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Electro-Optical Characterization at NREL

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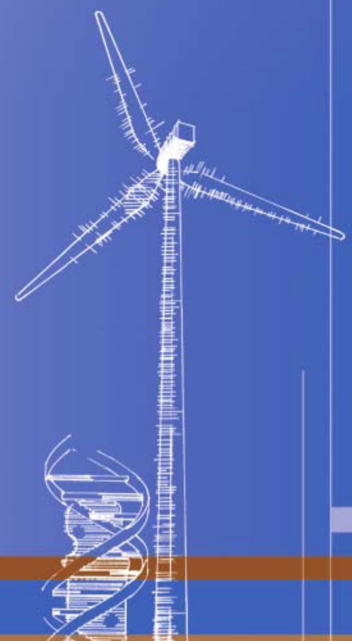

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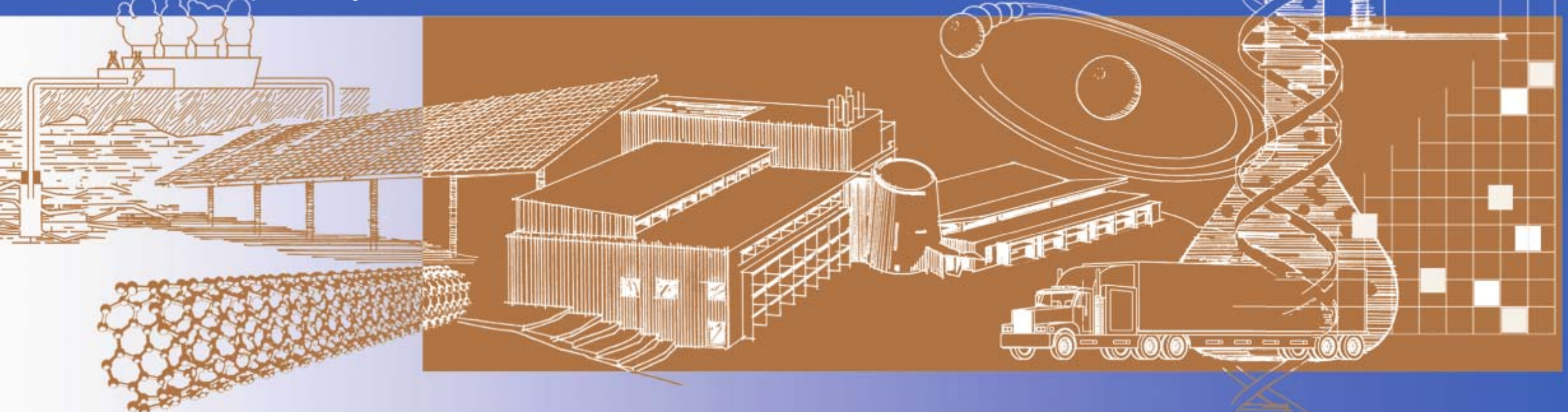

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Electro-Optical Characterization at NREL

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ABSTRACT

One of the core issues in all of the photovoltaics technologies is relating PV device performance to the methods and materials used to produce them. Due to the nature of PV devices, the electronic and optical properties of the materials are key to device performance. The relationship between materials growth and processing, the resulting electro-optical properties, and device performance can be extremely complex and difficult to determine without direct measurement of these properties. Accurate and timely measurement of the electro-optical properties as a function of device processing provides researchers and manufacturers with the knowledge they need to troubleshoot problems and develop the knowledge base necessary for reducing cost, maximizing efficiency, improving reliability, and enhancing manufacturability. The Electro-optical Characterization Team at NREL provides this support for all internal and external projects funded by the PV Program. Examples of this support are listed below.

1. Objectives

The overall objectives of the electro-optical characterization project are to; 1) provide routine and specialized measurement and characterization support for PV program research and industry teams, 2) lead and contribute to collaborative research that addresses critical issues in PV technology (e.g. improved performance, reliability, manufacturability, and reduced costs), and, 3) develop novel measurement techniques and diagnostics that advance understanding and/or manufacturability.

2. Technical Approach

This project uses electrical and optical techniques to examine fundamental properties of PV materials and devices. The types of information obtained by these techniques range from small-scale atomic bonding information to large-scale macroscopic quantities such as electron-transport properties. Additionally, 2-dimensional numerical modeling techniques are developed and employed to analyze experimental and device behavior.

3. Results and Accomplishments

Key and Control Milestones completed within this project are listed in Table 1. Additional results and accomplishments are listed in subparagraphs of paragraph 3.

Table 1. Key and Control Milestones

SETP MYTP Milestone
Organize the 15th Workshop on Crystalline Silicon Solar Cell Materials and Processes
Develop a prototype minority carrier lifetime measurement system capable of accurately measuring both crystalline and multi-crystalline Si wafers in an in-line manufacturing environment.
Apply Dessis 2-D device modeling software to elucidate fundamental limitations in crystalline and polycrystalline photovoltaic device designs. Submit at least one peer-reviewed paper that leads to an improved understanding of device performance and/or reliability.
Develop, construct and test an automated RCPCD minority carrier lifetime mapping system (one- or two-dimensional) that incorporates auto-tuning, and is capable of accepting samples up to 6” in diameter.
Conduct experiments to examine the structural, chemical and electrical properties of the crystalline Si/amorphous Si interface in HIT cells. Submit a peer-reviewed paper that correlates these properties to device performance.
Provide measurement support in the areas of analytical microscopy, surface analysis, electro-optical characterization, and cell and module performance to more than 70 PV research partners in Industry, University and NREL.

3.1 Measurements and Characterization Support

Measurements and characterization support for a broad spectrum of technologies important to the PV community (Industry, University and NREL) including: c-Si, a-Si, thin-Si, CIS, CdTe, III-V’s, higher performance, and future generation materials.

Examples include:

- The hydrogen content of a-Si:H and a-SiGe:H alloys by FTIR in support of the growth of multijunction devices and silicon recrystallization efforts.
- Composition and impurity characterization of a-SiOxNy and multicrystalline silicon (mc-Si) by FTIR in support of the mc-Si industry.
- RCPCD and TRPL material quality (lifetime) measurements of polycrystalline thin films (CIGS, CdTe), single and multicrystalline silicon, and high-efficiency multijunction materials (e.g. GaAs, GaAsN, InGaAsN) in support of understanding the effect of changes in growth and processing conditions.
- Nondestructive characterization of the free carriers in transparent conducting oxides (TCO) by FTIR in support of combinatorial growth of new TCOs.

3.2 Targeted Collaborative R&D Projects
Targeted R&D projects that address key MYTP goals are listed below (also see milestones listed above).

3.2.1 Improving the current state of c-Si photovoltaic device technology

- Organized the 15th Workshop on Crystalline Silicon Solar Cell Materials and Processes.

3.2.2 Improving the efficiency and manufacturability of c-Si devices

- In-situ growth monitoring and post-deposition analysis of crystallinity for silicon heterojunction solar cells using real-time spectroscopic ellipsometry (RTSE)
- In-situ monitoring of crystallinity for hot-wire chemical vapor deposited (HWCVD) epi-silicon
- Modeling RTP-like processing in order to gain increased control and efficiency of the thermal annealing process

3.2.3 Understanding the effect of grain boundaries on the performance and reliability of polycrystalline thin-film devices

- Applied Dessis 2-D device modeling software to elucidate fundamental limitations in crystalline and polycrystalline photovoltaic device designs
- Understanding the passivation of CIGS grain boundaries using Spectroscopic Ellipsometry.

3.2.4 Identifying performance-limiting defects in polycrystalline thin-film devices

- Determination of the defects responsible for reduced performance in CIGS solar cells using Deep Level Transient Spectroscopy (DLTS)
- Determination of the changes in defect properties that occur with stress testing and the ability of changes in the device structure to mitigate this degradation.
- Determination of the defect associated with Cu diffusion in CdTe.

3.2.5 Understanding the effect of hydrogen-related defects on the manufacturability of thin-film materials

- Understanding the unintentional incorporation of hydrogen in transparent conducting oxides (TCO) using Fourier-transform infrared (FTIR) spectroscopy
- Understanding the unintentional incorporation of hydrogen in MOCVD-grown III-V-N films using Fourier-transform infrared (FTIR) spectroscopy.

3.3 *Development of Diagnostic Tools that are Critical to R&D and the Si Manufacturing Communities*.

- Developed a prototype minority carrier lifetime measurement system capable of accurately measuring both crystalline and multi-crystalline Si wafers in an in-line manufacturing environment.
- Developed, constructed, and tested an automated RCPCD minority carrier lifetime mapping system (one- or two-dimensional) that incorporates auto-tuning, and is capable of accepting wafers up to 6” in diameter
- The development of a model for junction-dependent lifetime measurements
- Developed a high-speed, non-contact AR coating and wafer thickness measurement and mapping system
- Depth profiling of dopants in crystal silicon by Spectroscopic Ellipsometry
- Enhancement of an existing cluster tool with the addition RTSE for studies of surface properties.

4. Conclusions

The Team successfully contributed to the PV Program through support, collaborative R&D, and technique development involving numerous material and device technologies.

ACKNOWLEDGEMENTS

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MAJOR FY 2005 PUBLICATIONS

The team wrote and contributed to numerous conference presentations and 18 peer-reviewed publications including:

Analysis of charge separation dynamics in a semiconductor junction, Metzger W. K.; Ahrenkiel R. K.; Dashdorj D., Friedman D. J., Phys. Rev. B 71, 035301 (2005).

Infrared spectroscopy of polycrystalline ZnO and ZnO:N thin films, B.M. Keyes, L.M. Gedvilas, X. Li, T.J. Coutts, J. Crys. Gr. 281, Issues 2-4, 297 (2005).

Real-time spectroscopic ellipsometry as an in-situ probe of the growth dynamics of amorphous and epitaxial crystal silicon for photovoltaic applications, D.H. Levi, C.W. Teplin, E. Iwaniczko, Y. Yan, T.H. Wang, H.M. Branz, invited paper accepted for publication in Mater. Res. Soc. Symp. Proc. Vol. 862, (2005).

Dielectric Films for Si Solar Cell Applications, Bhushan Sopori, Journal of Electronic Materials, 34, 5, pp. 564-570, May 2005.

Observed trapping of minority-carrier electrons in p-type GaAsN during deep-level transient spectroscopy measurement, S. W. Johnston, S. R. Kurtz, D. J. Friedman, A. J. Ptak, R. K. Ahrenkiel, and R. S. Crandall, Appl. Phys. Lett., 86, 072109 (2005)

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