## PROCEEDINGS OF SPIE

# Organic Light Emitting Materials and Devices XX

Franky So Chihaya Adachi Jang-Joo Kim Editors

28–30 August 2016 San Diego, California, United States

Sponsored by SPIE

Cosponsored by ALS Technology Co., Ltd. (Japan) BRIGHT Co. Ltd. (Japan) MilliporeSigma (United States)

Published by SPIE

Volume 9941

Proceedings of SPIE 0277-786X, V. 9941

SPIE is an international society advancing an interdisciplinary approach to the science and application of light.

Organic Light Emitting Materials and Devices XX, edited by Franky So, Chihaya Adachi, Jang-Joo Kim, Proc. of SPIE Vol. 9941, 994101 · © 2016 SPIE · CCC code: 0277-786X/16/\$18 · doi: 10.1117/12.2262215

The papers in this volume were part of the technical conference cited on the cover and title page. Papers were selected and subject to review by the editors and conference program committee. Some conference presentations may not be available for publication. Additional papers and presentation recordings may be available online in the SPIE Digital Library at SPIEDigitalLibrary.org.

The papers reflect the work and thoughts of the authors and are published herein as submitted. The publisher is not responsible for the validity of the information or for any outcomes resulting from reliance thereon.

Please use the following format to cite material from these proceedings:

Author(s), "Title of Paper," in *Organic Light Emitting Materials and Devices XX*, edited by Franky So, Chihaya Adachi, Jang-Joo Kim, Proceedings of SPIE Vol. 9941 (SPIE, Bellingham, WA, 2016) six digit Article CID Number.

ISSN: 0277-786X

ISSN: 1996-786X (electronic)

ISBN: 9781510602731

ISBN: 9781510602748 (electronic)

Published by

SPIE

P.O. Box 10, Bellingham, Washington 98227-0010 USA Telephone +1 360 676 3290 (Pacific Time) · Fax +1 360 647 1445 SPIE.ora

Copyright © 2016, Society of Photo-Optical Instrumentation Engineers.

Copying of material in this book for internal or personal use, or for the internal or personal use of specific clients, beyond the fair use provisions granted by the U.S. Copyright Law is authorized by SPIE subject to payment of copying fees. The Transactional Reporting Service base fee for this volume is \$18.00 per article (or portion thereof), which should be paid directly to the Copyright Clearance Center (CCC), 222 Rosewood Drive, Danvers, MA 01923. Payment may also be made electronically through CCC Online at copyright.com. Other copying for republication, resale, advertising or promotion, or any form of systematic or multiple reproduction of any material in this book is prohibited except with permission in writing from the publisher. The CCC fee code is 0277-786X/16/\$18.00.

Printed in the United States of America.

 $\hbox{Publication of record for individual papers is online in the SPIE Digital Library.}$ 



**Paper Numbering:** Proceedings of SPIE follow an e-First publication model. A unique citation identifier (CID) number is assigned to each article at the time of publication. Utilization of CIDs allows articles to be fully citable as soon as they are published online, and connects the same identifier to all online and print versions of the publication. SPIE uses a six-digit CID article numbering system structured as follows:

- The first four digits correspond to the SPIE volume number.
- The last two digits indicate publication order within the volume using a Base 36 numbering system employing both numerals and letters. These two-number sets start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B ... 0Z, followed by 10-1Z, 20-2Z, etc. The CID Number appears on each page of the manuscript.

### **Contents**

vii	Authors
ix	Conference Committee
xi	Introduction
	TADF-BASED OLEDS I
9941 03	Efficient HOMO-LUMO separation by multiple resonance effect toward ultrapure blue thermally activated delayed fluorescence (Invited Paper) [9941-2]
9941 04	A series of pyrimidine based blue to green thermally activated delayed fluorescent emitters realizing a high EQE of 25% (Invited Paper) [9941-3]
	TADF MECHANISMS
9941 07	Role of intermediate state in the excited state dynamics of highly efficient TADF molecules (Invited Paper) [9941-6]
9941 OA	Turbocharged molecular discovery of OLED emitters: from high-throughput quantum simulation to highly efficient TADF devices (Invited Paper) [9941-9]
	OLED MATERIALS AND DEVICES
9941 OH	Magnetic field effect in organic light emitting diodes based on donor-acceptor exciplexes showing thermally activated delayed fluorescence (Invited Paper) [9941-93]
9941 OJ	Recent development of organic light-emitting diode utilizing energy transfer from exciplex to phosphorescent emitter (Invited Paper) [9941-18]
9941 OK	New ultra deep blue emitters based on chrysene chromophores [9941-19]
9941 OL	Green-emitting MADF complex for OLED applications (Invited Paper) [9941-92]
	INTERFACE AND DEGRADATION
9941 ON	A comprehensive and unified picture of energy level alignment at interfaces with organic semiconductors (Invited Paper) [9941-21]
9941 00	On the role of polar molecules and the barrier for charge injection in OLEDs [9941-22]
9941 OP	Effect of halogenated impurities on lifetime of organic light emitting diode [9941-23]

#### **SOLUTION PROCESSED OLEDS**

	SOLUTION PROCESSED OLEDS
9941 16	Multiscale study of the self-organized gradient effect of novel hole injection material PEDOT:PSS:PFI [9941-39]
	SIMULATIONS FOR OLEDS
9941 19	In silico evaluation of highly efficient organic light-emitting materials [9941-41]
9941 1C	Accelerated discovery of OLED materials through atomic-scale simulation [9941-44]
	POSTER SESSION
9941 1K	Improvement of amplified spontaneous emission performance in organic waveguides [9941-49]
9941 1L	The electrodeposition of multilayers on a polymeric substrate in Flexible Organic Light Emitting Diode (OLED) [9941-53]
9941 1M	N-type molecular electrical doping in organic semiconductors: formation and dissociation efficiencies of charge transfer complex [9941-54]
9941 10	Enhanced color purity of blue OLEDs based on well-design structure [9941-56]
9941 IT	Two stacked tandem white organic light-emitting diodes employing WO $_3$ as a charge generation layer [9941-61]
9941 1V	The two-dimensional optical pattern of a five inch diagonal white organic light emitting diode by rapid rotating measurement [9941-63]
9941 1X	Blue phosphorescent OLEDs with 34.1% external quantum efficiency using a low refractive index electron transporting material [9941-65]
9941 21	Characterization of the MoO <sub>3</sub> /Ag grids/MoO <sub>3</sub> sandwich electrode deposited on flexible substrate via thermal deposition method [9941-69]
9941 22	Quantifying charge trapping and molecular doping in organic p-i-n diodes [9941-71]
9941 24	Improved hole-injection and power efficiency of organic light-emitting diodes using an ultrathin cerium fluoride buffer layer [9941-73]
9941 26	Design and fabrication a simple and fast mass production line of light extraction film [9941-75]
9941 27	Deep-blue phosphorescent organic light-emitting diode with external quantum efficiency over 30% using novel Ir complex [9941-77]

- 9941 29 Physical characterizations of direct and inverted solution-processed organic light-emitting diodes [9941-79]
- 9941 2E Study of natural organic dyes as active material for fabrication of organic light emitting diodes [9941-85]

Proc. of SPIE Vol. 9941 994101-6

#### **Authors**

Numbers in the index correspond to the last two digits of the six-digit citation identifier (CID) article numbering system used in Proceedings of SPIE. The first four digits reflect the volume number. Base 36 numbering is employed for the last two digits and indicates the order of articles within the volume. Numbers start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B...0Z, followed by 10-1Z, 20-2Z, etc.

Adachi, Chihaya, 07 Aguilera-Iparraguirre, Jorge, 0A Akaike, Kouki, 0N Al-Shadeedi, Akram, 22 Altazin, S., 00 Aspuru-Guzik, Alán, 0A Baldo, Marc A., 0A Baniya, S., OH Basel, T., OH Bin, Jong-Kwan, 1T Brütting, W., 00 Cao, Yixiang, 19, 1C Castillo, D., 2E Chen, Ming-Hong, 1V Chen, Yueh-Hao, 26 Cheng, Yu-Hen, 1V Chien, Chao-Heng, 26 Chien, Wei-Cheng, 26 Chiu, Chuang-Hung, 26 Choi, H., 0H Chu, Sheng-Yuan, 21, 24 Cunha, Idaulo Jose, 1L Dixon, Steve, 19 Du, Qiangian, 1K, 1O Einzinger, Markus, 0A Espinosa, S., 2E Fan, Quli, 1K, 1O Fasquel, S., 29 Furube, Akihiro, 07 Gavartin, Jacob, 19, 1C Giesen, David J., 19, 1C

Gómez-Bombarelli, Rafael, 0A Guaman, A., 2E Guedes, Andre F. S., 1L Guedes, Vilmar P., 1L Ha, Dong-Gwang, 0A Halls, Mathew D., 19, 1C Hamada, Takao, 0J Hamada, Toshiki, 0P Hatakeyama, Takuji, 03 Hayasaka, Yuya, 04 Heimel, Georg, 0N Hirsch, L., 29 Hirzel, Timothy D., 0A Holloway, Sean, 0L Horikoshi, Nozomi, 0P

Hosokai, Takuya, 07

Hosoumi, Shunsuke, 27

Goldberg, Alexander, 19, 1C

Huang, Min, 16 Hughes, Thomas F., 19, 1C Huh, Jin-Suk, 1X Ikuta, Toshiaki, 03 Inoue, Hideko, OJ, OP, 27 Ishiaaki, Avumi, OP Jäger, L., 00, Jung, Hyocheol, 0K Kang, InByeong, 1T Kana, Seokwoo, OK Kao, Po-Ching, 24 Kaphle, Vikash, 22 Kataishi, Riho, OP Keum, Changmin, 22 Kido, Hiromitsu, 27 Kido, Junji, 04 Kim, Beomjin, OK Kim, Jae-Min, 1M Kim, Jang-Joo, 1M, 1X Kim, Jeong Won, 1M Kim, Jinook, 1T Kirsch, C., 0O Klimes, Kody, OL Knapp, E., 00 Koch, Norbert, 0N Komatsu, Ryutaro, 04 Kubota, Tomohiro, OP Kwak, H. Shaun, 19, 1C Kwon, O., 0H Laurent, J.-Y., 29 Lee, Hayoon, OK

Lee, Jaehyun, OK Lee, Jae-Hyun, 1M Lee, Jeong-Hwan, 1X Lee, Na Yeon, 1T Lee, SeungJae, 1T Li, Jian, OL Li, Shan-Rong, 21 Li, Shuhong, 1K, 1O Lim, Heeseon, 1M Lin, Yu-Hsuan, 1V Liu, Shiyi, 22 Lu, Hsin-Wei, 24 Lüssem, Björn, 22 Maindron, T., 29 Matsuzaki, Hiroyuki, 07 Mitsumori, Satomi, OJ, 27 Moon, Chang-Ki, 1M, 1X Murat, Y.,, 29

Mustard, Thomas J., 1C

Nakajima, Kiichi, 03

Nakamura, Rina, OP

Nakanotani, Hajime, 07

Nakao, Kohei, 04

Nakashima, Harue, OP

Ni, Jingping, 03

Nomura, Shintaro, 03

Nowatari, Hiromi, OJ, OP

Obregón, D., 2E

Oehzelt, Martin, 0N

Ohsawa, Nobuharu, 0J, 27

Pang, Z., 0H

Park, Jongwook, 0K

Ruhstaller, B., 00

Sánchez Juárez, A., 2E

Sasabe, Hisahiro, 04

Sasaki, Toshiki, OP

Schmidt, T. D., 00

Seo, Bomin, 1T

Seo, Satoshi, OJ, OP, 27

Shin, Hwangyu, OK

Shin, Hyun, 1X

Shiren, Kazushi, 03

Shitagaki, Satoko, OJ

Sim, Bomi, 1M, 1X

Sun, D., 0H

Suzuki, Kunihiko, OJ, OP

Suzuki, Tsunenori, OP

Takahashi, Tatsuyoshi, OJ

Tartari, Simone, 1L

Ting, Chu-Chi, 21

Tokumaru, Katsumi, 07

Tsutsui, Tetsuo, 07

Vardeny, Z. V., 0H

Wang, Chen-Tao, 21

Wang, Minghong, 1K, 1O

Wang, Qingru, 1K, 1O

Wang, Wenjun, 1K, 1O

Wantz, G., 29

Watabe, Takeyoshi, OJ, OP, 27

Wu, Tony, 0A

Xia, Shuzhen, 1K, 1O

Yahiro, Masayuki, 07

Yamada, Yui, 0J, 27

Yamawaki, Hayato, OP

Yang, Henglong, 1V

Yang, JoongHwan, 1T Yoo, Seung-Jun, 1M

Yoon, Soo Young, 1T

Yoon, Soo Yo Zhai, Y., 0H

Zhang, Bingyuan, 10

Zhang, Binyuan, 1K

Zhu, Zhi-Qiang, OL

Züfle, S., 0O

viii

#### **Conference Committee**

#### Symposium Chairs

Zakya Kafafi, Lehigh University (United States) Luisa Torsi, Università degli Studi di Bari (Italy)

#### Conference Chair

**Franky So**, North Carolina State University (United States)

#### Conference CoChairs

Chihaya Adachi, Kyushu University (Japan)
Jang-Joo Kim, Seoul National University (Korea, Republic of)

#### Conference Program Committee

Wolfgang Brütting, Universität Augsburg (Germany)

Malte C. Gather, University of St. Andrews (United Kingdom)

Hisao Ishii, Chiba University (Japan)

Hironori Kaji, Kyoto University (Japan)

Jiun-Haw Lee, National Taiwan University (Taiwan)

**Jian Li**, Arizona State University (United States)

Mathew K. Mathai, Apple Inc. (United States)

Jongwook Park, The Catholic University of Korea (Korea, Republic of)

Yong-Jin Pu, Yamagata University (Japan)

**Sebastian Reineke**, TU Dresden (Germany)

Ifor D. W. Samuel, University of St. Andrews (United Kingdom)

Joseph Shinar, Iowa State University (United States)

#### Session Chairs

1 TADF-based OLEDs I

Chihaya Adachi, Kyushu University (Japan)

2 TADF Mechanisms

Andrew P. Monkman, Durham University (United Kingdom)

3 TADF-based OLEDs II

Andrew P. Monkman, Durham University (United Kingdom)

4 OLED Materials and Devices

Ken-Tsung Wong, National Taiwan University (Taiwan)

- 5 Interface and Degradation
  Chung-Chih Wu, National Taiwan University (Taiwan)
- Light Outcoupling in OLEDs
   Jean Charles Ribierre, Kyushu University (Japan)
- 7 OLED Device Engineering Seunghyup Yoo, Korea Advanced Institute of Science and Technology (Korea, Republic of)
- 8 Solution Processed OLEDs Chihaya Adachi, Kyushu University (Japan)
- 9 Simulations for OLEDs Hironori Kaji, Kyoto University (Japan)
- 10 Organic Lasers IChihaya Adachi, Kyushu University (Japan)
- 11 Organic Lasers II

  Jang-Joo Kim, Seoul National University (Korea, Republic of)

#### Introduction

This year, we celebrated the 20th anniversary of the conference on Organic Light Emitting Materials and Devices. Over the past 20 years, this conference has been fortunate to attract a wide-variety of OLED researchers and contribute to the progress of OLED science and technologies. In fact, a deepening of the understanding of the physics of electronic and excitonic processes in OLEDs has greatly contributed to the progress of OLEDs. Even though OLEDs have been commercialized, we expect that further development and investigation of basic issues should be continued from the aspect of novel materials and device physics, and we believe that this SPIE conference will continue to play an important role for the OLED society.

This proceeding contains the cutting edge of OLED materials and devices, simulations, and organic lasing presented at this conference. We would like to thank the authors for their sincere contributions to this volume. The contributions of the organizing committee, session chairs, and SPIE staff are also gratefully appreciated.

Franky So Chihaya Adachi Jang-Joo Kim

Proc. of SPIE Vol. 9941 994101-12