REPORT DOCUMENTATION PAGE

Form Approved OMB NO. 0704-0188

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From - To)
12-04-2016	Final Report	1-Feb-2015 - 31-Jan-2016

4. TITLE AND SUBTITLE
Final Report: Singlet-Fission-Sensitized Hybrid Thin-Films For Next-Generation Photovoltaics.

5a. CONTRACT NUMBER
W911NF-15-1-0040

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
106012

6. AUTHORS
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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES AND ADDRESSES
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS (ES)
U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSOR/MONITOR'S ACRONYM(S)
ARO

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
66355-MS-REP.4

12. DISTRIBUTION AVAILIBILITY STATEMENT
Approved for Public Release; Distribution Unlimited

13. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

14. ABSTRACT
This grant enabled the acquisition of equipment for the fabrication of organic and nanocrystal based photovoltaic (PV) devices by creating rationally designed organic-inorganic hybrid systems that exploit the unique multi-excitonic properties of both types of materials. A suite of equipment associated with electronic spectroscopy and PV device fabrication and characterization was acquired. For spectroscopy, NIR laser diodes and a camera capable of ultrafast photoluminescence in the near infra-red (NIR) was procured. For PV fabrication, a glovebox with thermal evaporators and a spin-coater was constructed. In order to characterize PV devices, a solar simulator

15. SUBJECT TERMS
singlet fission, nanocrystal, triplet, hybrid, photovoltaic

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Ming Tang
UU	UU	UU	UU		19b. TELEPHONE NUMBER 951-827-5964

Report Title

Final Report: Singlet-Fission-Sensitized Hybrid Thin-Films For Next-Generation Photovoltaics.

ABSTRACT

This grant enabled the acquisition of equipment for the fabrication of organic and nanocrystal based photovoltaic (PV) devices by creating rationally designed organic-inorganic hybrid systems that exploit the unique multi-excitonic properties of both types of materials. A suite of equipment associated with electronic spectroscopy and PV device fabrication and characterization was acquired. For spectroscopy, NIR laser diodes and a camera capable of ultrafast photoluminescence in the near infra-red (NIR) was procured. For PV fabrication, a glovebox with thermal evaporators and a spin-coater was constructed. In order to characterize PV devices, a solar-simulator, semiconductor parameter analyzer and associated components to measure current density-voltage curves, external and internal quantum efficiencies were obtained.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received		Paper
02/04/2016	1.00	Zhiyuan Huang, Xin Li, Melika Mahboub, Kerry M. Hanson, Valerie M. Nichols, Hoang Le, Ming L. Tang, Christopher J. Bardeen. Hybrid Molecule–Nanocrystal Photon Upconversion Across the Visible and Near-Infrared, Nano Letters, (08 2015): 0. doi: 10.1021/acs.nanolett.5b02130
02/04/2016	2.00	Zhiyuan Huang, Xin Li, Benjamin D. Yip, Justin M. Rubalcava, Christopher J. Bardeen, Ming L. Tang. Nanocrystal Size and Quantum Yield in the Upconversion of Green to Violet Light with CdSe and Anthracene Derivatives, Chemistry of Materials, (11 2015): 0. doi: 10.1021/acs.chemmater.5b03731
04/11/2016	3.00	Zhiyuan Huang, Duane E. Simpson, Melika Mahboub, Xin Li, Ming L. Tang. Ligand enhanced upconversion of near-infrared photons with nanocrystal light absorbers, Chem. Sci., (2016): 0. doi: 10.1039/C6SC00257A
TOTAL:	**3**	

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received		Paper
TOTAL:		

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Zhiyuan Huang (4th year graduate student) presented a poster and a talk at the 251st ACS National Meeting in San Diego, March 2016:

Talk:
INOR 1286: Hybrid molecule-nanocrystal photon upconversion across the visible and near-infrared
Thu, Mar 17 2016
Publication Number: 1286

Poster:
INOR 283: CdSe/CdS core-shell nanocrystal sensitizers for molecule-nanocrystal photon upconversion
Sun, Mar 13 2016
Publication Number: 283

Number of Presentations: 2.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

TOTAL:

Number of Manuscripts:

Books

Received Book

TOTAL:

Received Book Chapter

TOTAL:

Patents Submitted

Acene-based transmitter molecules for hybrid molecular-nanocrystal photon upconversion

Patents Awarded

Awards

2016 Chinese American Faculty Association of Southern California (CAFA) Faculty Development Grant was awarded to Ming Lee Tang (PI)

Graduate Students

NAME	PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Names of Post Doctorates

NAME	PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Names of Faculty Supported

NAME	PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00
The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:..... 0.00
The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:..... 0.00
Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):..... 0.00
Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:..... 0.00
The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00
The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields: 0.00

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

This grant has enabled the Tang laboratory to establish itself as a diverse nanofabrication and characterization facility incorporating a wet lab for chemical synthesis and manipulation, general spectroscopic and device characterization equipment. Specifically, this grant enabled device fabrication and characterization with the procurement of:

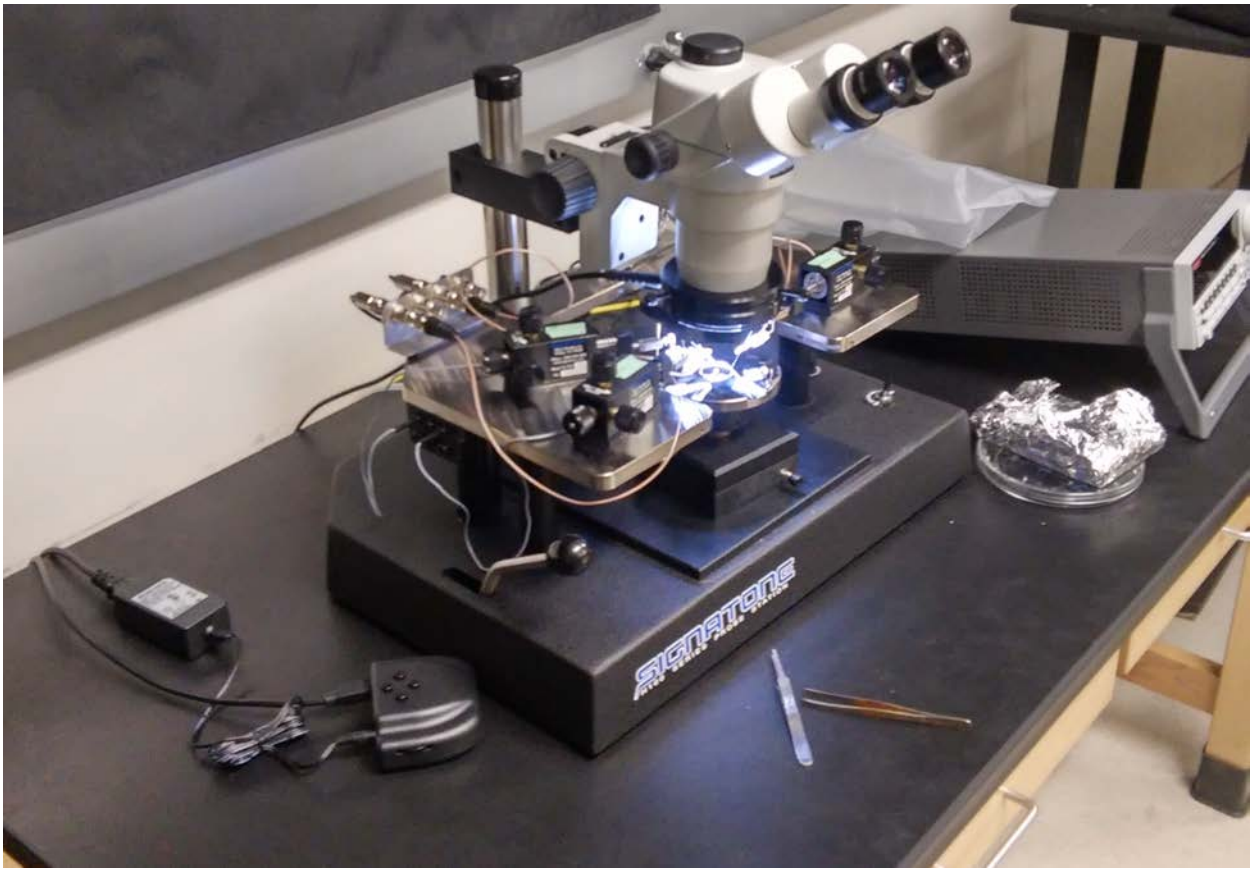
- Lorell spin-coaters in air and in glovebox; Harvard Apparatus syringe pumps
- Two thermal evaporators (Nexdep, Ångstrom Engineering) for metal and organic thin-film deposition integrated into (6 gloves) argon Inert Technology box. Separate evaporators are to prevent contamination of devices from residual organics.
- A separate device testing glovebox for the seamless transfer of devices in inert atmosphere in (2 gloves) argon box, equipped with a Keithley 2636B.
- There is a separate probe station in air (Signatone).
- Power Conversion Efficiency measurements for solar cells (Newport Solar Simulator).
- External Quantum Efficiency measurements from 400-1700nm (with Newport Tunable Light Source and detectors).

The instrumentation has facilitated the discovery last year, in this group, that photon upconversion is efficient using a combination of semiconductor nanocrystals (NCs) and conjugated organic molecules. The major discovery is that NCs can sensitize, or donate energy to molecular triplet states. Since this first demonstration, Baldo et al (Nature Photonics 2015) showed nanocrystal sensitized upconversion in thin film, while Castellano et al (Science 2016) directly confirmed molecular triplet sensitization from nanocrystal donors using transient absorption spectroscopy. Our hybrid molecule-nanocrystal photon upconversion technique makes used of 1) the large absorption coefficients of the nanoparticles and 2) their ability to extend into the near infrared (NIR). Both these characteristics, important for bioimaging, are unavailable simultaneously in existing lanthanide and molecule based photon upconversion

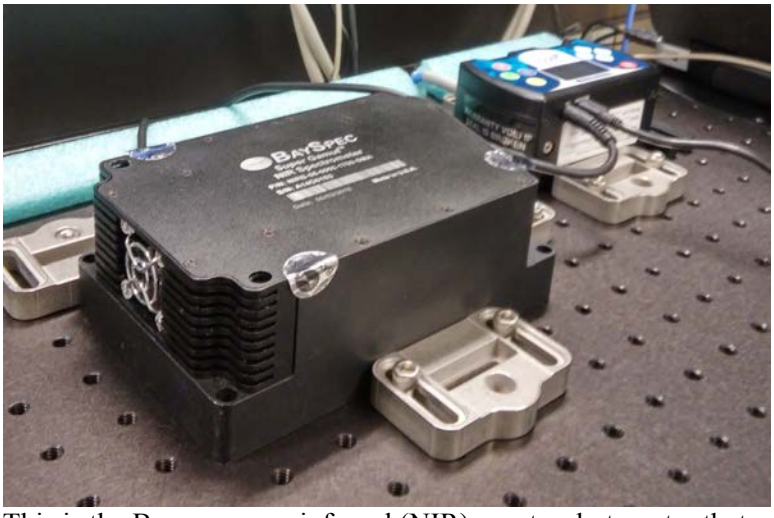
Technology Transfer

Equipment installed:

This is an eight-glove Innovative Technology glovebox that contains two thermal evaporators (Ångstrom Engineering), spin-coater, and a probe station for transistor and solar cell measurements. It is equipped with standard items like oxygen and moisture analyzers and purifiers, small and large antechambers. This glovebox has a spin-coater to coat substrates with nanoparticles or organic molecules, thus necessitating a special large reservoir to remove solvent within the glovebox. The thermal evaporator allows air-free manipulation of device substrates will be used to evaporate metal contacts on the hybrid film deposited on indium tin oxide (ITO). At ultra high-vacuum, the one on the left evaporates organics; the one on the right evaporates metal. Both evaporators are backed with a dry and turbopump. Substrate rotation and temperature control is included to control the crystallinity of thermally deposited organic semiconductors.



Shown here is the Keithley 2636B semiconductor parameter analyzer that can source and measure 2-channels with 0.1fA resolution at 200V. Here, it is paired with the probe station that operates in air, a bare bones Signatone system with a vacuum chuck, microscope, light, triax probes, etc. The same setup is replicated in the glovebox above for air-free measurements, but both systems share the Keithley 2636B



This is the Bayspec near-infrared (NIR) spectrophotometer that collects the nanocrystal emission with a fiber. This grant also supported the purchase of other equipment like a Newport solar simulator, a 488 nm Coherent OBIS laser, a Stanford Research Systems Lock-In Amplifier 830m, a Picoharp 300 and an InGaAs camera for NIR time-resolved experiments, various optical accessories from Newport and Thorlabs, as well as work by Physical Plants to install electrical and water cables.