Wyoming DOE Implementation Grant Final Report

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5. A brief description (abstract) of project goal and objective

In Phase I of this project we will investigate quantum dot sensitized solar cells (QDSSCs) based on ternary metal oxide nanowires and study the physical and chemical mechanisms that govern device operation. Our research has the following five objectives: (1) synthesis of ternary metal oxide nanowires, (2) synthesis of QDs and exploration of non-solution based QD deposition methods, (3) physical and electro-optical characterizations of fabricated solar devices, (4) device modeling and first-principle theoretical study of transport physics, and (5) investigation of long term stability issues of QD sensitized solar cells.

In Phase II of this project our first major research goal is to investigate magnetically doped quantum dots and related spin polarization effect, which could improve light absorption and suppress electron relaxation in the QDs. We will utilize both physical and chemical methods to synthesize these doped QDs. We will also study magnetically modified nanowires and introduce spin-polarized transport into QDSSCs, and inspect its impact on forward electron injection and back electron transfer processes. Our second goal is to study novel solid-state electrolytes for QDSSCs. Specifically, we will inspect a new type of polymer electrolytes based on a modified polysulfide redox couple, and examine the effect of their electrical properties on QDSSC performance. These solid-state electrolytes could also be used as filler materials for *in situ* sample fracturing in STM and enable cross-sectional interface examination of QD/nanowire structures. Our third research goal is to examine the interfacial properties such as energy level alignment at QD/nanowire interfaces using the newly developed Cross-sectional Scanning Tunneling Microscopy and Spectroscopy technique for non-cleavable materials. This technique allows a direct probing of band structures and alignment at device interfaces, which could generate important insight into the mechanisms that govern QDSSC operation. These investigations will be carried out through a close collaboration between our experimental and theoretical efforts in this project.

This project will initiate an important research direction in the jurisdiction of Wyoming. It will bring together researchers from different academic disciplines including physics, chemistry, materials science, and engineering to work on one common scientific theme, and is a vital step towards the establishment of an nationally competitive research program in energy-related nanomaterials in the state of Wyoming.

6. Description of accomplishments (no more than 5 pages)

(1) Synthesis and characterization of ternary metal oxide nanowires

a. We have synthesized different ternary metal oxide nanowires such as Zn_2SnO_4 nanowires and have characterized their physical and electrical properties. We have conducted examination of the synthesis conditions and obtained optimized synthesis parameters. The Zn_2SnO_4 nanowires have been utilized in both dye and QD sensitized solar cells, and improved device performance such as enhanced V_{OC} has been observed. The Zn_2SnO_4 nanowires also exhibited improved corrosion resistance than other metal oxide nanowires such as ZnO nanowires did.

b. We have synthesized magnetically doped nanowires such as Mn-doped ZnO nanowires and studied Mn doping level as a function of source materials ratio. We have conducted magnetization measurement of the Mn-ZnO nanowires and observed room temperature ferromagnetism.

c. We have fabricated single Mn-doped ZnO nanowire field effect transistors and have observed strong magnetoresistance (MR) manipulation and a sign reversal for the first time. At low temperature a positive MR was initially observed, and when the gate voltage was increased, the MR also increased and then reached a maximum value. Further increasing the gate voltage caused the MR to decrease, and eventually an MR sign reversal from positive to negative was observed. The MR change from the highest positive value to the lowest negative value was as high as 32 % at 5 K and 50 KOe. The observed MR behavior was modeled by considering the combined effects of quantum correction to carrier conductivity and bound magnetic polarons.

(2) Synthesis and characterization of semiconductor quantum dots

a. We have successfully developed methods to uniformly and directly deposit ligand-free quantum dots (QDs) on oxide nanowires with pulsed laser deposition (PLD). It has been demonstrated that some of the QDs can be treated with various ligands afterward to reduce the surface defect states known to trap photo-generated electrons. We have also developed a "green" method to prepare QDs in water using PLD.

b. We have studied Mn and Eu doping induced absorption in ZnS for improved QDSSCs. Combined PL excitation spectra and incident photon to electron conversion efficiency show absorption of Mn^{2+} internal energy levels in the visible region. The wavelength dependence of the solar cells performance is improved with the Mn doping due to its long lifetime (spin forbidden transitions). Our study showed that introducing intermediate energy levels in the QDs by Mn doping is an effective method to expand the absorption window into the visible region for this environmentally benign and earth abundant material.

c. We have studied exchange coupling induced band gap reduction in Mn doped CdSe and CdS QDs. Improved solar cell performance based on Mn:CdS QDs has been achieved, attributed to the change in the band gap by the doped Mn due to exchange splitting. The band gap reduction is supported in addition by giant Zeeman splitting (in the order of 100 meV) in the doped QDs and previous study of bulk Mn:CdS. For CdSe, the band gap is reduced from 2.1 eV of the undoped CdSe to 1.9 eV of Mn:CdSe due to exchange splitting of the conduction band. Improved solar cell performance based on Mn:CdSe QDs has been achieved, which is due to the change in the band gap by the doped Mn via exchange splitting. This work reveals the importance of exchange coupling to QD sensitized solar cell technology. Because of the proximity of the dopant energy level and conduction band of the host, which foster exchange coupling, we were also able to study the magnetic nature of the excited states in Mn/CdSe, i.e., exciton magnetic polarons.

d. We have optimized the solution synthesis of CdSe QDs using CdO dissolved in oleic acid, trioctyphosphineoxide, and octadecene and selenium powder in trioctyphosphine and octadecene. We have also prepared mercaptosuccinic acid (MSA, tridentate) and cysteine (Cys, tridentate) capped CdSe QDs. We have used solution ^{1}H NMR spectroscopy to determine (i) efficiency of ligand exchange, and (ii) determine the amount of capping ligands on the surface of CdSe QDs.

e. We have shown for the first time that cysteine capped CdSe QDs synthesized by ligand exchange exhibit circularly polarized luminescence. Two enantiomeric forms of cysteine as capping groups on CdSe QDs emitted circularly polarized light with opposite directions. We have proposed a theoretical model to explain the chiroptical activity in CdSe nanocrystals via the hybridization of highest occupied CdSe molecular orbitals with those of the chiral ligand.

f. We have evaluated the effect of ligand structure and the effect of ligand-to-surface ratio on the band edge emission spectra of CdSe QDs functionalized with N-acetyl-L-cysteine, L-cysteine, and L-homocysteine. The amount of ligand was varied by a series of precipitations and determined by thermogravimetric analysis. We have shown that L/S ratio influenced the most the emission of *N*-Ac-L-Cys-CdSe QDs.

g. We have studied the effect of chemical structure of the thiol capping ligands on the chiroptical properties of CdSe and CdS QDs. We have synthesized CdSe and CdS QDs of different diameters functionalized by six capping ligands, and found the structure of the capping ligand had a pronounced effect on the shape and intensity of the induced circular dichroism (CD) spectra of the QDs. To the best of our knowledge, this is the first example of mirror-image CD spectra of QDs induced by chiral ligands of same central chirality.

(3) Device characterization

a. We have carried out detailed characterizations of the physical properties of the synthesized nanowires and quantum dots using XRD, SEM, TEM, XPS, AFM, etc.

b. We have fabricated solar cells with different components including undoped ternary metal oxide nanowires such as ZTO nanowires, magnetically doped nanowires such as Mn-doped ZnO nanowires, undoped QDs such as CdSe QDs, magnetically doped QDs such as Mn-doped CdSe QDs, solid state electrolyte, etc., and have characterized the performance parameters including incident photon-to-current efficiency (IPCE), open-circuit voltage (V_{OC}), short-circuit current (J_{SC}), Fill Factor (FF), and energy conversion efficiency (η).

c. We have developed Intensity Modulated Photocurrent/Photovoltage Spectroscopy (IMPS/IMVS) instrumentation to characterize carrier transport dynamics in QDSSCs. This technique has been utilized to investigate carrier collection and recombination processes and derive charge transport and recombination time constants, diffusion coefficient and length, electron collection efficiency, and trap state distributions.

d. We have designed and implemented an ultrafast optical characterization system that is capable of conducting photoluminescence (PL), Time Resolved PL (TRPL), and Transient Absorption (TA) measurements on the various QDs, nanoparticle and nanowire samples. The heart of the system is a Coherent Libra regenerative amplifier which produces 100fs pulses of 800nm light at a repetition rate of 1KHz. We have also purchased a high repetition rate 400nm picosecond pulsed laser, from separate funds, which is optimized for the TRPL measurements. This system provides state of the art research capabilities which can be used for future proposals and is also already being used by other researchers at the university.

e. We have conducted and published a very detailed study of the physical and optical properties of ZTO nanowires. In this work we were able to determine the detailed electronic structure of the ZTO nanowires including the position and origin of the defect states, and an analysis of the transitions which contributed to the optical emission characteristics of these nanowires. We were able to show that the fast decaying blue emission was from oxygen related defects and that these blue states were also electronically linked to the red emissive states as the source of carriers into these much slower decaying red states.

(4) Theoretical studies

a. For CdSe quantum dots doped by Mn impurities we have found that at low Mn concentrations absorption spectra do not change compared to pure CdSe QDs. If the concentration increases, there is a significant increase of the absorption from the gap region. This absorption is due to electron transfer from one Mn atom to the other. The magnetic order is found to be antiferromagnetic. The magnetic order of CdSe QD doped by Mn impurities depends on the distance between the Mn atoms. If the atoms are in the close proximity, the system is in the ferromagnetic order. For the system where only one Cd atom is between two Manganese atoms, the system is sill a ferromagnet. Finally, if there are two Cd atoms are between two Mn atoms, the system is an antiferromagnet. Such a dependence on the magnetic order on a distance can be explained in the frame of the RKKY approach.

b. We have studied optical absorption spectra and magnetism of PbS QDs doped by Mn impurities. We show that with the increase of the concentration of Mn atoms the band gap shifts towards higher energies. The exciton peak, which is very distinct for pure PbS QDs smears over for higher concentrations of Manganese atoms. The calculated magnetic order indicates that PbMnS is an antiferromagnet for short, intermediate, and large distances. The band gap shifts toward the higher energies and the exciton peak smears over..

c. We have studied d^0 ferromagnetism in QDs. We consider d^0 ferromagnetism where Zn vacancies in ZnS semiconductor nanocrystals (quantum dots and nanowires). The absence of Zn atoms exhibits the ferromagnetic order at room temperatures. We find a magnetic moment in large quantum dots and nanowires by introducing a new model, the surface-bulk model, where a NC magnetic moment is presented as a sum of the surface and bulk contributions. We find how the magnetic moment depends on the concentration and size of a nanocrystal. In addition, we discovered the large, three orders of magnitude discrepancy between the experimental and calculated magnetic moments. Such a large disagreement between the experiment and theory is explained due to the condensation of impurities inside a nanocrystal.

d. We have studied the large enhancement in the efficiency of CdSe and PbS quantum dot sensitized solar cells by manganese doping. In the presence of Mn impurities with relatively small concentration (~2%) the photoelectric current increases by up to 190% in CdSe and 700% in PbS QDs, respectively. This effect cannot be explained by the light absorption mechanism because the theoretical absorption spectra demonstrate no change in the absorption coefficient in the presence of Mn impurities. To explain such a large increase in the photocurrent we propose the electron tunneling mechanism from the quantum dot LUMO state to the Zn_2SnO_4 semiconductor photoanode. This change is due to the presence of the Mn instead of Cd (Pb) atom at the CdSe(PbS)/ZTO interface. The ab initio calculations confirm the tunneling mechanism. This work proposes a new approach for significant improvement of the efficiency for quantum dot sensitized solar cells.

(5) Interfacial property studies by cross-sectional scanning tunneling microscopy

a. We have successfully achieved the spatial evolution of the dI/dV spectra across the CdSe QDs/Zn_2SnO_4 film interfaces using cross-sectional scanning tunneling microscopy and spectroscopy (XSTM/S). The valence band (bias < 0) of the Zn_2SnO_4 shifts away from the Fermi energy (zero bias) while an extra position-dependent feature was identified in conduction band (bias > 0) around 5 nm off the edge of the thin film, corresponding to the QD size. The dramatic shifting of the extra feature in the unoccupied states (positive bias) is believed to be due to the tip-induced band bending

b. We have successfully integrated lasers with various wavelengths with the STM system toward the capability of LESTM. Using Si(111) surface as the model sample, we have observed significant changes in the tunneling dI/dV spectrum with two different wavelengths (650 nm and 405 nm). Currently we are working on taking more data with different intensity of the light as well as other wavelength to obtain insights on the effects of the LESTM. This capability will allow us to study the band diagram shifting/changing due to the illumination of laser in solar cell materials in the future.

c. We have characterized the Mn doping effects in PbS QDs using STM/S. In PbS QDs, the Mn doping in PbS exhibits a clear bandgap broadening effect. The sp-d hybridization between the host PbS electrons and the localized Mn electrons is responsible for the bandgap broadening. A more detail analysis reveals that there are two different levels of bandgap broadening in Mn-doped PbS QDs samples. The sp-d hybridization is stronger when the Mn dopants are located inside the QDs compared to the case where the Mn dopants are located on the surfaces of the QDs. This result provides first clear evidences on how the locations of the dopants affect the physical properties of the host semiconducting QDs.

(6) Study of solid state electrolytes

a. We have developed a new type of solid-state electrolyte based on PEO-PVDF polymer blends with S/tetramethylammonium sulfate (S/TMAS) redox additive. UV-Vis and ionic conductivity measurements are performed to characterize the electrolytes' optical and electrochemical properties. QDSSCs are fabricated using the polymer electrolytes, and a new redox process is proposed. The study shows that the new polymer electrolyte can significantly improve the stability of QDSSCs, and allow time-consuming measurements such as IMVS/PS measurements to be performed.

b. We have studied the effects of cation type and cation concentration on the conductivity of polymer electrolytes based on PEO-PVDF with S/TMAS as redox additives. Our results show that the bulky cation size of $[(CH_3)_4N]^+$ significantly enhances electron transport processes in the QDSSCs with the polymer electrolyte.

(7) Study of long-term stability issues of QDSSCs

a. We have completed a set of dissolution and corrosion experiments at a range of temperatures and in a range of solution conditions with a purpose of thoroughly test the longevity of ternary oxide materials such as ZTO in the conditions that might be encountered in field deployment. We found that in terms of the rate of dissolution and surface leaching ZTO material is a good choice for non-solid state solar applications.

b. We have completed a set of experiments investigating the attachment and detachment of CdSe quantum dots to oxide surfaces using optical waveguide lightmode spectroscopy (OWLS) which allows us to quantitatively follow the sorption/adhesion of CdSe to the oxide surface in nanogram per square centimeter quantities.

c. We have completed a set of experiments with PLD-generated QD coatings on OWLS waveguides and have conducted a series of experiments quantifying the degradation of these coatings over time under a range of conditions.

(8) Accomplishments made since the submission of the 2016 progress report

a. We have synthesized Indium Tin Oxide nanowires and observed for the first time Kondo effect and coexistence of Kondo effect and ferromagnetism in a metal oxide nanostructure that did not contain any magnetic impurities. We have analyzed the experimental data using the n-channel Kondo theory and have proposed a model to explain the formation of local spin-1 centers in the material.

b. We have fabricated QDSSCs using undoped CdSe and Mn-doped CdSe QDs, and conducted IMPS/VS measurements to inspect the carrier transport dynamics in the devices. Compared to CdSe QDSSCs, Mn-doped CdSe QDSSCs exhibited shorter transport time constant, longer recombination time constant, longer diffusion length, and higher charge collection efficiency. These improved carrier transport and recombination properties contributed to the improved IPCE performance of QDSSCs with Mn-doped CdSe QDs.

c. We have studied tunable bandgap in halogen doped 2D nitrogenated microporous materials. We computationally study the evolution of the energy bandgaps, optical and transport properties with the following substituents: Hydrogen, Fluorine, Chlorine, and Iodine. We find that such a small perturbation by these atoms has a tremendous impact on the electronic properties of these materials. The application of the nitrogenated microporous materials is very broad. They can be useful as sensitizers in solar cells, for water splitting catalysis, in biomedicine, and for gas and energy storage.

d. We have studied the Mn doping effects in CdS QDs using STM/S measurements. The Mn doping induces extra states inside the CdS QD band edges. These induced states reduce the energy band gap, which is supported by the optical measurements. On the other hand, the band edges of the QDs (conduction band minimum and valence band maximum) shift significantly. The significant shift of the band edges are explained by the strong sp-d exchange interactions between the electrons in the semiconducting QDs and the electrons of the Mn dopants. This finding may lead to further study on the intriguing strong sp-d exchange interactions found in the CdS QDs.

e. We have synthesized Mn doped ZTO nanoparticles and characterized their physical, optical, and magnetic properties. We have sensitized the nanoparticles with CdSe QDs and performed charge transfer measurements on the combined system. The charge transfer was characterized by optically pumping the QDs when attached to the ZTO nanoparticles and measuring the time delayed white light probe transient absorption spectra. This data was compared to similar data collected when the QDs were deposited on a control substrate to isolate the effect of the charge transfer from the QDs to the Mn doped ZTO nanoparticles.

f. We have investigated the optical, electronic, and magnetic properties of Mn:PbS QDs. It was found that the presence of Mn in PbS results in an increase of the bandgap. The absorbance of Mn:PbS is reduced compared to PbS, which is verified by the first principles calculations. Although MnPbS absorbs less light than PbS, it can convert more photons into electrons. In addition, sulfur vacancies are believed to be the cause of ferromagnetism in both PbS and Mn:PbS. However, even though vacancies are responsible, Mn’s role in the magnetic properties is of interest. It was found that the nearest neighbor environment around Mn becomes more disordered for the films prepared in high sulfur environment, but it does not contribute to the magnetic properties of the material.

7. List of publications and conference presentations

Publications:

1. "The Effects of Synthesis Temperature and Mn doping on the Optical and Photovoltaic Properties of CdS Quantum Dots," S. Horoz, B. Yakami, U. Poudyal, A. Yost, J. M. Pikal, W. Wang, T.-Y. Chien and J. Tang, in preparation. This work was supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering under Award DE-FG02-10ER46728.
2. "Novel Mn doped Zinc Tin Oxide Nanoparticles: Synthesis, characterization and charge transfer study," Baichhabi R. Yakami, Shashank R. Nandyala, Caleb Rolsma, Gaurab Rimal, Theodore J. Kraus, Kevin Tvrdy, and Jon M. Pikal, in preparation. This work was supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering under Award DE-FG02-10ER46728.
3. "Effect of Mn dopant location on the electronic bandgap of PbS quantum dots," Andrew J. Yost, Artem Pimachev, Gaurab Rimal, Jinke Tang, Yuri Dahnovsky, and TeYu Chien, submitted, 2017. JT, YD, and TYC acknowledge the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering for financial support (DEFG02-10ER46728) of this research. AJY acknowledges graduate fellowship support from the National Science Foundation and the University of Wyoming EE-Nanotechnology Program (NSF- DGE-0948027) and from Wyoming NASA Space Grant Consortium, NASA Grant #NNX15AI08H.
4. "Observations of Kondo Effect and Coexistence of Ferromagnetism in an Undoped Metal Oxide Nanostructure," Keshab R. Sapkota, F. Scott Maloney, and Wenyong Wang, Physical Review Letters, under revision following reviewer comments, 2017. This work was supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering under Award DE-FG02-10ER46728.
5. "Tunable bandgap in halogen doped 2D nitroginated materials," Artem Pimachev, Vitaly Proshchenko, and Yuri Dahnovsky, Journal of Applied Physics, in press, 2017. This work was supported by a grant (No. DEFG02-10ER46728) from the Department of Energy to the University of Wyoming.
6. "Nanostructured Oxides: Cross-Sectional Scanning Probe Microscopy for Complex Oxide Interfaces," TeYu Chien, book chapter in Advances in Nanomaterials, edited by Prof. Ganesh Balasubramanian, in press. TYC acknowledges the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering for financial support (DEFG02-10ER46728).
7. "Carrier Dynamics in Mn doped CdSe Quantum Dot Sensitized Solar Cells," U. Poudyal, F. S. Maloney, K. Sapkota, and W. Wang, Nanotechnology, 28, 415401, 2017. This work was supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering under Award DE-FG02-10ER46728.
8. "Dramatic drop of d^0 ferromagnetism with ZnO nanocrystal size in vacuum and air," Artem Pimachev, Vitaly Proshchenko, and Yuri Dahnovsky, The Journal of Physical Chemistry C, 121, 19401-19406, 2017. This work was supported by a grant (No. DEFG02-10ER46728) from the Department of Energy to the University of Wyoming.

9. “Low temperature growth of CuO nanowires through direct oxidation,” J. Hilman, A. Yost, J. Tang, B. Leonard, and TeYu Chien, Nano-Structures & Nano-Objects 11, 124 (2017). J.H. and A.J.Y. acknowledge the financial support from Wyoming NASA Space Grant Consortium, NASA Grant #NNX10AO95H. J.H. also acknowledges the financial support from Center for Photoconversion and Catalysis, School of Energy Resources, University of Wyoming. A.J.Y. also acknowledges graduate fellowship sup- port from the National Science Foundation and the University of Wyoming EE-Nanotechnology Program (NSF-DGE-0948027). T.Y.C. and J.T. acknowledge the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering for financial support (DEFG02-10ER46728) of this research.
10. “A Facile Synthesis of Highly Stable Modified Carbon Nanotubes as Efficient Oxygen Reduction Reaction Catalysts,” J. Stacy, A. Yost, Y. N. Regmi, B. Leonard, TeYu Chien, and M. Fan, ChemistrySelect 2, 1932 (2017). This research was funded by the National Science Foundation grant for the Dissemination of Nanotechnologies for Energy Production and Environment Protection in Rural Areas of Wyoming (NSF-DGE-0948027). Dr. TeYu Chien acknowledges the U.S Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering for financial support (DEFG02-10ER46728) of this research. Andrew John Yost acknowledges graduate fellowship support from the National Science Foundation and the University of Wyoming EE-Nano- technology Program (NSF-DGE-0948027). The authors would like to thank Dr. Liang Huang for help with molecular modeling.
11. “Zn vacancy ferromagnetism in ZnS nanocrystals,” Vitaly Proshchenko and Yuri Dahnovsky, Journal of Magnetism and Magnetic Materials, 443, 9-12, (2017). This work was supported by a grant (No. DEFG02-10ER46728) from the Department of Energy to the University of Wyoming
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13. “The effect of spatial distribution of Zn vacancies in ZnS quantumdots on optical absorption spectra,” Artem Pimachev, Vitaly Proshchenko, Sabit Horoz, Omer Sahinb, and Yuri Dahnovsky, Solid State Communications, 257, 47-49 (2017). This work was supported by a grant (No. DEFG02-10ER46728) from the Department of Energy to the University of Wyoming.
14. “Magnetic hard gap due to bound magnetic polarons in the localized regime”, G. Rimal and J. Tang, Sci. Rep., 7 (2017) 42224, 7 pages. This work was supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering under Award DE-FG02-10ER46728.
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19. “Steady State and Time Resolved Optical Characterization Studies of Zn_2SnO_4 Nanowires for Solar Cell Applications,” B. R. Yakami, U. Poudyal, S. R. Nandyala, G. Rimal, J. K. Cooper, X. Zhang, J. Wang, W. Wang, and J. M. Pikal, Journal of Applied Physics, 120, 163101, 2016. This work was supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering under Award DE-FG02-10ER46728.
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22. “Giant photocurrent enhancement by Mn doping in PbS quantum dot solar cells,” G. Rimal, V. Proshchenko, A. Yost, U. Poudyal, S. Maloney, W. Wang, T.-Y. Chien, Yu. Dahnovsky and J. Tang, Applied Physics Letters 109, 103901 (2016). This work was supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering (DEFG02-10ER46728). G.R. and A.K.P. acknowledge the support from the School of Energy Resources of the

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Conference presentations and invited talks:

1. Yuri Dahnovsky, “Ferromagnetism in Semiconductor Nanocrystals,” Telluride Workshop: Nanomaterials: Computation, Theory, and Experiment, July 11-15, Telluride, CO 2017.
2. TeYu Chien, “Electronic Properties of Solar Cell Materials Studied by Scanning Tunneling Microscopy”, American Chemical Society Great Lakes Regional Meeting, June 27-30, Fargo North Dakota, 2017.
3. Andrew J Yost, Artem Pimachev, Chun-Chih Ho, Seth B. Darling, Leeyih Wang, Wei-Fang Su, Yuri Dahnovsky, and TeYu Chien, “Coexistence of Two Electronic Nano-Phases on a CH3NH3PbI3−xClx Surface Observed in STM Measurements”, American Physical Society March Meeting, March 13–17, New Orleans, Louisiana, 2017.
4. U. Poudyal and W. Wang, “Comparative study of polymer and liquid electrolytes in quantum dot sensitized solar cells,” APS March meeting, March 13-17, New Orleans, Louisiana, 2017.
5. Aaron Wang, Gaurab Rimal, Jinke Tang, and TeYu Chien, “Imaging oxygen vacancies in EuO1−x using Scanning Tunneling Microscopy and Spectroscopy”, American Physical Society March Meeting, March 13-17, New Orleans, Louisiana, 2017.
6. Artem Pimachev, Andrew Yost, Gaurab Rimal, Jinke Tang, Yuri Dahnovsky, and TeYu Chien, “Investigation of Mn Dopant Induced Electronic Band Structure Widening in PbS Quantum Dot Thin Films”, American Physical Society March Meeting, March 13-17, New Orleans, Louisiana, 2017.
7. Yuri Dahnovsky, “Transition metal doped semiconductor quantum dots: Optical and magnetic properties,” APS March meeting, March 13-17, New Orleans, LA 2017.
8. W. Wang, “Nanostructures for solar cell applications,” 2nd Global Nanotechnology Congress and Expo, December 1-3, Las Vegas, NV, 2016.
9. Gaurab Rimal, “Low Temperature Magnetic Hard Gap in Manganese Doped Lead Sulfide Films,” 61st MMM Annual Conference, New Orleans, LA, November 2016.
10. Jinke Tang, “Magnetically doped quantum dots,” 2nd Front Range Advanced Magnetics Symposium, Laramie, WY, August 2016.
11. Baichhabi Yakami, Uma Paudyal, Shashank Nandyala, Gaurab Rimal, Jason Cooper, Jiajun Chen, TeYu Chien, Wenyong Wang, Jon M Pikal, “Optical Properties of the Defect State Luminescence of Zn_2SnO_4 Nanowires,” APS march meeting, Baltimore, Maryland, 2016.
12. K. Sapkota, G. Rimal, J. Tang, and W. Wang, “Transport studies of quantum dots sensitized single Mn-ZnO nanowire field effect transistors”, APS March Meeting March 14-18, Baltimore, Maryland, 2016.

13. Andrew J. Yost, Gaurab Rimal, Jinke Tang, and TeYu Chien, “Mn Doping Effects on the Electronic Band Structure of PbS Quantum Dot Thin Films: A Scanning Tunneling Microscopy Analysis”, American Physical Society March Meeting, March 14-18, Baltimore, Maryland, 2016.
14. Aaron Wang, Andrew Yost, Vivek Jain, Qilin Dai, Jinke Tang, and TeYu Chien, “Controlling the electronic properties of Er2O3 thin film by oxygen vacancies”, American Physical Society March Meeting, March 14-18, Baltimore, Maryland, 2016.
15. Joann Hilman, Ravi Neupane, Andrew J. Yost, and TeYu Chien, “Controlled Growth of Copper Oxide Nano-Wires through Direct Oxidation”, American Physical Society March Meeting, March 14–18, Baltimore, Maryland, 2016.
16. TeYu Chien, Jian Liu, Andrew J. Yost, Jacques Chakhalian, John W. Freeland, and Nathan P. Guisinger, “Built-in Electric Field Induced Mechanical Property Change in Nb-doped SrTiO3”, American Physical Society March Meeting, March 14–18, Baltimore, Maryland, 2016.
17. TeYu Chien, “Many Body Interactions at Complex Oxide Interfaces Studied by Cross-Sectional Scanning Tunneling Microscopy and Spectroscopy (XSTM/S)”, Colloquium, Department of Materials Science and Engineering, National Taiwan University, September 1, Taipei, Taiwan, 2016.
18. TeYu Chien, “Magnetic Materials Studied with Scanning Tunneling Microscopy and Spectroscopy (STM/S)”, Colloquium, Department of Chemical and Petroleum Engineering, University of Wyoming, September 15, Laramie, Wyoming, 2015.
19. TeYu Chien, “Magnetic Materials Studied with Scanning Tunneling Microscopy and Spectroscopy (STM/S)”, Front Range Advanced Magnetics Symposium, September 22, Fort Collins, CO, 2015.
20. Yuri Dahnovsky, “Slow luminescence in CdSe quantum dots doped by a manganese impurity.” American Chemical Society Meeting, oral presentation, Denver, CO, 2015.
21. Yuri Dahnovsky, “Transition metal doped semiconductor quantum dots: Optical and magnetic properties,” Telluride Conference on Nanocrystal Materials, Telluride, CO, 2015.
22. Yuri Dahnovsky, “Transition metal doped semiconductor quantum dots: Optical and magnetic properties,” Front Range Advanced Magnetics Symposium CSU, Fort Collins, CO, 2015.
23. V. Proshcchenko and Y. Dahnovsky, “Multiconfigurational approach for studying magnetic properties of quantum dots doped with Mn impurities.,” Poster, Front Range Advanced Magnetics Symposium CSU, Fort Collins, CO, 2015.
24. A. Pimachev and Y. Dahnovsky, “Optical and magnetic properties of Mn doped PbS nanoparticles,” Poster, Front Range Advanced Magnetics Symposium CSU, Fort Collins, CO, 2015.
25. Jinke Tang, “Pulsed laser deposition of Mn-doped CdSe and ZnS quantum dots for solar cell applications,” Harbin Institute of Technology, Harbin, China, October 2015.
26. Jinke Tang, “Antiferromagnetic coupling and a magnetic polaron model for the enhanced Curie temperature in electron-doped EuO,” Front Range Advanced Magnetics Symposium, Fort Collins, CO, 2015.

27. Vivek Jain “Growth of EuO films on Si using pulsed laser deposition,” Front Range Advanced Magnetics Symposium, Fort Collins, CO, 2015.
28. Milan Balaz, 249th ACS National Meeting & Exposition, Denver, CO, USA. Division of Inorganic Chemistry: Chemistry of Materials (March 22-26, 2015)
29. Milan Balaz, March 2015 American Physical Society Meeting, San Antonio, TX, USA. Section: Nanostructures and Metamaterials (March 2-6, 2015)
30. Milan Balaz, University of North Texas, Department of Chemistry, Denton, TX, USA (November 7, 2014) Invited talk
31. Milan Balaz, Washington State University, Department of Chemistry, Pullman, WA, USA (October 6, 2014) Invited talk
32. Milan Balaz, Chirality 2014 (26th International Symposium on Chiral Discrimination), Prague, Czech Republic (July 27-30, 2014)
33. Jinke Tang, “Antiferromagnetic coupling and a magnetic polaron model for the enhanced Curie temperature in electron-doped EuO,” Max Planck Institute Chemical Physics for Solids, Germany, May 2014; Harbin Institute of Technology, China, December 2014.
34. J. Yost and T.Y. Chien, “Scanning Tunneling Microscopy Analysis of a Pentacene/Graphene/SiC(0001) system,” American Physical Society March Meeting, March 3-7, Denver, CO, March 2014.
35. Q. Dai, E.M. Sabio, W. Wang and J. Tang, “Pulsed laser deposition of Mn-doped CdSe quantum dots for solar cell applications,” University of Electronic Science and Technology, Chengdu, China, March 2014.
36. P. Liu and J. Tang, “Antiferromagnetic coupling and a magnetic polaron model for the enhanced Curie temperature in electron-doped EuO,” Max Planck Institute Chemical Physics for Solids, May 2014; University of Cambridge, UK, April 2014; University of Electronic Science and Technology, Chengdu, China, March 2014.
37. U. Tohgha and M. Balaz, “Inducing chiroptical properties in CdSe quantum dots using chiral organic capping ligands,” 247th ACS National Meeting, Division of colloid and surface chemistry, Session: Basic research in colloids, surfactants and nanomaterials. Paper #505, Dallas, TX, March 16-20, 2014.
38. TeYu Chien, “Many Body Interactions at Complex Oxide Interfaces Probed by Cross-Sectional Scanning Tunneling Microscopy and Spectroscopy (XSTM/S)”, Physical Chemistry Seminar, Department of Chemistry, University of Wyoming, September 25, Laramie, Wyoming, 2014.
39. TeYu Chien, “Many Body Interactions at Complex Oxide Interfaces Probed by Cross-Sectional Scanning Tunneling Microscopy and Spectroscopy (XSTM/S)”, Seminar, Materials Science and Engineering Program, University of Wyoming, March 20, Laramie, Wyoming, 2014.
40. Meg Mahat, Baichhabi R. Yakami, Qilin Dai, Jinke Tang, and Jon M. Pikal, “Ultrafast carrier dynamics of quantum dots prepared by pulse laser deposition of CdSe for photovoltaic applications,” Bulletin of the American Physical Society APS March Meeting Volume 58, Number 1, Baltimore, Maryland, 2013.
41. Baichhabi Yakami, Meg Mahat, Liyou Lu, Qilin Dai, Jiajun Chen, Jinke Tang, Wenyong Wang and J. M. Pikal, “Time Resolved Photoluminescence Study of ZnO and Zn_2SnO_4 Nanowires for Solar Cells Applications,” Bulletin of the American

Physical Society APS March Meeting Volume 58, Number 1, Baltimore, Maryland, 2013.

42. P. Liu and J. Tang, "Antiferromagnetic Couplings in EuO_{1-x}", 12th Joint MMM-Intermag Conference, Chicago, IL, January 2013.
43. U. Tohgha, K. Varga, M. Balaz, "Preparation of chiral optically active quantum dots", 245th ACS National Meeting, New Orleans, LA, April 7-11, 2013.
44. Ashlin Porter, Urice Tohgha, Sam Toan, and Milan Balaz, "Non-covalent porphyrin-quantum dot systems: Light harvesting and energy transfer", 245th American Chemical Society National Meeting, New Orleans, LA, April 7-11, 2013.
45. U. Tohgha and M. Balaz, "Fluorescence resonance energy transfer in porphyrin-Cadmium selenide quantum dots systems", 23rd Rocky Mountain Regional Meeting of the American Chemical Society, Westminster, CO, October 17-20, 2012.
46. Q. Dai, J. Chen, L. Lu, J. Tang, and W. Wang, "Pulsed laser deposition of CdSe quantum dots on Zn_2SnO_4 nanowires", Materials Research Society Spring Meeting, April 9-13, 2012, San Francisco, CA.
47. C. M. Eggleston, "Semiconducting Minerals and Photochemistry", Rutgers, Newark, Jan. 2012.
48. C. M. Eggleston, "Natural Solar Cells", Goldschmidt conference, Montréal, Canada, June 24-29, 2012.
49. Yu. Dahnovsky, "Correlated electron dynamics in quantum dot sensitized solar cells", Los Alamos National Lab, February 2012.
50. Yu. Dahnovsky, "Correlated electron dynamics in quantum dot sensitized solar cells", North Dakota State University, April, 2012
51. J. Chen, L. Lu, and W. Wang, "Growth of Ultralong Zn_2SnO_4 Nanowires for Photovoltaic Applications", Materials Research Society Fall Meeting, Nov. 27-Dec. 2, 2011, Boston, MA.

8. Total list of people who worked on the project

Postdoctoral researchers

1. Dr. Jiajun Chen. Support level: 100%. Dr. Chen has worked on the growth of ternary metal oxide nanowires, TEM structural characterizations, solar cell fabrication, and IPCE and J-V measurements.
2. Dr. Qilin Dai. Support level: 100%. Dr. Dai joined the project on May 1, 2011 and left the project in 2015. He was fully supported by the project and has been working on depositing and investigating doped and undoped QDs on wide bandgap semiconductors nanowires through PLD and various other chemical means.
3. Dr. Meg Mahat. Support level: 100%. June 2012 through August 2013. Dr. Mahat worked on the transient absorption measurement setup and characterization of PLD quantum dots
4. Dr. Seonggi Min. Support level: 100%. Dr. Min has worked on STM and ATM measurements, including the HAFM repair and application to the project.
5. Dr. Ying Yang. Support level: 100%. Dr. Yang has worked on solid-state electrolytes.
6. Dr. Weimin Chen. Support level: 50%. Dr. Chen has worked on the fabrication of magnetically doped nanowires,

7. Dr. Keshab Sapkota. Support level: 100%. Dr. Sapkota has worked on the magnetotransport measurement of magnetically doped nanowires.

Graduate students

8. Sabit Horoz. Support level: 0%. Sabit joined the project in August 2010. He is a PhD graduate student and works full time on the project, but he is supported by a separate external source. He graduated in December 2015.
9. Gaurab Rimal. Support level: 25%. Gaurab joined the project in the fall semester 2011. He was partially supported by the project. He obtained his PhD degree in physics in August 2017. His work focuses on expanding the PLD method to the preparation of doped PbS QDs and investigation of magnetic, transport and PV properties of Mn, Cu and Eu doped PbS.
10. Uppalaiah Erugu. Support level: 0%. Uppalaiah joined the project in the fall of 2014 as a PhD graduate student. He was supported by a UW Academic Affairs Energy Science GA and NASA EPSCoR materials science GA. His work focuses on QDs and amorphous EuTiO3.
11. Pan Liu. Support level: 20%. In addition to this grant, he was supported by a NSF grant. He obtained his PhD degree in physics in May 2014. He focused on the magnetic characterizations of the doped QDs as well as magnetic oxides.
12. Benjamin Haynie**.** Support level: 100%. From February – July 2015, chemistry graduate student. Haynie works on the synthesis and characterization of CdS and CdSe QDs functionalized by cysteine derivatives.
13. Tikarama Neupane. Support level: 0%. Graduate student supported by the School of Energy Resources.
14. Artem Pimachev. Support level: 100%. He was supported by a combination of DOE and UW SER GA award. He is working on the theoretical study of QD-nanowire solar cells.
15. Urice Tohgha. Support level: 0%. Urice worked on the synthesis of colloidal QDs and graduated in January 2015.
16. Jung Kyu Choi. Support level: 100%. Jung joined group in January 2014 and is a 5^{th} year chemistry graduate student. He is working on the post-synthetic ligand exchange using CdSe QDs and $(CdSe)_{13}$ nanoclusters. His objective is to comprehend the effect of ligand structure on the interactions between capping ligands and nanocrystals surface. He has successfully defended hid PhD dissertation thesis in June 2014.
17. Levente Pap. Support level: 100%. January - August 2014, 1^{st} year chemistry graduate student. Pap worked on the post-synthetic ligand exchange using CdSe QDs and $(CdSe)_{13}$ nanoclusters.
18. Baichhabi Yakami. Baichhabi is a PhD Student in Electrical and Computer Engineering: Baichhabi has been supported as a research assistantship on this project throughout this project. He was funded from this project full time from the start of this project in August 2010 to spring semester 2015 and has been ¾ time funded since then. His primary job function has been to perform optical characterization (PL, TRPL, TA, etc) on the quantum dot and nanowires samples provided by the other PIs on the grant. For the last year he has also been training Shashank on this equipment.

19. Vitaly Proschenko. Support level: 100%. Vitaly joined Dr. Dahnovsky's group in August 2012 and is working on the theoretical study of QDSSCs. He graduated in 2016.
20. Liyou Lu. Support level: 0%. Liyou worked on the synthesis of nanowires and fabrication and characterization of solar cells. He graduated in 2013.
21. Andrew J. Yost. Support level: 0%. Andrew joined the project in August 2013 and is the main man power working on the XSTM project with Prof. Chien. He was initially supported by NSF GK-12 Environmental and Energy Nanotechnology Fellowship and then by Wyoming NASA Space Grant Consortium Graduate Research Fellowship, but works full time on the project. He led all of the aforementioned STM studies and mentored an undergraduate student on the CuO nanowire growth work. He graduated in 2017.
22. Ravi Neupane. Support level: 0%. Ravi joined the project in January 2014 and worked in this project partially. He was initially supported by Energy GA Fellowship (Office of Academic Affairs in University of Wyoming) then by Competitive GA Fellowship from School of Energy Resources at University of Wyoming, but works part time on this project. His project was mainly focused on organic solar cell synthesis with spin coating technique with electric and magnetic fields. Ravi assist Andrew to take some SEM, XRD and STM data as well as some spin-coating processes..
23. Shitao Wang. Support level: 60%. Shitao joined the project in September 2014 and worked on this project partially. He was fully supported by this grant to assist Andrew for almost everything for two years then he was supported by the Competitive GA Fellowship from School of Energy Resources at University of Wyoming for one year. The participation in this project also serves as training for Shitao in lab skills. His own thesis project is mainly focused on oxide materials and now he devotes to the EuO system with a NSF grant..
24. Greogory Kolesov. Support level: 90%. He worked on theoretical studies of QDSSCs and graduated in 2014.
25. Scott Maloney. Support level: 100%. Support for Scott started in August 2015. He is working on the synthesis and characterization of magnetically doped semiconductor nanowires. He graduated in 2016.
26. Uma Poudyal. Support level: 100%. Support for Uma started in September 2015. She is working on the synthesis and characterization of quantum dot sensitized solar cells. She graduated in 2017.
27. Xin Tian. Support level: 75%. Support for Xin started in September 2015. Xin is a first-year graduate student, and is working on the synthesis and characterization of magnetically doped semiconductor quantum dots.
28. Shashank Nandyala. Shashank is new PhD student in Electrical and Computer Engineering: He has been supported as a research assistantship only part time from this project during this period, ¼ RA Fall semester 2015 through Spring semester 2017 and ½ RA for the summer of 2017. The rest of his salary funds have come from state TA funding. His work on this project so far has been mostly limited to training on the measurement system but he has taken or helped take PL, TRPL and TA data on several samples from various PIs on the grant.

29. Rabindra Dulal. Support level: 100%. Rabindra joined the project in September 2016 and worked in this project partially. He was fully supported by this grant to assist Andrew for the last year of the project. In particular, he was trained by Andrew on QD synthesis using chemical methods. The participation in this project also serves as training for Rabindra in lab skills. His own thesis project is mainly focused on organic solar cell synthesis and characterization using XSTM/S technique and now he will be supported by a NSF grant.

Undergraduate students

1. John Evans. Support level: 0%. Setting up a system for photoconductivity and photomagnetic measurements.
2. Vivek Jain. Support level: 0%. Magnetic semiconductor EuO. He was involved in the project from 2015 to 2016. He was supported by a Wyoming Research Scholarship of the Science Initiative. He graduated in the fall of 2016..
3. Samuel Bartko. Support level: 30%. Samuel joined the project in May 2014. He is an undergraduate student supported partially this grant. His project is mainly focused on designing and making the home-made remote controlled spin-coater. Samuel has finished the designing and the spin-coating is up and running. Recently, Samuel has just received admission letters for his graduate study, including one in Penn State.
4. Joann Hilman. Support level: 15%. Joann joined the project in April 2014. She is an undergraduate student supported partially by the Wyoming NASA Space Undergraduate Research Fellowship and partially by this grant. She works part time on this project, mentored by Andrew Yost on the CuO nanowire synthesis. Her work has been published recently.
5. Samuel Nissim. Support level: 30%. Samuel joined the project in May 2014. He is an undergraduate student supported partially this grant and partially by the PI's start-up fund. His project is mainly focused on designing and making the home-made remote controlled spin-coater. Samuel has finished the designing and the spin-coating is up and running.
6. Anri Karanovich. Support level: 0%. Undergraduate student, worked on theoretical studies of QDSSCs.
7. Justus Kornkven. Support level: 0%. Justus joined the project in May 2015. He is an undergraduate student supported by Wyoming EPSCoR Undergraduate Research Fellowship. His project is currently focused on Mn doping effects in lead-based organometallic halide perovskites.
8. Teneil Schumacher. Support level: 0%. Teneil joined the research group in August 2016. Her project was focused on synthesizing graphene-related materials from raw coal materials using chemical treatments.
9. Ryan Smith. Support level: 0%. Photoluminescent quantum cutter for energy conversion. He was involved in the project from 2012 to 2014.
10. Steven Bagley. Support level: 0%. Magnetic semiconductor EuO. He was involved in the project in 2014.
11. Robert Nielsen. Support level: 0%. PdS QDs synthesis. He was supported by a McNair scholarship and was involved in the project from 2012 to 2013.

12. Christoffer Masi. Support level: 0%. Chris joined the research group in April 2017. His project is currently focused on synthesizing graphene-related materials from raw coal materials using microwave treatments.

9. Current and pending support

Support information is required for each key personnel / senior investigator, including persons at collaborating institutions funded through subcontracts. All financial resources (Federal, non-Federal, commercial, or institutional) should be included. If another investigator is the lead PI on a reported grant/FWP, please put the lead PI's last name in parentheses after the investigator's name in the "Investigator" box for the reported grant/FWP. Provide a brief paragraph on synergies and/or overlaps between the scopes of the FWP and other supported projects. For laboratory staff, if support does not total 12 person-months, an explanation should be provided. For university faculty, explanations should be provided for support beyond normal summer-month levels. Add additional sheets as necessary. *This form has been modified from NSF 00form1239.	
Investigator: Tang (Co-PI: Chien / Dahnovsky)	Other Agencies to which this proposal has been/will be submitted:
Support (Current, Pending, Submission Planned in Future or Transfer of Support): Current	
Project/Proposal Title and grant number, if appropriate: Investigation of Magnetic Skyrmions and Magnetic Polarons in Oxygen Deficient EuO(1-x)	
Source of Support: NSF	Location of Project: University of Wyoming
Total Award Amount: $595,360	Total Award Period Covered: Aug. 2017 – Jul. 2020
Annual Award Amount to PI's Research: $68,000	
Person-Months Per Year Committed to Project: _0.3_ Pers. Months; Specify: Cal., Acad., or Sumr: S	
Describe research including synergies and/or overlaps with This Proposal/Award: This NSF proposal investigates the magnetic properties of oxygen deficient EuO. Although spin-orbit coupling and related spin structure/transport properties are the focus of the project, photo-induced magnetic states will be investigated, which is relevant to the current project.	
Investigator: Tang	Other Agencies to which this proposal has been/will be submitted:
Support (Current, Pending, Submission Planned in Future or Transfer of Support): Current	
Project/Proposal Title and grant number, if appropriate: Magnetic Characterizations of PRB Coal and Related Applications of its Derived Products	
Source of Support: University of Wyoming	Location of Project: University of Wyoming
Total Award Amount: $270,848	Total Award Period Covered: Jul. 2016 - Jun 2018
Annual Award Amount to PI's Research: $135,000	
Person-Months Per Year Committed to Project: _1__ Pers. Months; Specify: Cal., Acad., or Sumr: S	
Describe research including synergies and/or overlaps with This Proposal/Award: This grant provided partial support for a graduate student who also worked on the DOE implementation project. In addition, this grant has provided equipment support that was critical to the DOE implementation grant. Otherwise, the overlap between the two projects is insignificant.	
Investigator:	Other Agencies to which this proposal has been/will be submitted:
Support (Current, Pending, Submission Planned in Future or Transfer of Support):	
Project/Proposal Title and grant number, if appropriate:	
Source of Support:	Location of Project:
Annual Award Amount: $	Total Award Period Covered:
Annual Award Amount to PI's Research: $	
Person-Months Per Year Committed to Project: ____ Pers. Months; Specify: Cal., Acad., or Sumr:	

Describe research including synergies and/or overlaps with This Proposal/Award:

Investigator: TeYu Chien	Other Agencies to which this proposal has been/will be submitted:
Support (Current, Pending, Submission Planned in Future or Transfer of Support): P	
Project/Proposal Title and grant number, if appropriate: CAREER: Interfacial Electronic Properties Influenced by External Stimuli Studied with Cross-Sectional Scanning Tunneling Microscopy and Spectroscopy (PI: Chien)	
Source of Support: NSF Location of Project: University of Wyoming	
Total Award Amount: $577,594 Total Award Period Covered: 07/01/2018-06/30/2023	
Person-Months Per Year Committed to Project: _1_ Pers. Months; Specify: Cal., Acad., or Sumr: S	
Describe research including synergies and/or overlaps with This Proposal/Award: The use of the XSTM/S is the common technique use in this project and this proposal. The light illumination part of this proposal is an extension of the work from this project.	
Investigator: TeYu Chien	Other Agencies to which this proposal has been/will be submitted:
Support (Current, Pending, Submission Planned in Future or Transfer of Support): C	
Project/Proposal Title and grant number, if appropriate: Investigation of Magnetic Skyrmions and Magnetic Polarons in Oxygen Deficient EuO_{1-x} (PI: Tang; Co-PIs: Chien, and Dahnovsky)	
Source of Support NSF Location of Project: University of Wyoming	
Total Award Amount: $600,000 Total Award Period Covered: Aug. 2017 – July 2020	
Person-Months Per Year Committed to Project: 0.33 Pers. Months; Specify: Cal., Acad., or Sumr: S	
Describe research including synergies and/or overlaps with This Proposal/Award: The collaborating team in this proposal is a result of the DOE project.	
Investigator: TeYu Chien	Other Agencies to which this proposal has been/will be submitted:
Support (Current, Pending, Submission Planned in Future or Transfer of Support): C	
Project/Proposal Title and grant number, if appropriate: Collaborative Research: Concurrent Design of Quasi-Random Nanostructured Material Systems (NMS) and Nanofabrication Processes using Spectral Density Function (PIs: Chen, Chien, and Balasubramanian)	
Source of Support: NSF Location of Project: : University of Wyoming	
Total Award Amount: $ 250,000 Total Award Period Covered: 08/01/2017-07/31/2020	
Person-Months Per Year Committed to Project: 0.8 Pers. Months; Specify: Cal., Acad., or Sumr: S	
Describe research including synergies and/or overlaps with This Proposal/Award: The knowledge about the state-of-the-art solar cell applications is the root of this new proposal.	

10. Cost status

The approved budget for the full budget period from 08/15/2010 to 08/14/2017 is $3,908,926, and the actual costs incurred are:

CATEGORY	**COST INCURRED**
Senior Personnel:	$203,430.90
Post Doc Salaries:	$519,083.29
GA Salaries:	$670,390.39
Fringe Benefits:	$347,709.91
Part-time Salaries:	$11,906.66
Other Professionals:	$34,667.30
Materials & Supplies:	$272,495.94
Travel Expenses:	$99,049.29

Equipment:	$668,450.23
Tuition & Fees:	$188,401.00
Indirect Cost:	$893,340.78
Total:	$3,908,926