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Nailiang Yang

The Preparation of Nano Composites and Their Applications in Solar Energy Conversion

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Doctoral thesis accepted by University of Chinese Academy of Sciences, China

Springer

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Supervisor's Foreword

I first met Nailiang in 2006 when he was still a bachelor's candidate in Sun-Yet-Sen University. At that time, he interviewed in our institute for doctorate degree. I was very glad to see a young student who was so obsessed with science and had such solid knowledge in chemistry; hence, I introduced him to our group. After five years of research, I am very happy to see a rising young scientist coming from our group. This book not only comprises a summary of scientific thesis but also serves a review of his life in those years.

His main works are based on the novel two-dimensional (2D) carbon materials, specifically on graphene and graphdiyne, which are considered as the rising star in materials science. In this topic, he also focused on the applications of their nanocomposites forms with solar cells and photocatalysis as specialties. These works can be considered as the pioneer of graphene-related research, started two years before the announcement of graphene works in the Nobel Prize. The basis of these works was also the first few papers which reported and proved the charge transport between graphene and other semiconductors, and hence received many citations. Beyond them, in this thesis, he pointed out the potential applications and designation for graphene composite referring the structure and function of granum, which may be beneficial for designing new integrated circuit and chips. Importantly, he also honestly listed the defects of recent research in this field to give a thorough guide for further improvement. In the booming age of two-dimensional nanomaterials, I am confident that the ideas from this thesis can also be referred and extended to other materials.

I hope the publication of this thesis will be smooth, to allow more readers grasp new ideas from his discussions. As I know from him, Nailiang is still working on the synthesis and assembly of novel nanomaterials after his graduation. A broad and kind discussion with the author in the future will be very beneficial for both the readers and him.

Beijing, China
July 2016

Prof. Dan Wang

Acknowledgments

After graduation of 3 years, it is time to reread the original acknowledgment, and I can still feel my mixed feelings at that moment. Nine years ago, I walked through the gate of Graduate University of Chinese Academy of Sciences (now named as University of Chinese Academy of Sciences), and started my scientific research. Since then, I have witnessed lots of graduate defences, and every time I asked myself what it would be like for mine. I thought about what I should write and say in the acknowledgment. Now I understand that one can never know where to start how to write until that very moment. In this more than five years' period, I have too many things to say, with all the memories flashing in my mind. With the time prolonged, there are more and more people to whom I need to express my thanks. Because of them, I have this opportunity to write this acknowledgment. Because of them, I could overcome the difficult barriers and because of them, I could enjoy the fantastic research life.

First, with no doubt, I would like to express my great thanks to my supervisor, Prof. Dan Wang. I first met him in the summer of 2006, and he led me to the palace of science. In these years, he gave me lot of opportunities to exercise, so that I can access to the most advanced technology area, which made me grow up rapidly in science. In academy, his open and active mind, accompanied with his hard working deeply impressed me; in life, he is a model as a man in family and concerns about our happiness and health. To us students, he is more than a teacher, a friend.

Since 2008, I had the chance to attend the academician Lei Jiang's group and started a five-year research as a joint doctoral candidate. What I have to say is, the most impressive thing about Prof. Jiang is his strong "aura", which is full of confidence and energy, and I always felt nervous when talking with him. But with time passing by, I started to know he is very humorous and easy-going. He is always glad to help and encourage students to immerse in science. In those years, I admired on his broad knowledge and smart ideas very much. He taught us to stay curious about everything happening around us, and to explore the scientific reason behind it. He taught us the evolution of nature is a good teacher for scientists, and nature can tell you why it should be like this. He taught us to follow the traditional ideas in Chinese

culture, such as the philosophy of “Dao” and “Yin-Yang”. He taught us the synergistic effects in nature and applying them in science. He supplied the best equipment for research and supported our ideas positively. Moreover, he encouraged us to go abroad, to know more about the scientific frontier. Thank you, Sir.

Also, I would like to thank for Prof. Jin Zhai in Beihang University. She guided me thoroughly in the experiment and paper writing. I admire her very much for her solid chemistry knowledge and sensitive sense to the hottest topics in science. Thanks to her that I was supported to attend lots of academic conferences and meet many top scientists in the world, and know the culture of other countries.

I would also like to thank other staffs in our group, namely Dan Mao, Xiaoyong Lai, Jianxi Yao, Chaojian Xing, Nan Xu, Mei Yang, Luoxin Yi, Zhudong Hu, Jiajia Wu, and Quan Jin. You provided a kind environment in my daily life and studies. Also many thanks to the labmates, Jun Li, Zhenmin Li, Ronghai Zhu, Shengdong Wang, Rongguo Xu, Xiaoqing Jiang, Li Li, Jiang Du, Ying Cui, Yuanyuan Liu, Shuo Wang, Zhenghong Dong, Gongling Wang, Hongjie Tang, Jiangyan Wang, Yu Yang, Hao Ren, Simeng Xu, Dong Guo, Wei Xu, and others; because of you, we formed an active group, which brought us lot of happiness beyond the experiments. I also want to express my thanks to Dr. Yuanyuan Liu and Mr. Yibo Zhao for their kind help, which helped the conclusion of Chap. 5, and to Yu Zhang and Qi Yuan, who accompanied me to finish the LBL work through many nights. In addition, I would like to express my thanks for Jingtao Wang and Jiwei Li’s help in the Au-DSSC work, and also to the teachers, Ms. Lijuan Guo, Ms. Jing Wang, and Mr. Jianghua Ma in IPE, who provided good life and experiment experiences for all the graduated students.

Furthermore, dear Academician Daoben Zhu, thanks for guiding me in the synthesis and characterization of graphene. Dear Prof. Zhiyong Tang, Prof. Zhixiang Wei and Prof. Dong Han in Nanocenter, thanks for helping me in the material characterization. Dear Prof. Meixiang Wan, thanks for helping me in conductive polymer. Dear Prof. Qinghua Fan, thanks for helping me in organic synthesis. Dear Prof. Dongsheng Liu in Tsinghua University, thanks for helping me in the gold synthesis. Dear Prof. Tianxin Wei in Beijing Institute of Technology, thanks for helping me in in the preparing the gold film and SPR testing. Dear Prof. Jingxia Wang, Dr. Yu Huang and Dr. Libin Wang, thanks for helping me in PS synthesis and assembly. Dear Mrs. Guilan Wang and Dr. Ye Tian, thanks for helping me in the supporting of experimental and daily life. Dear Prof. Hao Wen, thanks for helping me in the thesis guiding and writing. Dear Dr. Luoxin Yi and Dr. Hao Ren, thanks for helping me in the thesis modification. And dear Ms. Ye Chen, thanks for helping me in the help of thesis translation.

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Here, I would like to appreciate my wife, Dr. Liying Wang. Because of the simple words “I do” 12 years ago, we decided to move forward together. No matter what kind of trouble we faced these years, I can always get the support from her. In the past 12 years’ life of study and work, I felt so blessed to have her always staying with me, encouraging me, comforting my sadness, and sharing my happiness. Because of her, I gained confidence to finish my doctor career; because of her, I overcame the difficulties one by one; because of her, I received so much joy which could never happen without her. It is fortunate to be with her.

Lastly, I need to say that the source of my happiness is also from my beloved parents. They always take care of my business as priority, bless me safe and happy, and support my choices. Although our distance became farther geographically, their concern was getting closer. Since 2003, I spent lesser time with them. I know they want me to be around, but they also hope that I would fight for my own career for a brighter future, so they even encouraged me to go overseas. This is the priceless love I will forever appreciate.

Yunnan Garden, Singapore
May 2016

Contents

Abbreviations

AFM	Atomic Force Microscopy
CBM	Conduction Band Minimum
CNT	Carbon Nanotube
DSSC	Dye-Sensitized Solar Cell
EIS	Electrochemical Impedance Spectroscopy
FT-IR	Fourier Transform Infrared
FTO	Fluorine-doped Tin Oxide
GD	Graphdiyne
GO	Graphene Oxide
GR	Graphene
HOMO	Highest Occupied Molecular Orbital
IPCE	Monochromatic Incident Photon-to-Electron Conversion Efficiency
LUMO	Lowest Unoccupied Molecular Orbital
PANI	Polyaniline
SEM	Scanning Electron Microscope
SPR	Surface Plasmon Resonance
TEM	Transmission Electron Microscopy
UV–Vis	Ultraviolet–Visible
VBM	Valence Band Maximum
XPS	X-ray Photoelectron Spectroscopy
XRD	X-ray Diffraction