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Integrating Deposition, Processing, and Characterization Equipment within the National Center for Photovoltaics

B. Nelson, S. Robbins, and P. Sheldon

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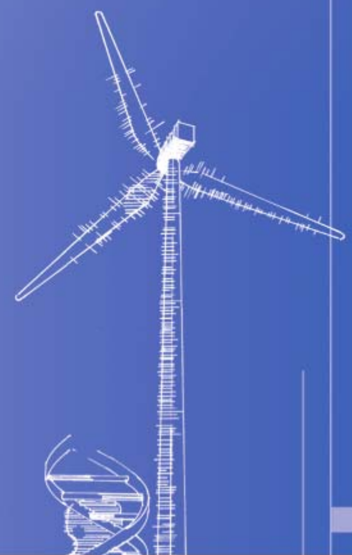

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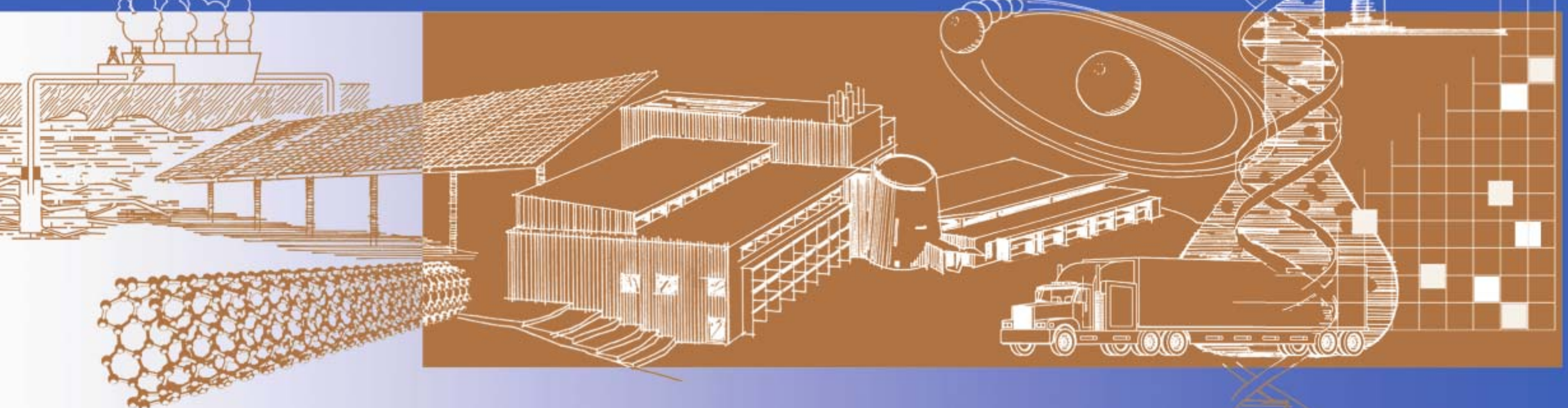

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Integrating Deposition, Processing, and Characterization Equipment within the National Center for Photovoltaics

Brent Nelson, Steven Robbins, and Peter Sheldon
National Center for Photovoltaics, National Renewable Energy Laboratory (NREL),
Golden, CO 80401-3393, USA, brent_nelson@nrel.gov

ABSTRACT

The purpose of the process integration project of the National Center for Photovoltaics (NCPV) is to develop an infrastructure that will allow researchers to gain new knowledge that is difficult—if not impossible—to obtain with existing equipment. This difficulty is due, in part, to the state of our existing tool set, which lacks sufficient in-situ or real-time measurement capabilities, or lacks access to analytical tools where the sample remains in a controlled environment between deposition and processing or measurement. This new infrastructure will provide flexible and robust integration of deposition, processing (etching, annealing, etc.), and characterization tools via a standardized transfer interface such that samples move between tools in a controlled ambient. Ultimately, this synergistic effort between NREL staff, universities, and the photovoltaic (PV) industry—around an integrated tool base—will add to the PV knowledge base and help move many PV technologies forward.

1. Objectives

We will achieve the purpose stated above by building a collection of integrated deposition, characterization, and processing tools. These integration standards must be flexible to allow for changing research needs, yet be robust and reliable. Deposition tools must be able to deposit uniformly and reproducibly over areas that are large enough to be meaningful to industry and be able to handle a wide variety of sample substrates. The benefits of having integrated tools include allowing researchers to:

- Answer previously inaccessible research questions.
- Control and characterize critical surfaces and assess the impact of these interfaces on subsequent layers.
- Assess process-related source chemistry, surface chemistry and kinetics, and bulk reconstruction.
- Grow layers and alter interfaces using controlled transfer ambients (without exposure to air).
- Develop new techniques, methodologies, device structures, materials, and tools.
- More effectively collaborate with university and industrial researchers.

This project is a 2005 goal as stated in the technology plan;[1] specifically, to “implement the thin-film process integration concept” within the high-performance and concentrator research area, which is under Fundamental Research. The Measurement and Characterization area target to: “Develop characterization platforms that support the Science and Technology Facility process integration concept” is a subset of this project. Additionally, it provides infrastructure to facilitate that area’s target to “Initiate partnerships with university and industry to develop next-generation process diagnostics necessary to enhance yield and throughput.”

2. Technical Approach

Individual deposition, processing, and characterization techniques will be integrated via one of several different modes.[2] Ideally, characterization techniques will be used for real-time analysis of deposition and processing techniques. The next best solution is in-situ diagnostics (in the original place, but not real-time data). When neither of these integration methods is possible, techniques will be integrated by transferring samples from one location to another either via intra-tool or inter-tool sample transport. *Intra-tool* transport is the movement of samples between techniques within the same set of interconnected chambers, that is, a cluster tool. The actual transfer mechanism could be robotic or a linear track transport mechanism. Initial cluster tools will use robotic transfers. *Inter-tool* transport is the movement of samples between techniques where those techniques do not share direct connection. These techniques could be in a stand-alone tool or a part of a cluster tool. The sample is moved from one tool into the pod, which is sealed and disconnected from that tool before being wheeled to another tool, where the process is reversed. The transfer ambient within the pod can be either an atmosphere of ultra-high-purity inert gas or high vacuum. This is similar to the Standard Mechanical InterFace (SMIF) used by the integrated-circuit (IC) industry to enclose and transport wafers between 200-mm tools or the newer Front-Opening Unified Pods (FOUP) used on 300-mm tools. One of the keys to the success of the IC industry was the creation of these mini-environments, in which the industry significantly reduced the contamination of wafers between processing steps.[3] While SMIFs and FOUPs are typically operated with particulate free, dry air, our initial pods will operate under high vacuum using a battery powered ion pump.

The main design goals of the NCPV Process Integration project are to:

- Develop a standard sample transport between tools
- Ensure the sample transport mechanism is robust
- Control the ambient of that sample transfer
- Be able to deposit uniformly and reproducibly over areas large enough to be meaningful to industry
- Handle a wide variety of sample substrates
- Standardize control and data logging software
- Integrate as many techniques as practical[4]

To integrate a diverse tool set requires a "universal" maximum substrate size and shape to be held in a platen. The platen drives the requirements for the entire design. Agreement by the various groups within the NCPV have set the maximum substrate size the platen can handle to be approximately 6" x 6". Although this size supports the silicon photovoltaic industry (having a "6-inch square" protocol in polycrystalline and a "6-inch round" protocol in single crystalline), this size also more than adequately supports the other technological areas studied by the NCPV. Various platen designs will need to accommodate a variety of different substrates, such as soda-lime glass, high-temperature glass (e.g., Corning 1737), crystalline wafers (e.g., Si, Ge, GaAs), thin stainless steel, ceramic, and exotic materials.

Because of our need to handle a variety of substrate sizes, shapes, and materials in a sample platen, there are no "off-the-shelf" solutions to integrating our tools. Therefore, we had to develop our own set of design standards for future tool development; especially for the pod. The progress on each of the various tools in this project is discussed in the next section. Each custom tool involves the following development steps:

- Conceptual design specifications
- obtain budgetary quotes
- Budgetary rescoping (change scope to fit budget)
- Final specifications
- Award contract and vendor fabrication
- Site preparation (for tool hookup at NREL)
- Acceptance and full operation at NREL

3. Results and Accomplishments

There is a three-year budget for essential capital equipment associated with the construction and operation of the Science and Technology Facility (S&TF). This essential capital equipment includes the following nine work packages, which are divided by status according to the development steps listed above.

<u>Projects with contracts awarded and being fabricated</u>:

1. Silicon CVD Cluster Tool *(to MVSystems, Inc.)*
2. TCO Sputtering Stand-Alone Tool *(to AJA International for the TCO chamber & Transfer Engineering for the transport pod)*

<u>Projects undergoing budgetary rescoping</u>:

3. User Characterization Equipment

<u>Projects developing conceptual specifications</u>:

4. Auger Electron Spectrometer Mobile Tool
5. CBD CdS-Controlled Ambient Stand-Alone Tool
6. Polycrystalline Thin-Film Cluster Tool
7. X-ray and Ultraviolet Photoelectron Spectrometer Stand-Alone Tool
8. Optical / Processing Cluster Tool
9. Characterization Stand-Alone Tool

The silicon cluster tool will be completed in approximately March of 2006 and be operated at MVSystems until the construction of the S&TF is complete later that summer; at which time it will be moved to NREL. The Transparent conducting oxide (TCO) sputtering tool will be completed at approximately the same time and shipped to NREL where it will be operated in the existing facilities until it can be moved to the S&TF.

The silicon cluster tool will not only perform thin-film silicon deposition and processing (supporting the technology plan goals), but will also serve as the project's first test for intra-tool transport having internal transfer zone containing a vacuum robot. The TCO sputtering tool will not only perform thin-film TCO depositions, but will also serve as the project's first test for inter-tool transport via the accompanying pod.

We are also developing the use of recipe/run control, as well as data logging, using XML-based data transfer. Software is critical to having fully integrated tools. Not only for automation, but for easy access to the data out of which information can be gleaned and knowledge built. The approach we are pursuing is illustrated in Figure 1.

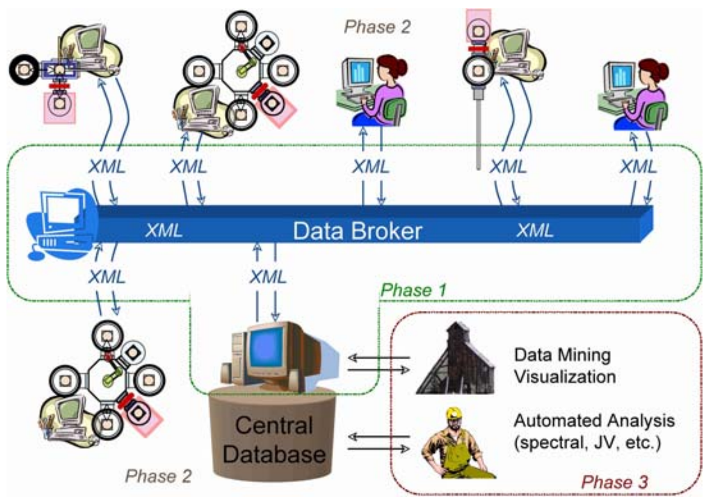

Figure 1: Schema for software integration.

4. Conclusions

We have achieved remarkable consent from individuals with a diverse spectra of research interests in the development of these process-integration standards. We are progressing toward the goals of having integrated deposition, processing, and characterization techniques by first prototyping an inter-tool transport scheme and then an intra-tool transfer platform.

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[2] Nelson BP, Robbins S, Sheldon P, NREL; 2005, Report No. NREL/CP-520-38864.
[3] D. Calhoun, Micro, Vol. 16, pp. 91, 1998.
[4] Nelson BP, Robbins S, Sheldon P, NREL; 2004, Report No. NREL/CP-520-36595.

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