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

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

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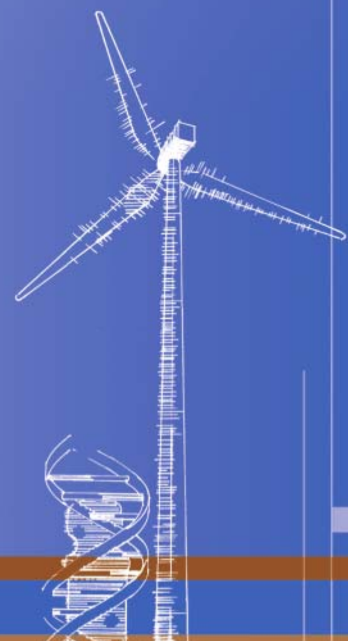

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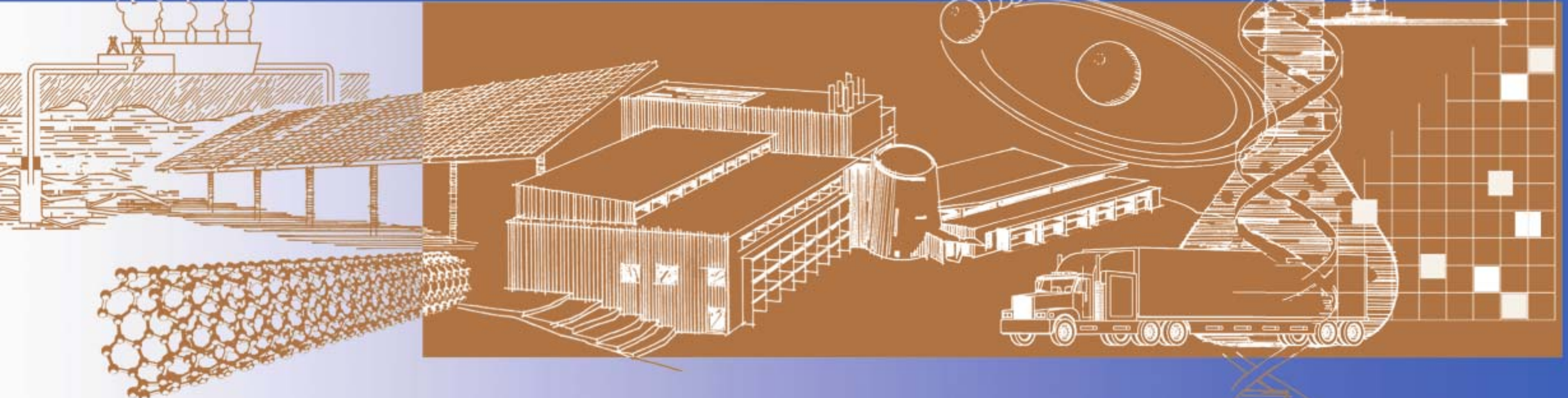

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Integrating Deposition, Processing, and Characterization Equipment within the National Center for Photovoltaics

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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. This concept will also require the cooperation of experts from various material technologies and characterization disciplines to work directly with each other to obtain answers to key scientific and technological questions. 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 (interfaces) and assess the impact of interfaces on subsequent layers.
- Assess process-related source chemistry, surface chemistry and kinetics, and bulk reconstruction.
- Grow layers and alter interfaces using controlled processes and 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. 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. *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.

Several key elements need to be engineered to have a working collection of integrated tools. First, we are prototyping the inter-tool transport. This prototype is a stand-alone tool that requires the engineering of the tool itself (in this case, a sputtering chamber) along with five main components that will become the standard for future tools. These components are:

- A mobile transport pod (inter-tool transport mechanism),
- a dock (the pod-to-tool interface),
- a substrate platen (to hold substrates of various types),
- a cassette (to hold multiple platens), and
- the transfer mechanism (moving a platen within the tool).

The intra-tool transport will be prototyped next. This consists of a handoff station to accept platens from the transport pod and the transfer mechanism within the cluster tools. It will either be a set of techniques/chambers around a centralized robotic transfer mechanism or distributed along a linear or track transfer mechanism. The first prototype intra-tool transport platform will be integrated with techniques for copper indium gallium diselenide deposition.

Concurrent with the engineering and construction of these prototype tools, we are defining the scope of which techniques to integrate with future tools and determining the optimal integration mode. The early designs will be refined into standardized designs for incorporation into future deposition, processing, and characterization tools. These new tools will provide the infrastructure for improved collaboration with both university and industrial researchers.

The Process Integration Project Engineering Team meets regularly with representatives from research groups throughout the NCPV to discuss all design features. Typically, these meetings focus on a particular design area, with a core group concentrating on each aspect. When a key decision is reached, the appropriate focus group gathers consent from their existing research team and then signs off on the appropriate aspect of the project. These focus groups tend to concentrate on the fine detail of the project.

An Umbrella Group was formed with representatives from the core research areas within the NCPV to ensure that the project is compatible with their future needs. This group gives guidance and signs off on all process integration tool purchase requests. They weigh the big picture of the project, considering overall integration and functionality.

An Advisory Group was formed with research collaborators from industry to ensure that the project is compatible with their future collaborative research needs. This group gives guidance to the project and provides feedback to their organization, including project status and soliciting ideas as to how they can best use this new infrastructure in future collaborations.

There are three foundational elements to a successful technological endeavor: 1) having adequate staffing to accomplish the goal, 2) giving those people the right tools for the job, and 3) having adequate facilities in which to operate those tools. The main thrust of this project is focused on giving the NCPV staff the right tools. However, NREL personnel are also working diligently on the construction of a new building, the Science and Technology Facility, which will provide optimal facilities for an integrated set of tools. Construction is planned to start in February 2005, with the building being ready for occupancy in late fall of 2006.

Finally, the IC industry has learned that the integration of control and data acquisition software is important and time consuming. It is not uncommon that an IC fabrication area spend four times the tool acquisition cost on software integration. Efforts to create “plug and play” integration of manufacturing tools and data are under way and being addressed as a part of this project.

3. Results and Accomplishments

To integrate a diverse tool set takes many people working together, thinking “outside of the box” of their current activities, and coming to consensus on multiple design issues. One of the most difficult decisions was converging on a universal maximum substrate size and shape. 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 6.18 in. X 6.18 in. (157 mm X 157 mm). 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 (e.g., plastics and thin foils). Individual researchers will be able to use platens that accommodate smaller (or multiple smaller) substrates, but must be able to accommodate the maximum size in their tool. The platen itself must be able to withstand 1000ºC; therefore, construction material will likely be molybdenum or Inconel or similar material.

Because of our need to handle a variety of substrate sizes, shapes, and materials, there are no "off-the-shelf" solutions to integrating our tools. Therefore, we had to develop our own set of design criteria for the prototype stand-alone tool with the inter-tool mobile transport pod. This design will be owned by NREL so that it can incorporate it into future tool designs. A contract was recently awarded to Transfer Engineering of Fremont, California (a vacuum design company) to develop detailed engineering drawings for the prototype process-integration tool. Once the design is accepted, a separate RFQ will be prepared for the fabrication of the prototype tool.

As we work with Transfer Engineering on the prototype stand-alone tool, we are working on specifying the requirements for the intra-tool transport platform and the techniques it will integrate within the cluster tool. Similarly, we are gathering information about the technical requirements of future techniques to integrate.

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. In the next few years, we will have significantly improved the tool base for collaborative research within the Solar Energy Technologies Program[2].

REFERENCES

[1] DOE Photovoltaics Technology Plan 2003-2007; September 2003. Report No.: DOE/GO-102003-1491.

[2] Nelson BP, Robbins S, Sheldon P. The National Center for Photovoltaics Process Integration Project. In: Sopori B, editor. 14th Workshop on Crystalline Silicon Solar Cells and Modules: Materials and Processes; 2004; Winter Park, Colorado: NREL; 2004, Report No. NREL/CP-520-36595.

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