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Physics of Organic Semiconductor Devices: Materials, Fundamentals, Technologies and Applications

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Abstract

Organic electronics and optoelectronics (OE) are fast developing branches of modern science and technology that are aiming to compliment conventional inorganic semiconductors with light, inexpensive, and flexible organic materials. A traditional approach in OE is to build the very same device architecture and optimize different parameters in order to obtain the highest device performance. Practically, this approach proved to be very effective; however, it lacks scientific challenges and thus, obtained fundamental knowledge is marginal. When conceptually a new idea is introduced into device's design, truly novel information can be revealed about mechanisms of device operation resulting in achieving a performance breakthrough. This can be done by using either one or a combination of following strategies: i) new engineering technology for device fabrication, ii) new type of devices, iii) utilization of a new class of materials. In my talk, I am going to show how those strategies facilitate recent progress in the field of OE.

Particularly, I consider an example of enabling technology, which is called *orthogonal*[1] *photolithography*. *Orthogonal lithography* is organic friendly, high resolution patterning technique, which enables the use of existing nano-fab methods for organic electronic devices. *Organic lithography* allowed building of e.g. high-voltage organic solar cells[2], OTFT based circuits[3] and RGB OLED displays[4]. Technology was recently commercialized and adopted by many research groups and companies.

Also, I would like to share my vision on recent progress in the thin film solar cell research area. Here, I'd like to focus my attention on the *new class of materials* - organic-inorganic halide *perovskites*. CH3NH3PbX3 (X = Cl, Br, or I) perovskite based thin film solar cells made a rapid progress in power conversion efficiency from 3.8% in 2009 up to almost 20% in 2014. I will make a quick review on that topic and try to explain why this particular class of materials outperforms organic solar cells and what are the challenges facing practical application.

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1. Al.A. Zakhidov, J.-K. Lee, H.H. Fong, J.A. DeFranco, M. Chatzichristidi, P.G. Taylor, C.K. Ober, G.G. Malliaras "Hydrofluoroethers as orthogonal solvents for the chemical processing of organic electronic materials", *Adv. Mat.* **20**, 3481 (2008)
2. Y.-F. Lim, J.-K. Lee, Al.A. Zakhidov, J.A. DeFranco, H.H. Fong, P.G. Taylor, C.K. Ober, G.G. Malliaras "High voltage polymer solar cell patterned with photolithography" *J. Mater Chem.* **19,** 5394 (2009)
3. Al.A. Zakhidov, H.H. Fong, J.A. DeFranco, J.-K. Lee, P.G. Taylor, C.K. Ober, G.G. Malliaras, M. He, M.G. Kane, "Fabrication of polymer-based electronic circuits using photolithography" *Appl. Phys. Lett*., **99**, 183308 (2011)
4. Al.A. Zakhidov, J.-K. Lee, J.A. DeFranco, H.Hang Fong, P.G. Taylor, M. Chatzichristidi, C.K. Ober, G.G. Malliaras "Orthogonal processing: A new strategy for organic electronics", *Chem. Sci*.,**2**, 1178 (2011)

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Education Profile

- 2004 M.Sc., Dipl.-Phys., Moscow State University, Russia,
- 2006 Ph.D., Physics, Moscow State University, Russia. Thesis: "Field electron emission properties of nano-carbon materials". Supervisor Prof. A.N. Obraztsov

Professional Profile

- Since 08/2014 Assistant Professor at Texas State University, Department of Physics.
- 2012-2014 Group Leader at Fraunhofer Institute for Organic Materials and Electronic Devices Dresden (COMEDD), Dresden, Germany
- 2010-2011 Alexander Von Humboldt Fellowship at Technische Universität, Dresden
- 2007-2010 Postdoctoral Fellow at Cornell University, MSE Department.
- 2006 - Visiting researcher at University of Texas at Dallas

Awards

- 2012 FhG ATTRACT Grant (for 2.5MEur)
- 2010 Alexander Von Humboldt Fellowship
- 2009 Materials Research Society 2009 Spring Meeting, poster award
- 2006 Russian Foundation for Basics Research Grant #06-02-26536
- 2004 Rem Khokholov award for the best student scientific work (MSU)
- 2003 M. Lomonosov award for academic excellence (MSU)

Professional Activities

- Member of American Physical Society (APS) and Materials Research Society (MRS).
- Reviewer for Applied Physics Letters, Journal of Applied Physics Letters, Organic Electronics, Optical Letters.
- Invited speaker and session chair in International workshop on flexible and printed electronics (IWFPE 2013).

Patents

(Co-) inventor of 6 patents

Selected Publications (In total 47 refereed publications. H-factor 14.)

1. S. Krotkus, F. Ventsch, D. Kasemann, Al.A. Zakhidov, S. Hofmann, K. Leo, M.C. Gather, “Photo-patterning of Highly Efficient State-of-the-Art Phosphorescent OLEDs Using Orthogonal Hydrofluoroethers”, Adv. Opt. Mat. DOI: 10.1002/adom.201400181 (2014).
2. M.P. Hein, Al.A. Zakhidov, B. Lüssem, J. Jankowski, M.L. Tietze, M.K. Riede, K. Leo, "Molecular doping for control of gate bias stress in organic thin film transistors", Appl. Phys. Lett. 104, 013507 (2014)
3. B. Lüssem, M.L. Tietze, H. Kleemann, C. Hoßbach, J.W. Bartha, Al.A Zakhidov, K. Leo, “Doped Organic Transistors: Inversion and Depletion Regime”, Nature Communications, 4, 275 (2013).
4. Al.A. Zakhidov, S. Reineke, B. Lüssem, K. Leo “Hydrofluoroethers as heat-transfer fluids for OLEDs: Operational range, stability, and efficiency improvement”, Organic Electronics 13, 356 (2012).
5. R. Brückner, Al.A. Zakhidov, R. Scholz, M. Sudzius, S.I. Hintschich, H. Fröb, V.G. Lyssenko, K. Leo “Phase-locked coherent modes in a patterned metal–organic microcavity”, Nature Photonics, 6 322 (2012).
6. Al.A. Zakhidov, J.-K. Lee, J.A. DeFranco, H.H. Fong, P.G. Taylor, M. Chatzichristidi, C.K. Ober, G.G. Malliaras, “Orthogonal processing: A new strategy for organic electronics”, Chem. Sci., 2, 1178 (2011).
7. Al.A. Zakhidov, B. Jung, J.D. Slinker, H.D. Abruña, G.G. Malliaras, “A light-emitting memristor”, Organic Electronics 11, 150 (2010).
8. Al.A. Zakhidov, J.-K. Lee, H.H. Fong, J.A. DeFranco, M. Chatzichristidi, P.G. Taylor, C.K. Ober, G.G. Malliaras “Hydrofluoroethers as orthogonal solvents for the chemical processing of organic electronic materials”, Adv. Mat. 20, 3481 (2008)

Research Interests

Dr. Zakhidov's research is focused on comprehensive study of organic semiconductors including: fundamentals, processing, mechanisms and applications in optoelectronics. Particular topics of interest, include:

- Organic light emitting diodes (OLEDs) for displays and lighting
- Perokvsite photovoltaic devices (solar cells and photodiodes)
- Organic thin film transistors (OTFTs) and circuits
- Organic micro-cavities and organic lasers
- Nano-carbon (carbon nanotubes and graphene) electrodes
- Molecular doping
- High resolution structuring of organic semiconductors

Dr. Zakhidov pioneered orthogonal micro- and nano-fabrication technique for organic semiconducting structuring and processing. This method essentially enables fundamental nano-science of organic electronic devices as well as their heterogeneous integration with the state of the art traditional electronics.