaped wires by dip-coating approach, a thicker uniform active coating, solution processable charge transporting buffer and a transparent hybrid electrode are desired, which underpin the optimum performance of the cells. Fiber-shaped perovskite solar cells (PSCs) are another attractive option for future fiber-shaped solar cells.

PSCs have attracted significant attentions due to the number of advantages such as high carrier mobility, high light absorption coefficient, large charge diffusion length and better charge transportation behavior. Different methods have been adopted for preparing active perovskite layer in PSCs for high performance. The structure of the PSCs, including conventional or inverted configurations, also is evaluated for achieving high efficiency hysteresis-free devices. We will extend the work to develop high performance fully solution processable high performance PSCs by engineering the interfacial properties at the perovskite/electrode interfaces. This includes incorporating an ultra-thin interlayer of Ag NPs at the contact/perovskite interface via the solution process route. The effect of AgNPs on the growth of perovskite active layer, charge collection and the overall power conversion efficiency of the PSCs will be analyzed.

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 aim of this collaborative project is to explore the new device concept of fiber-based solar cells, e.g., fiber-shaped dye-sensitized solar cells using TiOx-modified Ti wires. A fiber-shaped organic solar cell is an example of a three dimensional photovoltaic architecture that enables to harvest light irrespective to the angle of the incident light. The performance of the fiber solar cells in relation to the theoretical simulation, light harvesting, materials formulation and process optimization was investigated systemically. Such fiber-shaped solar cells show reasonable photovoltaic performance under normal and a near vertical angle of the incident light. In addition to being flexible and light-weight, the design and fabrication flexibility of a fiber-shaped solar cell also maintains its low cost benefits.

In addition to the research experience, the PhD students also enjoyed and greatly benefited from the multidisciplinary and collaborative research in device modelling, device physics and process integration. Such research skills are different from those that are obtained in a classical graduate research experience that is usually conducted under a narrowly defined problem within one group. We believe that the broad exposure and the interdisciplinary perspective will provide our PhD students with an opportunity to realize their full potential for research excellence.

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)*						
2014				Ming Peng, Shaocong Hou, Hongwei Wu, Qingyi Yang, Xin Cai, Xiao Yu, Kai Yan, Hsienwei Hu, Furong Zhu* and Dechun Zou*	Integration of fiber dye-sensitized solar cells with luminescent solar concentrators for high power output, J.Mater. Chem. A, 2 (2014) 926–932	2014	Yes	Yes	Yes
2014				Ming Peng, Xiao Yu, Xin Cai, Qingyi Yang, Hsienwei Hu, Kai Yan, Hui Wang, Bin Dong, Furong Zhu* and Dechun Zou*	Waveguide fiber dye-sensitized solar cells, Nano Energy, 10 (2014) 117-124	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)*
Aug 7-10, 2015 Beijing	Poster presentation: Light Trapping Strategy for Performance Enhancement in Organic Solar Cells	The 10th National Symposium on Electronic Process in Organic Solids	Included in this report	Yes	Yes file: Conf-4.pdf	Yes
Dec 9-11, 2013 Beijing	Poster presentation: Integration of fiber dye-sensitized solar cells with luminescent solar concentrators for high power output	Asian European symposium on organic optoelectronics	Included in this report	Yes	Yes file: Conf-3.pdf	Yes
Nov 18-19, 2013 Hong Kong	Invited talk: Progresses of fiber-shaped dye sensitized solar cells	Symposium on Recent Advances in Organic Electronics	The conference info included in this report	Yes	Yes file: Conf-2.pdf	Yes
Aug 25-29, 2013 San Diego	Invited talk: Integration of transmissible organic electronic devices for sensor application	Optics and Photonics SPIE 2013	Abstract included in the report	Yes	Yes file: Conf-1.pdf	Yes

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
Hongwei Wu	Ph.D	2009/09/01	Jul 10, 2014
Shaocong Hou	Ph.D	2009/09/01	Jul 10, 2014
Kafafy Hany	Ph.D	2010/09/01	Jul 10, 2014
Qingyi Yang	Ph.D	2010/09/01	Aug 10, 2014
Zhenghui Wu	Ph.D	2011/09/01	Aug 10, 2015
Weixia Lan	PhD	2013/09/01	Aug 8, 2016
Min-Hsuan Lee	PhD	2013/10/01	Sep 30, 2016

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

1) Wu Zhenghui, Best student poster award, the 17th Physical Society of Hong Kong Annual Conference, June 7, 2014
2) Lan Weixia, Recipient of Yakun Scholarship Scheme for Mainland Postgraduate Students, 2015