RGC Ref.: N_HKU709/12
NSFC Ref. : 51261160496
(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: Design of high performance organic solar cell structures with newly proposed polymer materials to beyond 10% efficiency

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

	Hong Kong Team	Mainland Team
Name of Principal Investigator *(with title)*	Prof. Wallace C.H. Choy	Dr. Lijun Huo
Post	Associate Professor	Associate Professor
Unit / Department / Institution	Department of Electrical and Electronic Engineering, The University of Hong Kong	Institute of Chemistry, Chinese Academy of Sciences/ BeiHang University
Contact Information	Same as above	Same as above
Co-investigator(s) *(with title and institution)*	Prof. Weng Cho Chew Chair Professor	

3. Project Duration

	Original	Revised	Date of RGC/ Institution Approval *(must be quoted)*
Project Start date	1 Jan 2013		
Project Completion date	31 Dec 2016		
Duration *(in month)*	48 months		
Deadline for Submission of Completion Report	30 Sept 2017		

Part B: The Completion Report

5. Project Objectives

5.1 Objectives as per original application

1. Schemes for realizing high performance thin-film OSCs
In order to achieve thin-film OSCs with PCE over 10% for practical photovoltaics, the team from Institute of Chemistry (IoC) and the University of Hong Kong (HKU) will work closely together from materials to device structures. IoC team will propose and optimize new polymer donors and pay particularly attention to (a) strong and wideband light absorption, (b) low HOMO and thus high *Voc*, and (c) high hole mobility. HKU team will propose (d) novel plasmonic nanomaterials and nanostructures incorporated to

polymer active layers for achieving the broadband absorption enhancement, and will introduce and optimize new (e) carrier transport layers and (f) transparent electrodes for achieving high efficiency OSCs. (Note: Details of the research objectives, plan and methodology of IoC team can be found from the NSFC-RGC proposal submitted by Prof. Huo.)

2. Novel plasmonic nanomaterials and nanostructures for the broadband absorption enhancement
We propose a new light trapping scheme of *double* plasmonic nanomaterials and nanostructures incorporated to the OSC active layer made from the new polymers of IoC for realizing the broadband absorption enhancement. The *double* plasmonic nanomaterials and nanostructures can be metal NPs, metal nanogratings, ordered metal nanopatterns, etc.

3. Low-temperature solution-processed metal-oxide-based CTLs doped with metal NPs
While metal oxides can function as CTLs of organic optoelectronic devices, the annealing temperature required for forming good metal-oxide-based CTLs is typically over 200degC, which may degrade the properties of underneath organic materials. We will develop new solution-based approaches to synthesize metal oxides with good carrier transport properties. For the formation of CTLs using our metal oxides, the annealing temperature with a magnitude < 100degC will be committed while our target is towards room temperature treatment. Importantly, through incorporating metal NPs into our newly synthesized metal oxides, we will further improve CTL electrical properties and the energy alignment with active layer.

4. Transparent electrodes for carrier collection
We will propose flexible, transparent and conductive electrodes composed from graphene and metal nanomaterials (e.g. metal NPs and nanowires). The metal nanomaterials offer very strong scattering and thus enhance transmission properties. By combining with graphene, we will investigate the optical transmission, electrical conduction and workfunction alignment of the composite with the adjacent layer (i.e. CTL or polymer active layer). Through the detailed studies of the transparent electrode of graphene–metal nanomaterial composites together with the novel polymer donors and the new approaches in improving the properties of active layer and CTLs described above, we aim to develop high performance OSCs for practical photovoltaics.

5.2 Revised Objectives

Date of approval from the RGC: N.A.

Reasons for the change: N.A.

6. Research Outcome

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

In order to achieve OSCs with PCE over 10%, the HKU team has studied the materials and layer systems of OSCs through introducing metal nanomaterials and nanostructures to the active layer and carrier transport layer and designing new class of electrodes. In this project, we demonstrate that

1. Through incorporating new plasmonic metal nanomaterials system of Au nanostars, and Ag dual nanoparticle and nanograting into OSCs, we can achieve wideband absorption enhancement [Adv. Opt. Mat., 3, 1220, 2015; Small, 12, 5200, 2016.]. We also demonstrate that a proper design of the metal nanomaterial system in OSCs, the electronic properties of active layer can be improved through balancing the (electron and hole) electrical properties [Sci. Rep., 5, 8525, 2015; IEEE J. Selected Topics Quant. Elect., 10.1109/ JSTQE.2015.2442679; Small, 12, 1547, 2016; Nanoscale, 7, 11291, 2015]. Three works on the plasmon-optical and electrical effects have been features as cover stories [Adv. Opt. Mat., 3, 1220, 2015; Small, 12, 5200, 2016; IEEE J. Selected Topics Quant. Elect., 10.1109/ JSTQE.2015.2442679], and one of our work has been highlighted in research news in MaterialsViewsChina.com published by Wiley [Small, 12, 5200, 2016]. The PCE of our plasmonic OSCs has reached over 10.5% [Small, 12, 5200, 2016] which from our understanding is the best reported plasmonic OSCs in the world.
2. Plasmonic metal nanostructures embedded in carrier transport layers (CTLs) can improve the device performances by hot carrier effects [Adv. Funct. Mat., 23, 4255, 2013], charge accumulation effects [Energy Environ. Sci., 6, 3372, 2013]. Meanwhile, simultaneous plasmon -optical and -electrical effects can be achieved through incorporating nanostars in CTLs and active layer at the same time [Small, 12, 5200, 2016]. To extend the application of metal nanomaterials in CTLs, a series of low-temperature solution processed metal oxides with good electrical properties and transparent have been developed [Adv. Mat., 27, 2930, 2015; Light: Science & Applications, 4, 6236, 2014; J. Mat. Chem. A, 3, 23955, 2015].
3. A new class of macroscopically periodic and microscopically random metal nanostructures have been experimentally demonstrated [Sci. Rep., 5, 7876, 2015.]. We also theoretically study the plasmonic properties of the new structure [Nanoscale, 7, 16798, 2015.]. By integrating Ag nanoparticles and nanowires together, we also demonstrate high efficient Ag nano-network electrode [Adv. Function. Mat. 25, 4211, 2015]. The light trapping of transparent electrode is further improved by 32% through a new system of hybrid metal/nanoparticle/dielectric nanostructure [Nano Energy, 17, 187, 2015.]. One of our work on transparent electrode has been featured as cover story [Adv. Function. Mat. 25, 4211, 2015].

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

For the future development and practical applications of OSCs, it would be good to study:

1. Further improvement of power conversion efficiency toward 15%
2. Stability of devices, and
3. Large scale devices.

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)

Organic solar cells (OSCs) have been widely investigated for the next generation of large area, low cost and flexible photovoltaic devices. However, most of the polymer active layer of OSCs is only about 100 to 300nm thickness. In order to increase the optical absorption of OSCs, new plasmonic metal nanostructures of nanostars and dual metal nanostructures have been incorporated into OSCs to improve light absorption. We also demonstrate that the plasmonic metal nanostructure can be used to improve the extraction of photogenerated carriers from active layer to electrode by the effects of hot carriers and carrier accumulation induced by plasmonic metal nanostructures embedded in carrier transport layers. Meanwhile, we design a new class of transparent flexible electrode and new scheme to improve the light trapping of transparent electrode by as much as 32%. By introducing and optimizing multiple plasmonic metal nanostructures in different layers and regions of OSCs, we have achieved PCE of 10.5% which is the best plasmonic OSCs in the world. Four of our work have been features as cover story and one has been highlighted as research news by Wiley.

<u>Part C: Research Output</u>

8. Peer-reviewed journal publication(s) arising <u>directly</u> 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.)

*** It is important to note that the output listed below is from ***1 Jan 2016 to 31 Dec 2016***. For the publications from 1 Jan 2013 to 31 Dec 2014 were stated in mid-term report. It should be noted that the works are supported by the NSFC-RGC fund from RGC and other external funds.***

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				T. Liu, X. Pan, X. Meng, Y. Liu, D. Wei, W. Ma, L. Huo*, X. Sun, T.H. Lee, M. Huang, H. Choi, J.Y. Kim, W.C.H. Choy, and Y. Sun*	"Alkyl Side-Chain Engineering in Wide-Bandgap Copolymers Leading to Power Conversion Efficiencies over 10%", Adv. Mat. DOI: 10.1002/adma.201604251.	N. A.	Yes	Yes	Yes
2016				X. Ren, J. Cheng, S. Zhang, X. Li, T. Rao, L. Huo, J. Hou, W.C.H. Choy*	"High Efficiency Organic Solar Cells Achieved by the simultaneous Plasmon-Optical and -Electrical Effects from Plasmonic Asymmetric Modes of Gold Nanostars", Small, vol. 12, No. 37, pp 5200-5207	N. A.	Yes	Yes	Yes

2016				W.C.H. Choy*, X. Ren	"Plasmon-Electrical Effects on Organic Solar Cells by Incorporation of Metal Nanostructures", IEEE J. Selected Topics Quant. Elect., 10.1109/JSTQE.2015.2442679.	N. A.	Yes	Yes	Yes
2016				G. Luo, X. Ren, S. Zhang, H. Wu*, W.C.H. Choy*, Z. He*, Y. Cao	"Recent advances in organic photovoltaic: device structure and optical engineering optimization in nanoscale", Small, vol. 12, pp. 1547–1571.	N. A.	Yes	Yes	Yes

2015				J. Cheng, F. Xie, Y. Liu, W.E.I. Sha, X. Li, Y. Yang*, W.C.H. Choy*	"Efficient Hole Transport Layers with Widely Tunable Work Function for Deep HOMO Level Organic Solar Cells, 2015, J. Mat. Chem. A, vol. 3, pp. 23955–23963.	N. A.	Yes	Yes	Yes
2015				H. Lu, X. Ren, W.E.I. Sha, H.P. Ho, W.C.H. Choy*	"Broadband near-field enhancement in macro-periodic and micro-random structure with a hybridized excitation of propagating Bloch-Plasmonic and localized surface-plasmonic modes", Nanoscale, vol. 7, 16798.	N. A.	Yes	Yes	Yes

2015				X. Ren, X. Li, and W.C.H. Choy*	"Optically Enhanced Semi-Transparent Organic Solar Cells through Hybrid Metal/Nanoparticle/Dielectric Nanostructure", Nano Energy, vol. 17, pp. 187–195.	N. A.	Yes	Yes	Yes
2015				J. Liu, X. Li, S. Zhang, X. Ren, J. Cheng, L. Zhu, D. Zhang, L. Huo, J. Hou*, W.C.H. Choy*	"Synergic Effects of Randomly Aligned SWCNT Mesh and Self-Assembled Molecule Layer for High-Performance Low Band-Gap Polymer Solar Cells with Fast Charge Extraction", Adv. Mat. Interface, vol. 2, pp. 1500324.	N. A.	Yes	Yes	Yes

2015				H. Lu, D. Zhang, J. Cheng, J. Liu, J. Mao, W. C. H. Choy*	"Locally Welded Silver Nano-Network Transparent Electrodes with High Operational Stability by a Simple Alcohol-based Chemical Approach", Adv. Function. Mat. vol. 25, pp.4211-4218.	N. A.	Yes	Yes	Yes
2015				X. Li, X. Ren, Y. Zhang,* W.C H. Choy,* B. Wei*	"An all-copper plasmonic sandwich system through directly depositing copper NPs on CVD grown graphene/copper film and its application in SERS", Nanoscale, vol. 7, pp.11291-11299.	N. A.	Yes	Yes	Yes

2015				X. Li, X. Ren, F. Xie, Y. Zhang*, T. Xu, B. Wei*, W.C.H. Choy*	"High Performance Organic Solar Cells with Broadband Absorption Enhancement and Reliable Reproducibility Enabled by Collectively Plasmonic Effects", Adv. Opt. Mat. vol. 3, pp. 1220-1231.	N. A.	Yes	Yes	Yes
2015				F. Jiang, W.C.H. Choy*, X. Li, D. Zhang, J. Cheng	"Post-Treatment-Free Solution Processed Non-Stoichiometric NiOx Nanoparticles for Efficient Hole Transport Layers of Organic Optoelectronic Devices", Adv. Mat., vol. 27, pp.2930–2937.	N. A.	Yes	Yes	Yes

2015				W.E.I. Sha, H.L. Zhu, L. Chen, W.C. Chew, and W.C.H. Choy*	"A General Design Rule to Manipulate Photocarrier Transport Path in Solar Cells and Its Realization by the Plasmonic-Electrical Effect", Scientific Reports, vol. 5, p.8525.	N. A.	Yes	Yes	Yes
2015				H. Lu, X. Ren, W. E. I. Sha, J. Chen, Z. Kang, H. Zhang, H.P. Ho*, W. C. H. Choy*	"Experimental and Theoretical Investigation on Macro-Periodic and Micro-Random Nanostructures with Simultaneously Spatial Translational Symmetry and Long-Range Order Breaking", Scientific Reports, DOI: 10.1038/srep07876.	N. A.	Yes	Yes	Yes

2015				X.C. Li, F.X. Xie, S.Q. Zhang, J.H. Hou, W.C.H. Choy*	"MoOx and V2Ox as Hole and Electron Transport Layers through Functionalized Intercalation in Normal and Inverted Organic Optoelectronic Devices", (Nature Publishing Group) Light: Science & Applications, doi: 10.1038/lsa.2015.46.	N. A.	Yes	Yes	Yes

2014				H. Lu, D. Zhang, X. Ren, J. Liu, W. C. H. Choy*	Selective Growth and Integration of Silver Nanoparticles on Silver Nanowires at Room Conditions for Transparent Nano-Network Electrode, ACS Nano, vol. 8, pp 10980–10987.	N.A	No	Yes	Yes
2014				X.C. Li, F.X. Xie, S.Q. Zhang, J.H. Hou and W.C.H. Choy*	Over 1.1 eV Workfunction Tuning of Cesium Intercalated Metal Oxides for Functioning as Both Electron and Hole Transport Layers in Organic Optoelectronic Devices, Adv. Function. Mat., vol.24, pp. 7348–7356.	N.A.	No	Yes	Yes
2014				W.E.I. Sha, X. Li, W.C.H. Choy*	Breaking the Space Charge Limit in Organic Solar Cells by a Novel Plasmonic-Electrical Concept", Scientific Reports, vol. 4, p. 6236 (10pp).	N.A.	No	Yes	Yes

2014				H.L. Zhu#, W.C.H. Choy#,*, W.E.I. Sha, X. Ren,	Photovoltaic mode ultraviolet organic photodetectors with high on/off ratio and fast response, Adv. Opt. Mat., vol. 2, pp.1082-1089.	N.A.	No	Yes	Yes
2014				F.X. Xie, S.J. Cherng, S. Lu, Y.H. Chang, W.E.I. Sha, S.P. Feng, C.M. Chen*, W.C.H. Choy*	The Functions of Self-assembled Ultrafine TiO2 Nanocrystals for High Efficient Dye-Sensitized SCs", ACS Appl. Mat. & Interfaces, vol. 6, pp. 5367-5373	N.A.	No	Yes	Yes
2014				W. C. H. Choy,* W. K. Chan,* Y. Yuan	"Recent Advances in Transition Metal Complexes and Light Management Engineering in Organic Optoelectronic Devices", Adv. Mat., vol. 26, pp.5368-5399	N.A.	No	Yes	Yes
2014 invited				W.C.H. Choy*	The Emerging Multiple Metal Nanostructures for Enhancing the Light Trapping of Thin Film Organic Photovoltaics, Chem. Comm., DOI: 10.1039/C4CC03767G	N.A.	No	Yes	Yes

2014 invited				W.C.H. Choy*, W.E.I. Sha, X. Li, D. Zhang	"Multi-physical Properties of Plasmonic Organic Solar Cells", Progress In Electromagnetics Research , vol. 146, pp. 25-46	N.A	No	Yes	Yes
2014				X.H. Li, W.C. H. Choy*, X. Ren, D. Zhang, H.F. Lu	Highly Intensified Surface Enhanced Raman Scattering by Using Monolayer Graphene as the Nanospacer of Metal Film- Metal Nanoparticle Coupling System, Adv. Funct. Mat., vol. 24, pp.3114–3122	N.A.	No	Yes	Yes
2013				X. Ren, W.E.I. Sha, W.C.H. Choy*	Tuning optical responses of metallic dipole nanoantenna using graphene, Opt. Express, vol. 21, pp. 31824-31829	N.A.	No	Yes	Yes
2013				F.X. Xie, W.C.H. Choy*, W.E.I. Sha, D. Zhang, S. Zhang, X. Li, C.W. Leung, J. Hou,	Enhanced Charge Extraction in Organic Solar Cells through Electron Accumulation Effects Induced by Metal Nanoparticles, Energy Environ. Sci., vol. 6, pp.3372 – 3379	N.A.	No	Yes	Yes

2013				L. Chen, W.C.H. Choy*, W.E.I. Sha	Broadband absorption enhancement of organic solar cells with interstitial lattice patterned metal nanoparticles, Appl. Phys. Lett., vol. 102, 251112 (4pp)	N.A	No	Yes	Yes
2013				X.C. Li, W.C.H. Choy*, F. Xie, S. Zhang and J. Hou,	Room-Temperature Solution-Processed Molybdenum Oxide as Hole Transport Layer with Ag Nanoparticles for Highly Efficient Inverted Organic Solar Cells, J. Mater. Chem. A, vol. 1, p.6614-6621	N.A.	No	Yes	Yes
2013				X.H. Li, W.C.H. Choy*, X. Ren, J. Xin, P. Lin, D.C.W. Leung,	Polarization-independent efficiency enhancement of organic solar cells by using 3-D plasmonic electrode", Appl. Phys. Lett., vol. 102,153304	N.A.	No	Yes	Yes
2013				P. Lin, W.C.H. Choy*, D. Zhang, F. Xie, J. Xin, C. W. Leung,	Semitransparent OSC with hybrid monolayer graphene/metal grid as top electrodes", Appl. Phys. Lett., vol. 102, p.113, 303	N.A.	No	Yes	Yes

2013				D. Zhang, W.C.H. Choy*, F. Xie, W.E.I. Sha, X. Li, B. Ding, K. Zhang, F. Huang, and Y. Cao	Plasmonic-electrically Functionalized TiO2 for High Performance Organic Solar Cells”, Adv. Funct. Mat., vol. 23, pp.4255–4261	N.A	No	Yes	Yes
2013				D. Zhang, F. Xie, P. Lin, W.C.H. Choy*	Al-TiO2 Composite Modified Single-Layer Graphene as an Efficient Transparent Cathode for Organic Solar Cells", ACS Nano, vol. 7, pp.1740–1747	N.A.	No	Yes	Yes
2013				F. Xie, W.C.H. Choy*, C. Wang, X. Li, S. Zhang, J. Hou	Low-temperature Solution-Processed Hydrogen Molybdenum and Vanadium Bronzes for Efficient Hole Transport Layer in Organic Electronics, Adv. Mat., vol. 25, pp.2051–2055	N.A.	No	Yes	Yes
2013				X.H.Li, W. C. H.Choy*, H.F. Lu, W.E.I. Sha, and H. P. Ho.	Efficiency Enhancement of Organic Solar Cells by Using Shape Dependent Broadband Plasmonic Absorption in Metallic Nanoparticles", Adv. Funct. Mat., vol.23, pp. 2728–2735	N.A.	No	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.)*

*** It is important to note that only those "invited" talk in conference are provided in the table below.***

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)*
13-18 September, 2015, Aachen, Germany, invited	Novel Approaches to Improve Optical Absorption and Carrier Extraction of Organic Photovoltaic Cells	the 26th International Conference on Amorphous and Nanocrystalline Semiconductors (ICANS2015)	N. A.	Yes	Yes	No
9-13 Aug, 2015, San Diego, USA, invited	New concept to break the intrinsic properties of organic semiconductors for optical sensing applications	SPIE Optics and Photonics 2015	N. A.	Yes	Yes	No
1-3 Jul., 2015, Kyoto, Japan, invited	Plasmonic and metal oxide systems for high performance OLEDs and OPVs	22nd International Workshop on Active-Matrix Flat Panel Displays and Devices -TFT Technologies and FPD Materials- (AM-FPD '15)	N. A.	Yes	Yes	No

23-24 May, 2015, Beijing, China, invited	New schemes of room-temperature solution-processed carrier transport layers for high performance Organic/Inorganic Solar Cells	The 2nd conference on New Generation Solar Cells	N. A.	Yes	Yes	No
25-28 Jun, 2015. Hangzhou, China, Invited	New approaches and concept of hybrid material system for high efficiency OSCs and OLEDs	the 13th International Conference of Polymers for Advanced Technologies (PAT2015)	N. A.	Yes	Yes	No
14-19 June, 2015, Hong Kong, Invited	Comprehensive studies of new schemes for enhancing the carrier extraction and light absorption of Organic/Inorganic Solar Cells	the 11th International Conference on Optical Probes of Conjugated Polymers and Organic Nanostructures (OP 2015)	N. A.	Yes	Yes	No
5-8 January 2015, Hong Kong, invited	New Schemes for Enhancing the Optical Management and Carrier Transport Properties of Organic Optoelectronic Devices	International Conference on Molecular Electronic Materials and Devices (MEMD2015)	N. A.	Yes	Yes	No
12-14 Nov., 2014 Washington, DC, invited,	Breaking the Space Charge Limit in Organic Solar Cells by a Novel Plasmonic-Electrical Concept	OSA Incubator on the Fundamental Limits of Optical Energy Conversion	N. A.	Yes	Yes	No

17 Sept, 2014. Taipei, Taiwan. invited	Multiple Metal (Plasmonic) Nanostructures, Novel Carrier Transport Layers & Transparent Flexible Electrodes for High-Performance Organic Photovoltaics A new approach of efficient carrier transport layer for organic optoelectronics	Sustainability-Science Summer Workshop for Organic Solar Cells.	N. A.	Yes	Yes	No
8-10 December 2014, Sydney, Australia, invited	A new approach of efficient carrier transport layer for organic optoelectronics	9th Asian Conference on Dye-sensitized and Organic Solar Cells (DSC-OPV9)	N. A.	Yes	Yes	No
25-28 Aug., 2014 Guangzhou, China, invited tutorial	The Recent Progress of Organic Solar Cells	the 34 th Progress in Electromagnetic Research Symposium (PIERS).	N. A.	Yes	Yes	No
25-28 Aug., 2014 Guangzhou, China, invited	Plasmonic-electrical effects of metal nanoparticles for Highly Efficient Organic Solar Cells	the 34th Progress in Electromagnetic Research Symposium (PIERS)	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
Xuanhua Li	PhD	Sept 2010	Jan 2014
Di Zhang	PhD	Sept 2010	Jun 2014
Fengxian Xie	PhD	Jan 2010	Jun 2013
Luzhou Chen	PhD	Nov 2009	Oct 2013

(All thesis title pages submitted in mid-term report.)

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

Recognition:
- OSA Fellow for his extensive contribution in in optical nanostructures for plasmonic, photovoltaics and light emitting devices. **2016**

- Top 1% of most-cited scientists in Thomson Reuter's Essential Science Indicators (ESI). **2016**

- Top 1% of most-cited scientists in Thomson Reuter's Essential Science Indicators (ESI). **2015**

- Top 1% of most-cited scientists in Thomson Reuter's Essential Science Indicators (ESI). **2014**

- Recognized as Prolific researcher on organic solar cells in the index (WFC in physical sciences) in *Nature Index* 2014 Hong Kong published **by *Nature*.**
2014

Patents:
W.C.H. Choy, F. Xie, C.D. Wang, "Solution-Processed Transition Metal Oxides", Patent Application Pending. PCT/CN2013/082830, 05 Sept, 2012.

W.C.H. Choy, H.F. Lu, "A simple approach for integration of silver nanowires and silver nanoparticles as conductive metal network", Patent Application Pending. 14/455,584. 2014.

W.C.H. Choy, F. Jiang, "A Simple Approach for Preparing Post-Treatment-Free Solution Processed Non-Stoichiometric NiOx Nanoparticles as Conductive Hole Transport Materials", Patent Application Pending. 14/883,131, 2015.

Book Chapter:
W.C.H. Choy, Chapter 7, "Solution-processed Metal Oxides and Hybrid Metal Oxides as Efficient Carrier Transport Layers of Organic Optoelectronic Devices" in Polymer Photovoltaics: Materials, Physics, and Device Engineering, (Royal Society of Chemistry, 2015), ISBN: 978-1-84973-987-0.