RGC Ref.: N_PolyU505/13
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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

High-performance Sunlight-driven Water Purification Pilot Plant based on Plasmonic Photocatalysis and Microfluidic Planar Reactors

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

	Hong Kong Team	Mainland Team
Name of Principal Investigator *(with title)*	Dr Xuming Zhang	Dr Weixing Yu
Post	Associate Professor	Senior Research Fellow
Unit / Department / Institution	Applied Physics / The Hong Kong Polytechnic University	Key Laboratory of Spectral Imaging Technology, Xi'an Institute of Optics and Precision Mechanics, Chinese Academy of Sciences
Contact Information	Hung Hom, Kowloon, Hong Kong S.A.R., China Tel.: +852-3400 3258 Email: apzhang@polyu.edu.hk	Xinxi Road No. 17, New Hitech District, Xi'an, Shaaxi Province, China Email: yuwx@opt.ac.cn
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-2014		
Project Completion date	31-DEC-2017		
Duration *(in month)*	48		
Deadline for Submission of Completion Report	31-DEC-2018		

Part B: The Completion Report

5. Project Objectives

5.1 Objectives as per original application

1. To develop next-generation photocatalytic reactors by intelligently integrating microfluidics and plasmonic photocatalysis to solve the major problems in traditional photocatalytic water purification such as mass transfer limit, photon transfer limit and low photonic efficiency.
2. To develop novel sunlight-responsive plasmonic photocatalytic nanomaterials in large area to meet the highly-efficient and cost-effective requirements of the new photocatalytic reactors.
3. To investigate high-performance light harvesting and anti-reflection nanostructures to enhance the utilization of sunlight.
4. To develop large-scale microfluidic-based plasmonic photocatalytic reactors for high process capacity and high purification efficiency under sunlight.
5. To nurture a close collaboration between the Hong Kong team and the Mainland team.
6. To arrange 2 visits/year with 2 members to the Mainland team for technical discussions, project progress meeting, review meeting and on-site experiments.
7. To receive 2 visits/year of Mainland delegates (2 members) for project meetings and on-site experimental demonstrations.

5.2 Revised Objectives

Date of approval from the RGC: _____

Reasons for the change: _____
N.A.

6. Research Outcome

Major findings and research outcome

(1) In the photocatalytic materials, we have developed the Au/TiO_2 microsphere, whose surface has many feathery TiO_2 nanostructures and is dispersed with Au nanoparticles by photoreduction process. As compared to the TiO_2 microsphere, the Au/TiO_2 microsphere measure an enhancement factor of 46 in the reaction rate constant when tested in the suspension mode, 3.2 in the film mode and 2.1 in the stuffed mode.
(2) In the new plasmonic films, we have developed a plasmonic black absorber using rough Au surface covered by TiO_2 film, which shows 20 times enhancement of photocurrent.
(3) In the reactor design, we have presented a new packed-bed microreactor, whose reaction chamber is stuffed with Au/TiO_2 microspheres and presents an enhancement factor of 8.0 as compared to the TiO_2 film microreactor.
(4) In the fabrication technique, we have developed a new soaking-spray technique that can fabricate photocatalyst films in large area.
(5) In the large reactor, we have fabricated a bench-scale reactor (chamber dimension 0.6 m × 0.4 m × 2 mm), which can degrade 30% of MB in the field tests under the irradiation of sunlight for 2 hours, 23.6 times faster than the photolysis.

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

(1) To file a patent for the new packed-bed microreactor, which would be very useful for many photochemical reactors.
(2) To file a patent for the new soaking-spraying technique, which enables to fabricate the photocatalyst film in meter size.
(3) To further develop the solar reactor to handle real wastewater.

7. The Layman's Summary

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

In wastewater treatment, many dissolved toxic chemicals cannot be efficiently treated by the prevailing biochemical methods, posing a severe threat to environment. Photocatalysis using TiO_2 stands out as a promising solution but the energy efficiency is typically < 1%. In collaboration with Professor Weixing Yu of Xi'an Institute of Optics and Precision Mechanics, the research team of Dr Xuming Zhang in Hong Kong Polytechnic University aims to overcome the existing problems by designing new reactors guided by microfluidics principles and by making full use of sunlight energy. In the photocatalytic materials, they developed the new material of Au/TiO_2 microsphere, which had many feathery nanostructures on surface and showed 46 more efficient than TiO_2 microspheres in degrading the model chemical methylene blue (MB). In the reactor design, they presented a new packed-bed microreactor. In the large reactor, they fabricated a bench-scale reactor (chamber footprint 0.6 m × 0.4 m) that degraded 30% of MB in the field tests under the irradiation of sunlight for 2 hours, which was 23.6 times faster than the photolysis. This project would make it feasible to provide on-the-spot clean water in remote areas with no access to public water supply.

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)*						
1	2014				S. Y. Cao, W. X. Yu, T. S. Wang, H. H. Shen, X. D. Han, W. B. Xu, **X. M. Zhang**	Meta-microwindmill structure with multiple absorption peaks for the detection of ketamine and amphetamine type stimulants in terahertz domain, Optical Materials Express, vol. 4, no. 9, pp. 1876 – 1884.	2016	Yes	Yes	Yes
2	2014				**N. Wang, F. R. Tan, L. Wan, M. C. Wu, X. M. Zhang***	Microfluidic reactors for visible-light photocatalytic water purification assisted with thermolysis, Biomicrofluidics, vol. 8, no. 5, pp. 054122.	2016	Yes	Yes	Yes
3	2015				Y. Bao, **X. W. Yi,** Z. H. Li*, **Q. M. Chen,** J. P. Li, X. D. Fan and **X. M. Zhang***	A digitally generated ultrafine optical frequency comb for spectral measurements with 0.01-pm resolution and 0.7-μs response time, Light: Science& Applications, vol. 4, paper no. e300.	2016	Yes	Yes	Yes
4	2015				S. Cao, T. S. Wang, J. L. Zhao, **F. R. Tan, X. M. Zhang**, W. X. Yu*	Hierarchic random nanosphere model for broadband solar energy absorbers, Optical Materials Express, vol. 5, no. 12.	2016	Yes	Yes	Yes
5	2015				**Tenghao Li, Qingming Chen**, Yunfeng Xiao and **Xuming Zhang***	Variable optical delay line using discrete harmonic oscillation in waveguide lattices, Journal of Lightwave Technology, vol. 33, no. 24, pp. 5095 – 5102.	2016	Yes	Yes	Yes

6	2016				**Xiaowen Huang, Yujiao Zhu, Xuming Zhang***, Zhiyong Bao, Dang Yuan Lei, Weixing Yu, Jiyan Dai, Yu Wang	Clam-inspired nanoparticle immobilization method using adhesive tape as microchip substrate, Sensors and Actuators B Chemical, vol. 222, pp. 106 – 111.	No	Yes	Yes	Yes
7	2016				Wuxia Liao, **Ning Wang**, Taisheng Wang, Jia Xu, Xudong Han, Zhenyu Liu, **Xuming Zhang***, and Weixing Yu*,	Biomimetic microchannels of planar reactors for optimized photocatalytic efficiency of water purification, Biomicrofluidics, vol. 10, paper no. 014123.	No	Yes	Yes	Yes
8	2016				**Ning Wang, Furui Tan, Yu Zhao, Chi Chung Tsoi**, Xudong Fan, Weixing Yu & **Xuming Zhang***	Optofluidic UV-Vis spectrophotometer for online monitoring of photocatalytic reactions, Scientific Reports, vol. 6, paper no. 28928.	No	Yes	Yes	Yes
9	2016				**Furui Tan, Tenghao Li, Ning Wang, Sin Ki Lai, Chi Chung Tsoi**, Weixing Yu, **Xuming Zhang***	Rough gold films as broadband absorbers for plasmonic enhancement of TiO_2 photocurrent over 400 – 800 nm, Scientific Reports, vol. 6, paper no. 33049.	No	Yes	Yes	Yes
10	2017				**Furui Tan, Ning Wang,** Dang Yuan Lei, Weixing Yu **and Xuming Zhang***	Plasmonic black absorbers for enhanced photocurrent of visible-light photocatalysis, Advanced Optical Materials, vol. 5, no. 1, paper 1600399.	No	Yes	Yes	Yes
11	2018				**Xiaowen Huang,** Jianchun Wang, **Tenghao Li,** Jianmei Wang, Min Xu, Weixing Yu, Abdel El Abed, and **Xuming Zhang***	Review on optofluidic microreactors for artificial photosynthesis, Beilstein Journal of Nanotechnology, vol. 9, pp. 30 – 41.	No	Yes	Yes	Yes
12	2018				**Qingming Chen, Tenghao Li,** Zhaohui Li, Chao Lu* and **Xuming Zhang***	Dielectrophoresis-actuated liquid lenses with dual air/liquid interfaces tuned from biconcave to biconvex, Lab on a Chip, vol. 18, no. 24, pp. 3849 – 3854	No	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)*
1	August / 2014 / Guangzhou, China	*Optofluidics microreactors for photocatalytic water purification*.	The 4th International Conference on Optofluidics (**Optofluidics 2014**)	No	Yes	Yes	Yes
2	November / 2014 / Singapore	Microfluidics for photocatalytic water purification: now and beyond,	Lab-on-a-Chip Asia – Microfluidics and Point of Care Diagnostics (**Lab-on-a-Chip Asia 2014**)	No	Yes	Yes	Yes
3	May / 2015 / San Jose, CA, USA	Optofluidic microreactors for visible-light photocatalysis	The Conference on Lasers and Electro-Optics (**CLEO2015**)	No	Yes	Yes	Yes
4	July / 2015 / Taipei, Taiwan	Microfluidics for artificial photosynthesis of glucose using sunlight (invited talk)	The 5th International Conference on Optofluidics (**Optofluidics2015**)	No	Yes	Yes	Yes
5	June / 2016 / Hong Kong	Artificial photosynthesis for carbohydrates generation with immobilized enzyme on gold nanoparticles patterned microfluidic reactors **(Cheminas Best Poster Awards)**	The 8th International Symposium on Microchemistry and Microsystems (**ISMM2016**)	No	Yes	Yes	Yes
6	May / 2017 St Petersburg, Russia	Plasmonic black absorbers for photocurrent enhancement under visible light	The 38th Progress in Electromagnetics Research Symposium (**PIERS2017)**	No	Yes	Yes	Yes
7	July / 2017 / Singapore	Solar reactor for photocatalytic water purification (**Best Paper Award)**	The 7th International Multidisciplinary Conference on Optofluidics (**IMCO2017)**	No	Yes	Yes	Yes

8	July / 2017 / Singapore	Photocatalytic water purification by using nanomaterial	The 7th International Multidisciplinary Conference on Optofluidics (**IMCO2017**)	No	Yes	Yes	Yes
9	June / 2018 / Hong Kong	Complementary plasmonic absorbers for visible-light photocatalysis	Asia-Pacific Conference on Transducers and Micro-Nano Technology (**APCOT2018**)	No	Yes	Yes	Yes
10	July 2018 / Macau	Solar vapor desalination of seawater	Joint Annual Conference of Physical Societies in Guangdong-Hong Kong-Macao Greater Bay Area (**YGA2018**)	No	Yes	Yes	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
Chen Qingming	Ph.D.	05-SEP-2014	Graduated on 21-JUN-2018

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

(1) This project is highlighted by *International Innovation* by a 3-page article in 2014 (see below).

Benjamin Skuse, Waste not, want not, International Innovation, no. 148, 14 August 2014, pp. 66–68.

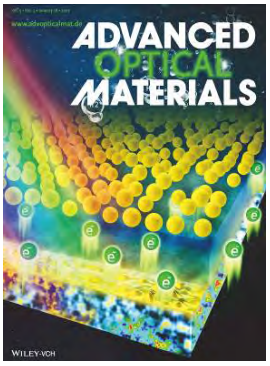

Waste not, want not

An expert in photonics, Dr Xiaoming Zhang is applying his expertise to water process technology. Here, he describes his fortuitous entry into the field, the principles of photocatalysis and the particular importance of this work in his native China, where access to clean water is a significant problem

Widening water supply

(2) One of the journal papers was selected as the back cover page in 2017 (see below).

Furui Tan, Ning Wang, Dang Yuan Lei, Weixing Yu and Xuming Zhang*, Plasmonic black absorbers for enhanced photocurrent of visible-light photocatalysis, Advanced Optical Materials, vol. 5, no. 1, paper 1600399, 19 January 2017. (Back cover)



(3) Three conference papers won the Best Paper Awards in 2014, 2016 and 2017 (see below).

- **Best Poster Awards**, N. Wang, F. R. Tan and X. M. Zhang, The 4th International Conference on Optofluidics (**Optofluidics 2014**), 28 – 30 August 2014, Guangzhou, China, paper title: *Optofluidics microreactors for photocatalytic water purification*.

- **Cheminas Best Poster Awards**, Yujiao Zhu, Xiaowen Huang, and Xuming Zhang, The 8th International Symposium on Microchemistry and Microsystems (**ISMM2016**), 30 May – 1 June 2016, Hong Kong, paper title: *Artificial photosynthesis for carbohydrates generation with immobilized enzyme on gold nanoparticles patterned microfluidic reactors*.

- **Best Paper Award**, Chi Chung Tsoi, Pui Hong Yeung and Xuming Zhang, The 7th International Multidisciplinary Conference on Optofluidics (**IMCO2017**), 25 – 28 July 2017, Singapore, paper sciforum-012821, paper title: *Solar reactor for photocatalytic water purification*.

(4) Won two 2nd-prize awards in industrial exhibitions in 2015 and 2018 (see below).

- **National Second prize (國家二等獎)**, The 14th "Challenge Cup" national university students extracurricular academic and technical competition ("挑戰杯"全國大學生課外學術科技作品競賽), Central Committee of the Communist Youth League, Science and Technology Association of China, Ministry of Education and the National Student Union (共青團中央,中國科協,教育部和全國學聯), November 2015.

- **Second prize**, The 11th National College Students' Energy-saving and Emission Reduction Social Practice and Technology Competition (第十一屆全國大學生節能減排社會實踐與科技競賽), Ministry of Education, China, August 2018.

(5) 1 book chapter (see below).

- Ning Wang and Xuming Zhang, "Chapter 16. Microfluidic Photocatalysis", in Optical MEMS, nanophotonics, and their applications, ed. Guangya Zhou and Chengkuo Lee, Productivity Press, 14 December 2017.