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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

Microengineering Organic Semiconductor Materials for Flexible OTFT Devices

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

	Hong Kong Team	Mainland Team
Name of Principal Investigator *(with title)*	Prof. Aping ZHANG	Prof Qingdong ZHENG
Post	Professor	Professor
Unit / Department / Institution	Department of Electrical Engineering / The Hong Kong Polytechnic University	Fujian Institute of Research on the Structure of Matter / Chinese Academy of Sciences
Contact Information	azhang@polyu.edu.hk	qingdongzheng@fjirsm.ac.cn
Co-investigator(s) *(with title and institution)*	Dr Yang CHAI The Hong Kong Polytechnic University	Dr Shanci CHEN Fujian Institute of Research on the Structure of Matter / Chinese Academy of Sciences

3. Project Duration

	Original	Revised	Date of RGC/ Institution Approval *(must be quoted)*
Project Start date	1 January 2016	N.A.	
Project Completion date	31 December 2019		
Duration *(in month)*	48		
Deadline for Submission of Completion Report	31 December 2020		

Part B: The Completion Report

5. Project Objectives

5.1 Objectives as per original application

1) Develop new organic semiconductor materials for high-performance field-effect transistors;
2) Develop new maskless lithography technology for patterning organic semiconductor materials;
3) Develop large-area high-performance flexible tactile sensors based on high-density OFET array.

5.2 Revised Objectives

N.A.

6. Research Outcome

Major findings and research outcome
(maximum 1 page; please make reference to Part C where necessary)

The major research findings and outcomes of the project include:

I. Two kinds of new organic semiconductor materials with good optoelectronic properties have been developed.

Our collaboration partner has successfully developed two asymmetric-indenothiophene-based organic semiconductors (PITBT and PITFBT). Both organic semiconductors (or copolymers) exhibit good solubility in common organic solvents such as chloroform, toluene, and chlorobenzene. Thermogravimetric analysis indicates that both copolymers are stable up to 360 °C. Charge transporting properties of these novel semiconductors have been investigated by using bottom-gate OFET structure. Both copolymers exhibit typical *p*-type semiconductor characteristics. For PITBT, its hole mobility of OFETs is measured to be 7.42 ×

10^{-4} cm^2 V^{-1} s^{-1}. By contrast, the OFETs based on PITFBT show a greatly enhanced hole mobility of 2.53×10^{-3} cm^2 V^{-1} s^{-1} and a much higher on/off current ratio.

II. New optical maskless lithography technology has been developed for microengineering functional organic materials.

With the recently developed digital light processing technology, we have successfully established an optical maskless lithography technology, see Fig. 1(A), to microengineer organic semiconductor and functional polymer materials for fabrication of OTFT devices and sensors. The developed maskless lithography showed great flexibility in microengineering of different kinds of organic materials for 2D or even 3D microstructures. Our researches have demonstrated that such a maskless lithography technology can not only flexibly microengineer various kinds of functional organic materials, such as elastic conductive hydrogel (see the **Paper-2**) and elastic ionic hydrogel (see **Paper-3**), for OTFT sensors and devices, but also directly print the micropatterns of silver nanoparticles (see **Paper-4**) and 3D microstructures of polytetrafluoroethylene (see **Paper-5**).

III. High-performance flexible OTFT-based tactile sensors have been developed for wearable applications.

With the developed organic semiconductor materials and maskless lithography technology, we have designed and fabricated several kinds of high-performance flexible OFET-based tactile sensors. High-performance flexible OFET pressure sensors based on a novel gradient PMMA/PAA dielectric have been fabricated for pressure sensing (see Fig.2A & **Paper-1**). Notably, micropatterned elastic ionic polyacrylamide hydrogel can render OFET sensors not only extremely high sensitivity but also very low operation power for low-pressure mapping (see Fig.2B & **Paper-3**).

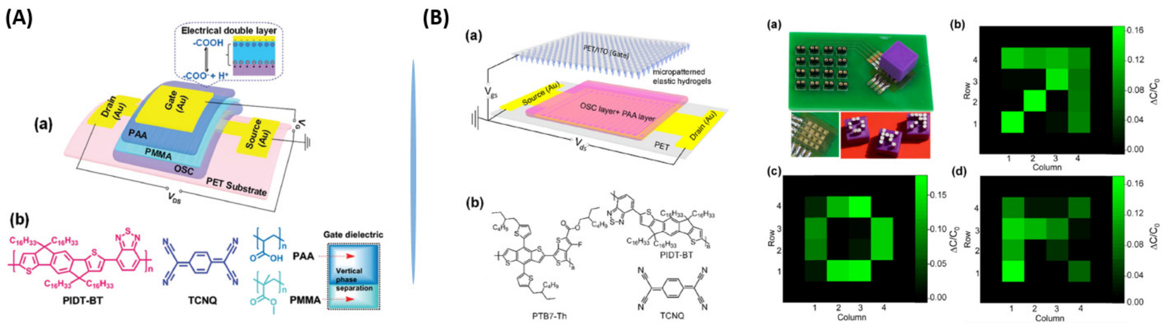

Fig. 2. (A) High-performance flexible OFET pressure sensors with a novel gradient PMMA/PAA dielectric. (B) OFET tactile sensors with micropatterned elastic ionic polyacrylamide hydrogel.

These research outcomes have been published in top international journals, such as *Advanced Science* (***IF: 12.4***) and *Nano Energy* (***IF: 12.4***). The work published in *Advanced Materials Technology* (***IF: 5.969***) was highlighted on *Back Cover* and featured by *Materials Views China* (see more details in Part C).

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

The developed organic semiconductor materials showed good electronic and optoelectronic properties and thus can be used to develop not only high-performance flexible organic thin-film transistor tactile sensors but also flexible optoelectronic devices, such as organic solar cells, while the developed optical maskless lithography technology exhibited great flexibility in microengineering various kinds of organic materials toward 2D and even 3D microstructures.

Further research may bridge the developments on new materials and advanced microfabrication technologies to develop new kinds of flexible electronic/optoelectronic devices such as wearable sensors, organic solar cells, organic light-emitting diodes, large-area rollable displays, etc.

Notably, our fabricated flexible capacitive OTFT pressure sensor with microengineered elastic ionic polyacrylamide hydrogel has not only extremely high sensitivity (i.e. 17.95 kPa^{-1}) but also very low operation voltage (i.e. 2 V) where are thus very promising for a myriad of E-skin applications ranging from tactile sensors to personalized healthcare devices.

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)

Flexible electronic devices have attracted remarkable attention due to their enormous promise in wearable electronics and personalized healthcare applications. In particular, organic thin-film transistors (OTFTs) have shown their great potential due to not only good physical and mechanical properties but also excellent performances in terms of field-effect mobility and on-off ratio.

This project aims to collaborate with the partner in mainland to develop both new organic semiconductor materials and optical microfabrication technology so as to microengineer organic materials for the development of high-performance flexible OTFT sensors and devices.

During the period of the project, the collaborative research team has successfully developed two kinds of new organic semiconductor materials. Both of them exhibit good microelectronic and optoelectronic property and can be used to fabricate high-performance flexible electronic devices. A new optical maskless lithography technology has also been successfully developed by using high-speed UV-grade spatial light-modulator. It can rapidly micropattern various kinds of organic materials toward 2D and even 3D microstructures.

High-performance OTFT tactile sensors with the advantages of both extremely high sensitivity and very low operation voltage have been fabricated for highly sensitive pressure sensing and mapping, which demonstrated the great promise of OTFTs for E-skin and personalized healthcare applications.

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)*						
2018 (**Paper-1**)	-	-	-	Z. Yin, M.-J. Yin, Z. Liu, Y. Zhang, **A. P. Zhang***, and **Q. Zheng***,	"Solution-processed bilayer dielectrics for flexible low-voltage organic field-effect transistors in pressure sensing applications," ***Advanced Science***, Vol. 5, p.1701041, 2018. (***IF: 12.4***)	No (Submitted the draft for review, but not the finally published version)	Yes	Yes	Yes
2018 (**Paper-2**)	-	-	-	M.-J. Yin, Y. Zhang, Z. Yin, **Q. Zheng**, and **A. P. Zhang***	"Micropatterned elastic gold-nanowire/ polyacrylamide composite hydrogels for wearable pressure sensors," ***Advanced Materials Technologies***, Vol. 3, p. 1800051, 2018. (***IF: 5.969;*** highlighted on the ***Back Cover***; featured by ***Materials Views China***)	No (Submitted the draft for review, but not the finally published version)	Yes	Yes	Yes

2019 (**Paper-3**)	-	-	-	M.-J. Yin, Z. Yin, Y. Zhang, **Q. Zheng*,** and **A. P. Zhang***	"Micropatterned elastic ionic polyacrylamide hydrogel for low-voltage capacitive and organic thin-film transistor pressure sensors," **Nano Energy**, Vol. 58, pp. 96-104, 2019. (***IF: 13.1***)	No	Yes	Yes	Yes
2018 (**Paper-4**)	-	-	-	Y. Zhang, Q. Zhang, X. Ouyang, D. Y. Lei, **A. P. Zhang***, and H.-Y. Tam	"Ultrafast light-controlled growth of silver nanoparticles for direct plasmonic color printing," **ACS Nano**, Vol. 12, pp.9913-9921, 2018. (***IF: 13.7;*** press reported by ***eeNews Europe***)	No	Yes	Yes	Yes
2020 (**Paper-5**)	-	-	-	Y. Zhang, M.-J. Yin, X. Ouyang, **A. P. Zhang***, and H.-Y. Tam	"3D μ-printing of polytetrafluoroethylene microstructures: a route to superhydrophobic surfaces and devices," ***Applied Materials Toda***y, Vol. 19, p.100580, 2020. (***IF: 8.01***)	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)*
Jan/2018/ Belfast, Northern Ireland	Optical 3D μ-printing of polytetrafluoroethylene (PTFE) microstructures	The 31st IEEE International Conference on Micro Electro Mechanical Systems (MEMS 2018)	Yes (2018)	No	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
Feng XIONG	MPhil	11 May 2016	25 April 2019

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

Nil.

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]	5	1	0	0	0