Photovoltaics Research and Development: Device Architecture for Next-Generation CdTe PV

Cooperative Research and Development Final Report

CRADA Number: CRD-17-00662

NREL Technical Contact: Darius Kuciauskas

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
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Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5900-80756
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Cooperative Research and Development Final Report

Report Date: August 18, 2021

In accordance with requirements set forth in the terms of the CRADA agreement, this document is the final CRADA report, including a list of subject inventions, to be forwarded to the DOE Office of Scientific and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: Colorado State University (CSU)

CRADA Number: CRD-17-00662

CRADA Title: Photovoltaics Research and Development: Device Architecture for Next-Generation CdTe PV

Responsible Technical Contact at Alliance/ National Renewable Energy Laboratory (NREL):

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DOE Program Office: Office of Energy Efficiency and Renewable Energy (EERE), Solar Energy Technologies Office (SETO)

Joint Work Statement Funding Table showing DOE commitment: No NREL Shared Resources

Estimated Costs	NREL Shared Resources a/k/a Government In-Kind
Year 1	$.00
TOTALS	$.00

Executive Summary of CRADA Work:

Pass-through Entity (PTE): CSU
Subrecipient: NREL
PTE Principal Investigator (P1): James Sites
Subrecipient Principal Investigator (P1): Darius Kuciauskas
PTE Federal Award No: DE-EE0007543
FAIN: Federal Awarding Agency: DEEE0007543
Federal Award Issue Date: September 27, 2016
Total Amount of Federal Award to PTE: $999,922
CFDA No: 81.087
CFDA Title: Renewable Energy Research and Development
Project Title: Device Architecture for Next-Generation CDTE PV
Subaward Period of Performance: The effective date of this CRADA through July 31, 2017 and annually amended thereafter.
Amount Funded This Action: $40,000
Subaward No.: G-50351-1
Estimated Project Period (if incrementally funded): 8/1/16 — 7/31/20
Incrementally Estimated Total: $160,000
Is this Award R & D: Yes
Subject to FFATA: Yes, Attachment 3B must be completed and returned at time of signature
Cost Sharing: Not Applicable

Purpose:

Despite remarkable efficiency improvements at the cell and module level, thin-film CdTe PV suffers from a significant voltage deficit compared with the ideal. The proposed solution is to build cells with fully depleted absorbers and with energy barriers front and back to direct electrons and holes in appropriate directions. Combined with minimal interfacial recombination, this approach, which is similar to the successful silicon HIT cells, circumvents the need for higher lifetimes and carrier concentration to achieve higher voltage, Colorado State is particularly well-positioned to the address the depleted absorbed architecture. It has robust single-vacuum closed-spaced-sublimation deposition chamber, currently being enhanced with new sources for CdTe alloys and grading. It has made reasonable-efficiency cells with absorbers as thin as 0.3 um, it has demonstrated electron reflection at the rear of the absorber with a continuous CdMgTe layer, it has replaced CdS with MgZnO, which has several advantages including tunable band offsets, and it has achieved 16.8% efficiency. It also has a mature suite of measurement equipment for cell evaluation and the experience to effectively analyze its results for refinement in cell fabrication. Several healthy collaborations will continue within the CdTe community.

Summary of Research Results:

Task 1: Analyze interface passivation in polycrystalline CdTe with different buffer layers using time- and energy-resolved photoluminescence spectroscopy

In this task we used photoluminescence (PL) and time-resolved PL (TRPL) spectroscopy to understand and improve semiconductor interface passivation in CdTe solar cells. Solar cells were fabricated at CSU, and improvements were achieved using several approaches. First, alloyed CdSeTe absorber was studied. Representative data is shown in Figure 1. The presence of CdSeTe alloy is indicated by PL shift to 1.43 eV (from CdTe bandgap of 1.50 eV). Improved passivation is evident from increased PL amplitudes (left) and carrier lifetimes (right). Similar absorbers are now commonly used in solar cells fabricated at CSU and other laboratories. Measurements at NREL for such devices quantify increased radiative efficiency and carrier lifetime. Additional details are published in Ref. 1.

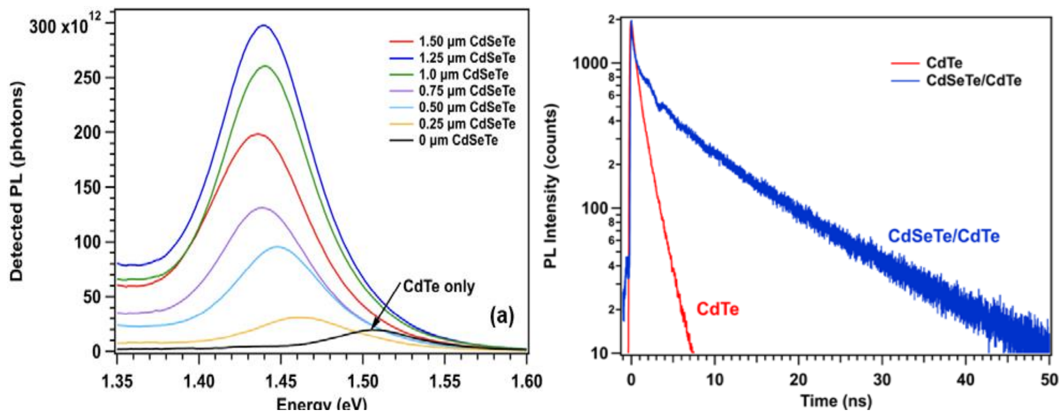


Figure 1. Comparison of PL emission spectra (left) and TRPL data (right) for CdTe and CdSeTe/CdTe absorbers.

In this task, we also used TRPL spectroscopy to characterize carrier lifetimes when CdMgTe layer was applied at the back of the solar cells. The goal is to create an electron reflector at the back, a concept earlier developed at CSU. Representative data is illustrated in Figure 2 (left), where recombination in solar cells where CdMgTe is deposited by close spaced sublimation (CSS) and sputtering is compared. The next step in device fabrication is deposition of the back contact, and in this project Cu/Te back contact was commonly used. Figure 2 (right) shows TRPL data for analysis of back contact fabrication. Additional details for electron reflector fabrication and analysis are also given in Ref. 1.

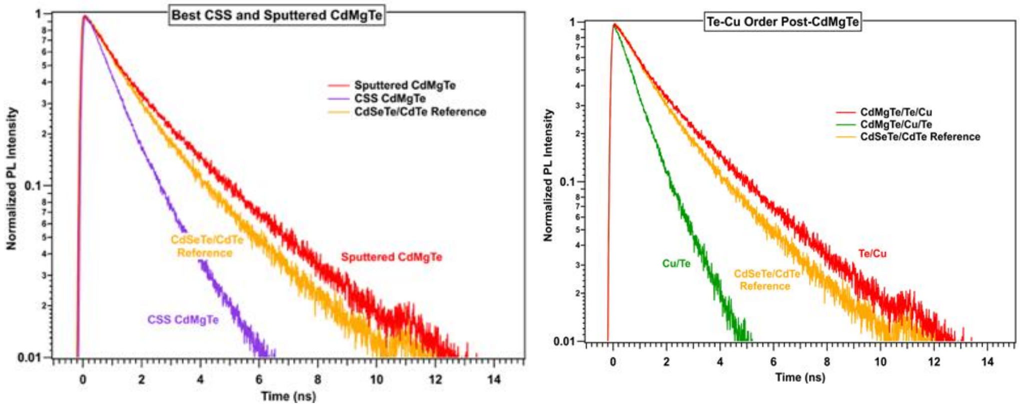


Figure 2. Left: Comparison of TRPL data for solar cells with CSS and sputtered CdMgTe electron reflectors. Right: TRPL data for solar cells with electron reflectors where back contact composition was varied.

<u>Task 2</u>: Analyze minority carrier lifetimes in CdTe solar cells from time-resolved photoluminescence with one- and two-photon excitation

In this task, we applied TRPL measurements with different carrier generation: near front interface of the solar cell (one-photon excitation) and with two-photon excitation, where carriers are uniformly generated in the absorber bulk. This approach is illustrated in the scheme in Figure 3. The goal is to understand interface vs. bulk carrier recombination. 1PE and 2PE data is also shown in Figure 3. The time scale for TRPL is longer with 1PE (center) and time scale is shorter with 2PE (right). This result is attributed to two factors: larger defect density in CdTe (in comparison to CdSeTe), and also to larger recombination at the back contact. In contrast, there are fewer recombination center defects at the front interface and in the CdSeTe region of the solar cell device, and as result carrier lifetimes are longer with 1PE.

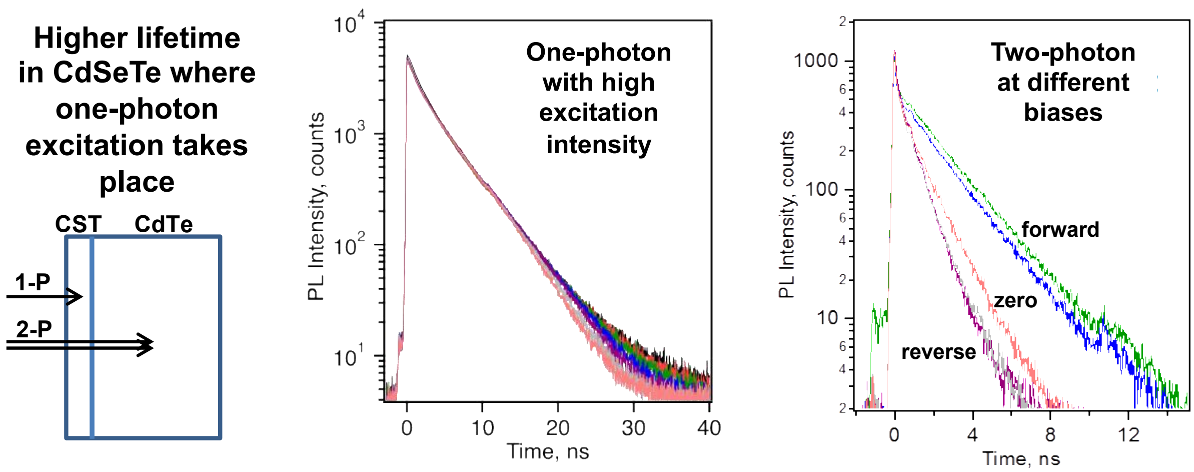
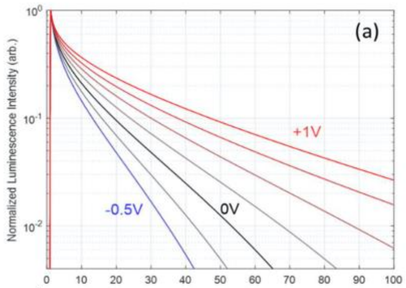
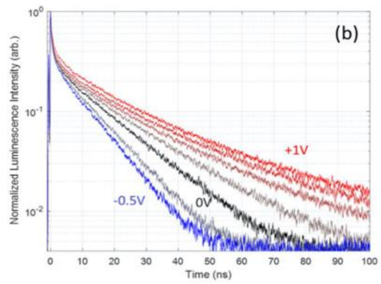


Figure 3. One- and two-photon excitation TRPL data for bilayer (CdSeTe/CdTe) solar cells.

Task 3: Analyze minority carrier transport characteristics CdTe polycrystalline films and in solar cells

Research in this task was very detailed, and was carried out in collaboration with CSU. Results were presented at two conferences and published in two conference proceedings (Ref. 2 and 3); additional publications are in preparation. For research in this task, we developed a novel experimental approach, TRPL measurements on electrically biased solar cells. The photograph of this experimental setup is shown in Figure 4. In addition, Pascal Jundt developed numerical codes for TRPL data simulation, and applied these codes to simulate experimental data. As an illustration of this approach, Figure 4 shows results from Ref. 3. Here, analysis shows that minority carrier lifetime of 10 ns is accurately determined in experiments when solar cells is based at +1 V, which corresponds to flat band conditions. Additional analysis was applied to determine other parameter sensitivity, such as carrier mobility.





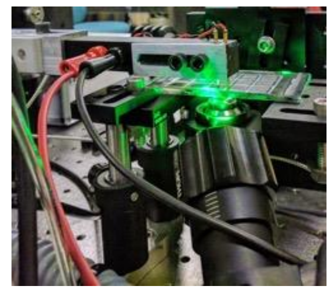


Figure 4. Simulated (left) and measured (center) TRPL decays for electrically biased CdTe solar cells. Picture shows experimental setup developed for biased-TRPL measurements.

Summary Conclusion:

NREL's role in this CRADA was to provide PL and TRPL measurements in PVRD (photovoltaics research and development) project at CSU. As illustrated in brief descriptions for tasks 1-3, measurements were successful and provided detailed information about carrier dynamics in CdTe solar cells. This data was used for understanding and reducing recombination, which enables higher voltage in solar cells. More detailed data sets and analysis are available in journal and conference publications.

References:

1. Bothwell, Alexandra M.; Drayton, Jennifer R.; Jundt, Pascal M.; and Sites, James R., "Characterization of thin CdTe solar cells with a CdSeTe front layer," *MRS Advances* 4 (2019), pp 2053-2062, https://doi.org/10.1557/adv.2019.332
2. Jundt, Pascal M.; Kuciauskas, Darius; and Sites, James R., "Field effect in CdSeTe/CdTe solar cells with biased spectroscopy," in Proceedings 2019 IEEE 46th Photovoltaics Specialists Conference (PVSC), Chicago, June 2019, https://doi.org/10.1109/PVSC40753.2019.8980487
3. Jundt, Pascal M.; Kuciauskas, Darius; and Sites, James R., "Simulating the effect of p-n junction fields on TRPL transients of CdSeTe/CdTe thin-film solar cells," in Proceedings 2020 IEEE 47th Photovoltaics Specialists Conference (PVSC), Virtual, June 2020, https://doi.org/10.1109/PVSC45281.2020.9300522

Subject Inventions Listing:

None

ROI #:

None