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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

New fluorescent sensors with aggregation-induced emission characteristics

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

	Hong Kong Team	Mainland Team
Name of Principal Investigator *(with title)*	Prof. Ben Zhong Tang	Prof. Zhen Li
Post	Chair Professor	Professor
Unit / Department / Institution	Department of Chemistry/The Hong Kong University of Science & Technology	College of Chemistry and Molecular Sciences/Wuhan University
Co-investigator(s) *(with title)*	N/A	N/A

3. Project Duration

	Original	Revised	Date of RGC/ Institution Approval *(must be quoted)*
Project Start date	01-1-2012	N/A	N/A
Project Completion date	31-12-2014	N/A	N/A
Duration *(in month)*	36	N/A	N/A

Part B: The Completion Report

5. Project Objectives

5.1 Objectives as per original application

1. Generation of new AIE fluorogens through innovative synthetic routes;
2. Investigation of their photophysical processes to gain mechanistic understanding;
3. Exploration of their technological, especially environmental and biological, applications.

5.2 Revised Objectives

No revision was made.

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)

In this research, we have observed a novel AIE phenomenon first in siloles and later in other molecules with propeller shapes such as tetraphenylethene. These molecules are weakly/non-luminescent in solution but their emission is greatly enhanced by aggregate formation. With elaborate efforts, we have proposed that the restriction of intramolecular motion (RIM) accounts for the AIE phenomenon. Based on the mechanistic understanding, we have developed a large number of new AIE luminogens with different molecular structures, emission colors covering the whole visible spectrum and high luminescence efficiencies up to unity. These AIE luminogens have been applied as chemical sensors and biological probes with high sensitivity and specificity. Their potential applications are only limited by our imagination.

The AIE concept has changed people's view on light-emitting process in the aggregated state and has drawn great attention of scientist worldwide, as evidenced by the exponentially increasing numbers of publications and citations (e.g., 4724 in 2012, 6592 in 2013 and 11096 in 2014) in this theme over the years. Prof. Tang's research group has earned the reputation as pioneer of AIE research in the scientific community and the RIM mechanism proposed by Prof. Tang have been wildly utilized by other scientists to explain the AIE phenomena of their systems. Thomson Reuters have ranked "aggregation-induced emission characteristics and compounds" as the third topic in the fields of Chemistry and Materials Science in the list of Top 100 in 2013. In recent years, a number of international conferences on the topic of AIE have been held and attracted scientists all over the world to participate, reflecting the increasing global interest in this research area.

Aggregation-caused quenching (ACQ) is a common phenomenon observed in most aromatic hydrocarbons and their derivatives, which is harmful for their applications in the solid state. Through such investigation, we find that it is not necessarily true that a poor emitter in the solution state will not luminesce efficiently in the solid state. We clear the name of aggregation and prove that it can work to our benefit through judicious structural design or molecular engineering. This evidently helps widen our search avenue for efficient light emitters in the solid state. The AIE effect permits the use of concentrated solutions of luminogens and their aggregate suspensions in aqueous media for sensing applications. Sensors based on AIE luminogens are more emissive, sensitive and photobleaching-resistant than those of conventional luminophores with ACQ effect. They enjoy high signal-to-noise ratio and their turn-on nature makes them promising for field trials, on-site screening, household testing, etc.

As you can see in Part C of this report, we have obtained promising results and published more than 20 scientific papers with high citation indexes. Some are written by invitation. We are confident that further research in this field will lead to more fruitful result.

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

In this proposal, we have prepared a variety of molecules and polymers with AIE characteristics and deciphered that their AIE working mechanism as the restriction of intramolecular motion in the aggregated state. Their high-technological applications as

sensitive and specific fluorescent chemosensors and bioprobes have been explored with promising results. Since the first discovery by Förster in 1954, the ACQ effect has still been under study for more than half century. On the contrary, the AIE concept is debuted in 2001 and thus it remains much to be studied in this young research area. Although the project is completed, we are still working on the synthesis of new AIE materials and exploring their high-tech applications. Recently, we observed efficient room temperature phosphorescence in crystals of some organic AIE luminogens, which has long been regarded as an "impossible mission", due to their highly thermal-susceptible triplet excited states. Thus, we will take effort to develop such systems. Their structure–property relationships will be studied by delicate molecular design. Such information is of great academic value, which guides further molecular design on new compounds cater for different needs in various areas. If we are able to get further support from RGC, we will hire experts to explore further the practical applications of our materials.

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)

Optical sensors can offer high sensitivity, low detection limit, great interference tolerance, and specific analyte targeting, as well as fast response, simple operation, field portability, and in-situ workability. However, traditional luminophores used for fabricating optical sensors are highly emissive when molecularly dissolved in organic solvents but become weakly emissive or non-fluorescent in concentrated solutions or when aggregated in poor solvents or fabricated as thin films in the solid state. This aggregation-caused quenching (ACQ) effect has significantly hampered their practical utilization for sensitive detection and assay of chemical and biological analytes. We have observed a novel photophysical phenomenon named aggregation-induced emission (AIE), which is diametrically opposite to the ACQ effect. Instead of quenching, aggregate formation has boosted the light emission of AIE luminogens. The restriction of intramolecular motion (RIM) in the aggregated state is the main cause for such phenomenon. Based on the RIM mechanism, many AIE luminogens with various structures have been designed and synthesized and their applications as sensitive and specific chemosensors and biological probes have been explored with promising results.

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.))

(Revised 07/09)

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)*
Year of publication	Year of Acceptance *(For paper accepted but not yet published)*	Under Review	Under Preparation *(optional)*					
2014				Gao, M.; Sim, C. K.; Leung, C. W. T.; Hu, Q.; Feng, G.; Xu, F.; Tang, B. Z.*; Liu, B.*	"A Fluorescent Light-up Probe with AIE Characteristics for Specific Mitochondrial Imaging to Identify Differentiating Brown Adipose Cells" *Chemical Communications* **2014**, *50*, 8312–8315.	2015	Yes	Yes
2014				Qin, W.; Li, K.; Feng, G.; Li, M.; Yang, Z.; Liu, B.*; Tang, B. Z.*	"Bright and Photostable Organic Fluorescent Dots with Aggregation-Induced Emission Characteristics for Noninvasive Long-term Cell Imaging" *Advanced Functional Materials* **2014**, *24*, 635–643.	2015	Yes	Yes
2014				Chen, Y.; Lam, J. W. Y.; Chen, S.; Tang, B. Z.*	"Synthesis, Properties, and Applications of Poly(ethylene glycol)-Decorated Tetraphenylethenes" *Journal of Materials Chemistry B*, **2014**, *2*, 6192–6198.	2015	Yes	Yes

2014				Yu, C. Y. Y.; Kwok, R. T. K.; Mei, J.; Hong, Y.; Chen, S.; Lam, J. W. Y.; Tang, B. Z.*	"A Tetraphenylethene-Based Caged Compound: Synthesis, Properties and Applications" *Chemical Communications* **2014**, *50*, 8134–8136.	2015	Yes	Yes
2014				Kwok, R. T. K.; Geng, J.; Lam, J. W. Y.; Zhao, E.; Wang, G.; Zhan, R.; Liu, B.*; Tang, B. Z.*	"Water-Soluble Bioprobes with Aggregation-Induced Emission Characteristics for Light-up Sensing of Heparin" *Journal of Materials Chemistry B*, **2014**, *2*, 4134–4141.	2015	Yes	Yes
2014				Song, Z.; Kwok, R. T. K.; Zhao, E.; He, Z.; Hong, Y.; Lam, J. W. Y.; Liu, B.*; Tang, B. Z*	"A Ratiometric Fluorescent Probe Based on ESIPT and AIE Processes for Alkaline Phosphatase Activity Assay and Visualization in Living Cells" *ACS Applied Materials & Interfaces* **2014**, *6*, 17245−17254.	2015	Yes	Yes

2014				Chen, S.; Hong, Y.; Liu, J.; Tseng, N.-W.; Liu, Y.; Zhao, E.; Lam, J. W. Y.; Tang, B. Z.*	"Discrimination of Homocysteine, Cysteine and Glutathione Using an Aggregation-Induced Emission-Active Hemicyanine Dye" *Journal of Materials Chemistry B* **2014**, *2*, 3919–3923.	2015	Yes	Yes
2014				Wang, E.; Zhao, E.; Hong, Y.; Lam, J. W. Y.; Tang, B. Z.*	"A Highly Selective AIE Fluorogen for Lipid Droplet Imaging in Live Cells and Green Algae" *Journal of Materials Chemistry B* **2014**, *2*, 2013–2019.	2015	Yes	Yes
2014				Song, Z.; Hong, Y.; Kwok, R. T. K.; Lam, J. W. Y.; Liu, B.*; Tang, B. Z.*	"A Dual-Mode Fluorescence "Turn-on" Biosensor Based on an Aggregation-Induced Emission Luminogen" *Journal of Materials Chemistry B* **2014**, *2*, 1717–1723.	2015	Yes	Yes
2014				Leung, C. W. T.; Hong, Y.; Hanske, J.; Zhao, E.; Chen, S.; Pletneva, E.; Tang, B. Z.*	"Superior Fluorescent Probe for Detection of Cardiolipin" *Analytical Chemistry* **2014**, *86*, 1263–1268.	2015	Yes	Yes

2014				Zhao, N.; Lam, J. W. Y.; Sung, H. H. Y.; Su, H. M.; Williams, I. D.; Wong, K. S.; Tang, B. Z.*	"Effect of the Counterion on Light Emission: A Displacement Strategy to Change the Emission Behaviour from Aggregation-Caused Quenching to Aggregation-Induced Emission and to Construct Sensitive Fluorescent Sensors for Hg^{2+} Detection" *Chemistry–A European Journal* **2014**, *20*, 133–138.	2015	Yes	Yes
2014				Leung, N. L. C.; Xie, N.; Yuan, W.; Liu, Y.; Wu, Q.; Qian, P.; Miao,Q.; Lam, J. W. Y; Tang, B. Z.*	"Restriction of Intramolecular Motions: the General Mechanism behind Aggregation-Induced Emission" *Chemistry–A European Journal* **2014**, *20*, 15349–15353.	2015	Yes	Yes

2013				Zhao, E.; Hong, Y.; Chen, S.; Leung, C. W. T.; Chan, C. Y. K.; Kwok, R. T. K.; Lam, J. W. Y.; Tang, B. Z.*	"Highly Fluorescent and Photostable Probe for Long-Term Bacterial Viability Assay Based on Aggregation-Induced Emission" *Advanced Healthcare Materials* **2013**, *2*, 88–96.	2013	No	Yes
2013				Leung, C. W. T.; Hong, Y.; Tang, B. Z.*	"Probing Proteins and Differentiating Their Native and Denatured States with Aggregation-Induced Emission Fluorogen" *Journal of Molecular and Engineering Materials*, **2013**, *1*, 1340005.	2013	No	Yes
2013				Hong, Y.; Chen, S.; Leung, C. W. T.; Lam, J. W. Y.; Tang, B. Z.*	"Water-Soluble Tetraphenylethene Derivatives as Fluorescent 'Light-Up' Probes for Nucleic Acid Detection and Their Applications in Cell Imaging" *Chemistry–An Asian Journal* **2013**, *8*, 1806–1812.	2013	No	Yes

2013				Wang, Z.; Chen, S.; Lam, J. W. Y.; Qin, W.; Kwok, R. T. K.; Xie, N.; Hu, Q.; Tang, B. Z.*	"Long-Term Fluorescent Cellular Tracing by the Aggregates of AIE Bioconjugates" *Journal of the American Chemical Society* **2013**, *135*, 8238−8245.	2013	No	Yes
2013				Chen, S.; Hong, Y.; Liu, Y.; Liu, J.; Leung, C. W. T.; Li, M.; Kwok, R. T. K.; Zhao, E.; Lam, J. W. Y.; Yu, Y.; Tang, B. Z*	"Full-Range Intracellular pH Sensing by an AIE-Active Two-Channel Ratiometric Fluorogen" *Journal of the American Chemical Society* **2013**, *135*, 4926–4929.	2013	No	Yes
2013				Leung, C. W. T.; Hong, Y.; Chen, S.; Zhao, E.; Lam, J. W. Y.; Tang, B. Z*	"A Photostable AIE Luminogen for Specific Mitochondrial Imaging and Tracking" *Journal of the American Chemical Society* **2013**, *135*, 62−65.	2013	No	Yes
2013				Li, K.; Qin, W.; Ding, D.; Tomczak, N.; Geng, J.; Liu, R.; Liu, J.; Zhang, X.; Liu, H.; Liu, B*.; Tang, B. Z*	"Photostable Fluorescent Organic Dots with Aggregation-Induced Emission (AIE Dots) for Noninvasive Long-Term Cell Tracing" *Scientific Reports* **2013**, *3*, 1150.	2013	No	Yes

2013				Li, J.; Liu, J.; Lam, J. W. Y.; Tang, B. Z*	"Poly(arylene ynonylene) with Aggregation-Enhanced Emission Characteristic: Fluorescent Sensor for both Hydrazine and Explosive Detection" *RSC Advances* **2013**, *3*, 8193–8196.	2013	No	Yes
2013				Li, M.; Hong, Y.; Wang, Z,; Chen, S.; Gao, M.; Kwok, R. T. K.; Qin, W.; Lam, J. W. Y.; Zheng, Q*.; Tang, B. Z*	"Fabrication of Chitosan Nanoparticles with Aggregation-Induced Emission Characteristics and Their Applications in Long-Term Live Cell Imaging" *Macromolecular Rapid Communications* **2013**, *34*, 767–771.	2013	No	Yes
2013				Mei, J.; Wang, Y.; Tong, J.; Wang, J.; Qin, A.; Sun, J. Z*.; Tang, B. Z*	"Discriminatory Detection of Cysteine and Homocysteine Based on Dialdehyde Functionalized AIE Fluorophores" *Chemistry–A European Journal* **2013**, *19*, 612–619.	2013	No	Yes

2013				Li, M.; Lam, J. W. Y.; Mahtab, F.; Chen, S.; Zhang, W.; Hong, Y.; Xiong, J.; Zheng, Q*.; Tang, B. Z*	"Biotin-decorated Fluorescent Silica Nanoparticles with Aggregation-Induced Emission Characteristics: Fabrication, Cytotoxicity and Biological Applications" *Journal of Materials Chemistry B* **2013**, *1*, 676–684.	2013	No	Yes
2012				Shi, H.; Kwok, R. T. K.; Liu, J.; Xing, B.; Tang, B. Z*.; Liu, B*	"Real-time Monitoring of Cell Apoptosis and Drug Screening Using Fluorescent Light-up Probe with Aggregation-Induced Emission Characteristics" *Journal of the American Chemical Society* **2012**, *134*, 17972−17981	2013	No	Yes
2012				Shi, H.; Liu, J.; Geng, J.; Tang, B. Z*.; Liu, B*	"Specific Detection of Integrin $\alpha_v\beta_3$ by Light-up Bioprobe with Aggregation-Induced Emission Characteristics" *Journal of the American Chemical Society* **2012**, *134*, 9569–9572.	2013	No	Yes

2012				Hong, Y.; Meng, L.; Chen, S.; Leung, C. W. T.; Da, L.; Faisal, M.; Silva, D.-A.; Liu, J.; Lam, J. W. Y.; Huang, X*.; Tang, B. Z*	"Monitoring and Inhibition of Insulin Fibrillation by a Small Organic Fluorogen with Aggregation-Induced Emission Characteristics" *Journal of the American Chemical Society* **2012**, *134*, 1680−1689.	2013	No	Yes
2012				Mei, J.; Tong, J.; Wang, J.; Qin, A.; Sun, J. Z*.; Tang, B. Z*	"Discriminative Fluorescence Detection of Cysteine, Homocysteine and Glutathione via Reaction-Dependent Aggregation of Fluorophore-Analyte Adducts" *Journal of Materials Chemistry* **2012**, *22*, 17063–17070.	2013	No	Yes
2012				Chen, S.; Liu, J.; Liu, Y.; Su, H.; Hong, Y.; Jim, C. K. W.; Kwok, R. T. K.; Zhao, N.; Qin, W.; Lam, J. W. Y.; Wong, K. S.; Tang, B. Z*	"An AIE-Active Hemicyanine Fluorogen with Stimuli-Responsive Red/Blue Emission: Extending the pH Sensing Range by 'Switch + Knob' Effect" *Chemical Science* **2012**, *3*, 1804–1809.	2013	No	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)*

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)*
21 Sept /2012/Shanghai	"Chemosensors Based on AIE Materials"	The 3rd Unilever-RSC International Symposium on Functional Materials Science	2013	No	No (the abstract does not contain an acknowledge section)
17 Sept/2012/ Beijing	"Biological Applications of AIE Materials"	The 3rd Unilever-RSC International Symposium on Functional Materials Science	2013	No	No (the abstract does not contain an acknowledge section)
29 May–1 June/2012/ Hangzhou	"Biosensors Based on AIE Fluorogens"	International Forum of Biomedical Materials: Nanobiomaterials for Tissue Regeneration	2013	No	No (the abstract does not contain an acknowledge section)

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
Engui Zhao	Doctor of Philosophy	Sept 2011	July 2015
Wai Tung Leung	Doctor of Philosophy	Sept 2011	July 2015
Yee Yung Yu	Doctor of Philosophy	Sept 2012	Aug 2016

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

N.A.