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506 Keystone Dr.

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UU	UU	UU	UU		19b. TELEPHONE NUMBER: 724-779-2711

RPPR Final Report
as of 13-Mar-2018

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INVESTIGATOR(S):

Name: J. Ardie Dillen
Email: dillen@mrs.org
Phone Number: 7247792711
Principal: Y

Organization: **Materials Research Society**
Address: 506 Keystone Dr., Warrendale, PA 150867573
Country: USA
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Submitted By: Donna Gillespie Email: gillespie@mrs.org
Phone: (724) 779-2732
Distribution Statement: 1-Approved for public release; distribution is unlimited.

STEM Degrees: **STEM Participants:**

Major Goals: The focus of Symposium ED6 was on the science and engineering of quantum confined nanostructures for various key applications including solar cells, photodetectors, functional conductors, light-emitting devices and bio-integrated electronics. The intent was to present recent insights and future ideas for realizing quantum confinement in emerging materials systems such as organic semiconductors and perovskites, as well as in classic inorganic II-VI and III-V systems. Applications were oriented towards optoelectronic devices which benefit from utilizing quantum-confined states. Specifically, the symposium covered nanostructures including 0-D quantum dots; nano-rods, nano-wires and related 1-D nanostructures; as well as 2-D systems with a major focus on solution-based emerging materials.

By addressing both fundamental science and engineering applications, the symposium had a strong conceptual overlap with both the Physical Sciences Directorate and Engineering Sciences Directorate of the ARO.

Accomplishments: Symposium ED6 provided a cutting-edge forum for scientists and engineers developing optoelectronic devices from (colloidal) quantum materials. The focus was spread across several relevant fields encompassing light-emission and lasing, light-trapping and advanced optics, solar cells and electronic (and electrochemical) applications. Attendees included mainly academic researchers to showcase the breadth of their work from fundamental research to industry-relevant and early-stage prototype developments. The symposium featured work from international institutions and industry partners, and MRS will be publishing the proceedings of the meeting in MRS Advances (a peer-reviewed journal).

Training Opportunities: Nothing to Report

Results Dissemination: Nothing to Report

Honors and Awards: Nothing to Report

Protocol Activity Status:

Technology Transfer: Nothing to Report

PARTICIPANTS:

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Authors: Multiple
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URL: http://www.mrs.org/spring2017
Date Received: 12-Feb-2018
Title: 2017 MRS Spring Meeting
Description: The 2017 MRS Spring Meeting was the key forum to present research to an interdisciplinary and international audience. It provided a window on the future of materials science and offered an opportunity for researchers to exchange technical information and network with colleagues.

Report to Army Research Office (ARO)

MRS 2017 Spring Meeting, Phoenix, AZ, April 17-21, 2017

Symposium ED6: *Nanostructured Quantum-Confined States for Advanced Optoelectronics*

Organizers:

Philipp Stadler (Johannes Kepler University Linz, Linz, Austria)

Susanna M. Thon (Johns Hopkins University, Baltimore, MD, USA)

Mikhailo Sytnyk (Friedrich-Alexander University Erlangen-Nuremberg, Erlangen, Germany)

Edward H. Sargent (University of Toronto, Toronto, ON, Canada)

Summary

Quantum materials – in particular solution-based colloidal systems – have seen tremendous developments over the past decades. Symposium ED6 provided a cutting-edge forum for scientists and engineers developing optoelectronic devices from (colloidal) quantum materials. The focus was spread across several relevant fields encompassing light-emission and lasing, light-trapping and advanced optics, solar cells and electronic (and electrochemical) applications. Attendees included mainly academic researchers to showcase the breadth of their work from fundamental research to industry-relevant and early-stage prototype developments. The symposium featured work from international institutions and industry partners, and MRS will be publishing the proceedings of the meeting in *MRS Advances* (a peer-reviewed journal run by MRS).

Objectives

Quantum materials introduced a paradigm shift in the field of semiconductors with the introduction of optoelectronic properties beyond the classical picture – size-tunablity of energy states provided new directions for scientific research leading to groundbreaking insights into the interplay of photon waves and confined states. Paired with processibility from solution, colloidal quantum materials represent one rapidly emerging technology spreading across all relevant fields of optoelectronics: Thin-film transistors, photovoltaic cells, light detection in the infrared and visible, sensors, as well as light trapping and waveguides, light-conversion and, most prominently, light emission and lasing. Earlier restrictions in material quality have been resolved so that, to date, colloidal systems are on the brink of fundamental breakthroughs such as electrically pumped lasing, high photovoltaic power conversion efficiencies and quantitative quasi-unity-yields in optical waveguides. As such, quantum materials are applied in manifold ARO-relevant fields, including information technology and energy. Besides being relevant to these established (and emerging) fields, the technology is also breaking into new scientific frontiers, such as quantum optomechanics, quantum optics, and related areas. The symposium reflected this wide array of systems and materials challenges relevant for optoelectronic device engineering. ED6 generated a platform for in-depth discussion of top-level devices and applications impacting the near

future. Specifically, one highlight of the symposium related breakthroughs in light-emission and lasing: a demonstration of low-threshold continuous wave lasing in a colloidal quantum dot laser. In addition, ED6 addressed advances in sustainable and non-toxic materials, new electrode- and supplementary materials for superior device architectures, and quantum material integration in large-area applications. ED6 also covered fundamental questions in 0-, 1- and 2-dimensional confinement, physical limitations in light-emission and electrical transport, as well as novel fields covering aspects of electrochemistry and bio-integration.

Statistics:

Symposium ED6 spanned 18-21 April, 2017 offering more than 114 peer-reviewed scientific contributions, among them 14 invited presentations (30 minute talks), 60 contributed oral presentations and 40 poster presentations. The symposium was kicked off by Prof. Uri Banin on Tuesday, April 18 with the opening session on “Frontiers 1D and 2D Quantum Materials” and continued with 16 session including 2 poster sessions from Tuesday morning until Friday afternoon, with a 4:30pm closing time.

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Research Highlights

These are the presentation highlights (organizers’ picks):

(1) Chemical strategies – frontiers in material research

(2) Quantum Dot Lasing – electrically and optically pumped

(3) Quantum Materials – Surface and Trapping

(4) Perovskite Quantum Materials

(1) Chemical strategies:

Prof. Dmitry Talapin (University of Chicago, ED6.2.01, “Chemical Strategies for Nanocrystal Devices – Designing the Core and the Surface) opened the 2nd session on material strategies. He introduced innovations from past years and, once more, showed novel aspects in quantum dot chemistry by designing novel surfaces and matrices. He demonstrated innovative steps to ease the processing of quantum materials for simpler device fabrication. His work addressed the main challenge in colloidal quantum dot devices – the design of the core and surface resolving persistent limitations such as trapping. Prof. Talapin furthermore presented an outlook in the chemistry of quantum dots, profound insights into their synthesis and implementation to device matrices and frontiers in new materials. He demonstrated recent applications with hallmark performances in electronics.

(2) Quantum Dot Lasing

Colloidal quantum dot lasers – a dream and quasi “holy-grail” since the development of colloidal quantum dots in the early 1980s – have been theoretically and intensively discussed. Prof. Victor I. Klimov (Los Alamos National Laboratory, ED6.5.01, “Recent Advances in Colloidal Quantum Dot Lasing – Towards Solution-Processible Laser Diodes”) demonstrated experimental evidence of continuous-wave colloidal quantum dot lasing using facet-selective epitaxy. This has been a breakthrough recently reported in a peer-reviewed journal. He covered all aspects of quantum physics and strategies to overcome the lasing threshold – in particular elucidating fundamentals in photon excitation dynamics and recombination paths. His complementary approach showed the tremendous development of colloidal systems enabling superior quality and making inexpensive, efficient photon sources now possible. In addition, he proposed a way towards making electrically pumped lasing possible in the near future and showed electrically-pumped emission very close to the lasing threshold, with the outlook, almost commitment, to demonstrate electrically-pumped continuous-wave quantum lasers in the near future. The talk from Prof. Klimov was the highlight of the symposium.

(3)

Prof. Vanessa Wood (ETH Zurich, ED6.8.01 “Surface Engineering and Electron-Phonon Interactions”) presented on an important priority in quantum material research over the past years. Surface states, passivation and quantum matrices are the crucial elements in designing devices from quantum materials. She provided detailed analysis on the impact of electron-phonon interactions on the quantum states and paths to resolve problems at the interface-surface between quantum materials and matrices and subsequent contact layers. In particular, her discussion on exact phonon interaction represents a milestone in designing novel strategies to implement quantum materials for high-performance devices. Solar cells, light-emitting diodes and detector have been limited by surface dynamics. She demonstrated ways to resolve these limitations and hence impressed with a clear physical model underlined by concrete experimental results.

(4) Perovskites Quantum Materials – the new star materials

In parallel to bulk perovskites, quantum dot perovskites represent a recent trend in quantum science using the attractive optoelectronic properties of complex lead halides for optoelectronic applications, in particular for solar energy conversion. One showcase of implementing perovskite quantum dots in solar cells was given by Dr. Joseph Luther (National Renewable Energy Laboratory, ED6.14.01, “Solar Cells of Perovskite Quantum

Dots – Stable Cubic CsPbI3 Films for High-Efficiency Photovoltaics"). The talk covered the recent efforts in achieving superior photovoltaic energy conversion efficiency – including a record in the field of quantum materials and a paradigm-shift in novel solution-processed quantum dot materials.

ARO Grant - Funding

In regards to the ARO grant, the organizers used this funding to pay for registration fees for two organizers (100%) and invited speakers (60%). These speakers were invited based on several criteria such as the impact of their advancements, their reputations as scientists, and the innovative nature of their work.

Contributions to the Discipline

Symposium ED6 was a large program compared to other symposia (within the top 15), offering a comparatively narrow scope (quantum materials and optoelectronics). ED6 brought together an interdisciplinary group of researchers and engineers working on fundamental materials research closely integrated with device-related quantum engineering. As such, ED6 promoted an effort to bring together scientists working on similar materials and thus similar problems, with different goals in applications. ED6 had the goals of addressing the important and relevant challenges, promoting controversial and inspiring discussions, fostering collaboration, and generating new ideas and a knowledge base for future research. The symposium initiated scientific understanding – a forum beyond the every-day routine by raising critical and thorough questions and answers. In summary, the organizers observed evidence of personal meetings, vivid discussions, shared experiences and critical eye-to-eye peer review at the Symposium that are important ingredients in strengthening scientific strategies and advancements. Symposium ED6 helped to drive the continuous and successful development of the field of quantum materials to generate new solutions for energy and information technology for a prosperous and sustainable future.

Future Directions

Energy sustainability is *the* critical issue facing our society today. In light of continued international attention, including the recent climate treaty reached at the Paris summit in 2016, sustainable energy solutions will remain a top priority in in every meeting and industry. Quantum materials represent an important and impactful column in terms of energy savings (light emission from highly efficient quantum dot diodes) and solar energy conversion (quantum materials for solar cell absorbers; photon concentrators and waveguides for large-area photon harvesting; strategies towards harnessing the sun´s infrared light in infrared solar cells). In parallel, quantum materials are crucial in information technology (quantum photonics for cryptographic applications, quantum materials for electronic devices such as field-effect transistors). The organizers believe that symposium ED6 stimulated and highlighted major breakthroughs in these particular two fields. The net benefits include

further facilitating novel and viable device strategies with clear paths towards technology prototypes and industrial production. Many of these advances perfectly align with crucial national interests, including those of the US Army.

Acknowledgements

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All abstracts are available under
http://www.mrs.org/spring2017/spring-2017-symposia/?code=ED6
Tuesday, April 18 2017 until Friday, April 21 2017