Bay Area Photovoltaic Consortium

Photovoltaic Manufacturing Technology Research

Request for Proposals (RFP)

Advancing BAPVC Technology to the Next Level

Issue Date: June 17, 2014
Responses Due: July 25, 2014

1. Solicitation Purpose

This Request for Proposals aims to fund additional research to support BAPVC's core technologies either by increasing the level-of-effort or duration of existing projects or by funding new projects addressing topics needed to accelerate progress of the existing technologies toward industrial adoption.

2. Introduction to Bay Area Photovoltaic Consortium (BAPVC)

BAPVC develops and tests innovative new materials, device structures, and fabrication processes necessary to produce cost-effective PV modules in high volumes. The research aims to find technologies which can increase photovoltaic conversion efficiencies and simultaneously reduce manufacturing cost. Success in research is measured by transfer of the technologies to industry for further development and manufacturing.

BAPVC projects have aggressive goals set to develop disruptive technologies. Such projects frequently present multi-faceted challenges needing collaborative, consortium-sized efforts to advance to the next technology readiness level. BAPVC brings together materials scientists, device engineers, manufacturing specialists and equipment suppliers to capture the revolutionary advantage of our technologies.

BAPVC is a consortium led by Stanford University (SU) and University of California Berkeley (UCB) that is funded by the U.S. Department of Energy, industry members and the participating universities. The consortium provides a vibrant forum for interaction among PV industry and academic experts to address the critical challenges in converting the U.S. leadership in PV R&D into leadership in PV manufacturing. The collective efforts of manufacturing and academic experts working together can spark great innovation. BAPVC conducts industry-relevant research and development that will impact high-volume PV manufacturing, produce a highly trained workforce, and speed up commercialization of cutting-edge PV technologies.

BAPVC research is composed of the following thrusts: 1) High performance and multijunction cells; 2) Silicon absorbers and cells; 3) Thin film absorbers and cells; 4) Photon management and transparent conductors; and, 5) Encapsulation and reliability.

The high performance and multijunction thrust explores new growth processes, material systems, and device architectures offering high device efficiencies at low processing costs. In particular, two parallel approaches are being explored, one relying on reducing the processing costs of III-V single junction solar cells and the other exploring tandem device architectures based on Si bottom cells. The highest performance for single-junction cells, currently at 28.8% efficiency, has been demonstrated in III-Vs. However, their module costs have been estimated by NREL to be currently >10x of those of Si cells. This high cost mainly arises from the initial substrate and epi-growth by the MOCVD process. Thus, BAPVC is developing disruptive growth and processing technologies that will drastically lower the cost without sacrificing the device efficiencies. The second path is exploring tandem cells based on Si (or CIGS, CdTe, or III-V) bottom cells to enhance the efficiency of the existing PV technologies. Cost analysis, device modeling, and experiments are being performed in parallel in a collaborative manner to ensure success.

Silicon-based solar cells are the dominant PV technology today with more than 80% market share. While the Si cost component has been decreasing steadily (from over 40% to 19% over the last decade) it is still a significant cost at the module level. Thinner Si cells can reduce the module cost further and leverage the potential higher efficiency and form factor to reduce balance-of-system costs. In this thrust, the key problems which are being addressed to enable high volume manufacturing of high efficiency Si cells include: 1) Commercially viable manufacturing of thin crystalline Si below 50um; 2) Passivation of thin crystalline Si to meet the high efficiency targets; 3) Absorption of all available light within a reduced absorber volume; and, 4) Metallization and packaging of thin Si cells into lightweight modules.

Thin Film PV technologies have established themselves in commercial markets. As the global market continues to expand, the competitiveness of thin film solutions faces four significant Grand Challenges: (1) increasing efficiency of modules; (2) reducing direct materials costs; (3) reducing capital intensity of manufacturing; and, (4) design and validation for long-term field reliability.

The Photon Management and Transparent Conductors thrust attacks several grand challenges including: 1) develop materials and structures to couple maximum sunlight into the solar cells and to control the above bandgap photon distribution for complete absorption with significantly reduced absorber materials; 2) use photon management to enhance the solar cells parameters including short circuit current and open circuit voltage; 3) Develop low-cost highly transparent (~95%) and low sheet resistance electrodes (<5 ohm/sq) for solar cells with n- and p-type contact capability; and, 4) develop processes to implement the above materials and structures in practical, scalable solar cell manufacturing.

Characterizing the stability and reliability of PV materials, including barrier-films and encapsulants, is necessary not only to design accelerated testing protocols to standardize PV module requirements, but also to provide the fundamentals for the design of improved PV materials and product designs. The encapsulation and reliability thrust attacks these barriers to develop understanding of the coupled thermo-mechanical, electro-chemical, and photo-chemical degradation mechanisms that determine the reliability and operational lifetimes of PV technologies.

3. Objective

This procurement intends to promote greater coordination among BAPVC projects; address cost, performance and reliability goals for each research thrust and project; and, support additional research either by increasing the level-of-effort or duration of existing projects or by addressing topics needed to accelerate progress of the existing technologies toward industrial adoption.

4. Scope of Interest

Successful proposals will offer research to advance BAPVC technologies to a higher technology readiness level by enhancement to existing projects or by focused efforts on a topic supporting the acceleration of progress in the technologies of the existing projects. BAPVC academic and industry members have developed Thrust Area Strategies found at http://bapvc.stanford.edu/ under Our Research/Current Investigations which identify needed research. Specific topics from these documents are listed below.

Successful proposals will offer research that is coordinated with the needs of one or more projects currently participating in the BAPVC. A listing of current projects and links to project reports is found at http://bapvc.stanford.edu/ under Our Research/Current Investigations.

Some example research topics of interest are listed below.

High Performance and Multijunction

- More cost analysis of the explored research projects in collaboration with NREL. Currently 2-3 of the projects within the thrust have had cost analysis discussions with NREL. More projects can follow this path.
- Exploring the device processing and manufacturability of the new III-V growth technologies, such as the thin-film VLS process.
- Exploring surface passivation effects and back-contact reflectors for the new III-V growth technologies, such as the thin-film VLS process.
- Better understanding (experiments and modeling) of the types of defects that their correlation to performance for the new III-V growth technologies, such as the thin-film VLS process.
- Development of high bandgap (III-V, II-VI, perovskite or other) solar cells for performance in tandem devices
- Defect mitigation during silicon cell fabrication, for improved multijunction bottom-cell performance.
- Defect recognition and characterization in high-quality Czochralski silicon for high-efficiency PV devices.
- Light management in tandem and other high performance solar cells.
- Development of tunnel junctions, recombination layers, polymer electrolytes, or other transparent contacts that will enable current matching between silicon solar cells and a high bandgap solar cell.

Silicon Absorbers and Cells

- Processes for thin Si absorber preparation, such as spalling, epi-lift-off, templated growth, etc.
- Fundamental science of crystal growth and bulk defects for low-cost, high-quality ingots
- Methods for nano-texturing on thin Si surfaces, such as colloidal lithography, nano-imprint, etc.
- Improved passivation of thin crystalline Si foils including passivation of nano-textured surfaces
- Printing contacts on thin Si foils, including liquid precursor development

Thin Film PV

- *Theory and Modeling*. Improved collaborative device-modeling resources that, in coordination with materials and device characterization, will inform and guide materials and device development.
- *Materials Chemistry of absorbers*. Improved understanding of defects and grain growth, and their role in metastability, composition, morphology and heterogeneities present both intra-grain and at interfaces and grain boundaries, is critical to advancing device design, process optimization, and performance.
- *Thin Film Device Architecture*. Efforts to optimize heterojunctions, interfaces, transparent conducting layers, carrier-selective contacts, and interconnects are desired. Efforts are also needed to explore means of de-coupling processes, e.g. separating of the "activation" of the absorber layer from intermixing at the CdS/CdTe interface which currently occur simultaneously during the $CdCl_2$ treatment.
- *Device and Materials Stability*. Collaborative research is needed to proactively test innovative device and materials stability under operating conditions (temperature, bias, and light) in order to screen for

commercial viability.

- *Device Reliability*. Evaluation of packaged device reliability under combined thermo-mechanical, electro-chemical, and photo-chemical stresses in combination with commercial or BAPVC-developed encapsulants is needed to quickly identify interface adhesion issues and screen for commercial viability.
- *Low Capital Cost Manufacturing*. An expanded focus on developing new low capital cost processing routes to CdTe and CIGS would help thin film technologies compete with crystalline silicon.

Photon Management and Transparent Conductors

- *Extension.* Thus far, photon management is mainly aimed for enhancement of short circuit current. There are exciting opportunities to explore photon management to reduce photon entropy loss to increase open circuit voltage.
- *Integration.* Integrate photon management together with electrical transport to fully engineer the structure to enhance solar cell efficiency as a whole. In addition, there are significant opportunities to integrate the materials in the transparent conductor projects with the design and modeling efforts in the photon management projects. For example, transparent electrodes may be designed as an efficient structure for light management purposes. Alternatively, one may incorporate advanced optical design to reduce the loss in transparent electrode while maintaining its electrical properties.
- *Manufacturability.* Photon management will only be viable, if it can be implemented in a cost effective way. Study the integration of new photonic structures and transparent electrodes into practical scalable solar cell manufacturing.

Module Reliability, Encapsulation and Barrier Films

- Expansion of current work to characterize, model and predict coupled thermo-mechanical and photo-chemical degradation processes in PV technologies to include electro-chemical processes like those responsible for *potential induced degradation (PID)*.
- *Increased interaction with other thrusts* to support reliability and degradation characterization and modeling with particular interests in emerging perovskite, ultra-thin silicon, CdTe and InP PV, along with transparent conductors.
- Development of *multi-layer thin-film mechanics and degradation models* for cell, interconnect, and encapsulant interfaces in PV module packaging technologies, both cell-based and monolithically-integrated.
- Connecting these models with *detailed transport models* for photons, electrons, phonons, and ions in a hierarchical fashion, in order to predict other failure modes.
- *Analysis and development of a database* of thermo-mechanical, electro-chemical, and photo-chemical degradation properties of materials for benchmarking BAPVC innovations, to guide field testing, and inform computer simulations.
- Refinement and redesign of standardized reliability testing capabilities for the broader BAPVC community, re-designing testing for field exposed samples, and calibration/validation of kinetic degradation models and lifetime prediction procedures using in-service and field-exposed data.

5. Project Funding, Duration and Reporting

Projects will have an end date of June 30, 2016. Investigations led by a single PI intend to support one or two graduate students or a Post Doc under an annual budget of up to $125,000. Projects with multiple-PI teams will be considered at budgets up to $250,000 annually. BAPVC research is funded by U.S. Department of Energy, industry members and the participating universities. Cost sharing is encouraged.

It is anticipated that this procurement will fund more than 20 extensions of existing projects adding 6 to 12 month to the original 3-year period-of-performance. The remaining available funds will support approximately 10 projects for research selected from the list of additional topics shown in the Scope-of-Interest.

Industry interaction is an important element of BAPVC and PIs will be required to participate in Bi-Annual Meetings. These meetings serve to both guide the research and review progress. Project PIs and students will be expected to participate in at least one meeting annually. Projects submit a brief (2-page) Annual Report and a comprehensive Final Report. Each project will also deliver a seminar to industry members using WebEx or similar conferencing facilities.

6. Eligibility

Domestic educational institutions, Lawrence Berkeley National Laboratory (LBNL), National Renewable Energy Laboratory (NREL), and SLAC National Accelerator Laboratory (SLAC) are eligible to apply for funding as a standalone applicant, as the lead organization for a project team, or as a member of a project team. To qualify as a project with multiple-PI team status, the secondary recipients must receive not less than one third of the total proposed funding.

Other entities including for-profit or nonprofit entities, FFRDCs, state or local government entities are not eligible to apply for funding. These entities may participate as a member of a project team, but they cannot receive BAPVC funds.

7. Proposal Format

Proposals must adhere to a rigid format so that key information such as Objectives, Research Task Statements and Milestones can be quickly and simply located for ease of review. Proposals should not exceed five pages including the Summary Slide. Proposals will be entered into a standard template included with this Request for Proposals as attachment A The length of individual topic-sections may be adjusted as needed to best present the project; however, in no case shall the total document exceed the five page limit. The document should be single spaced using the formatting of the templates and a font size no less than 10 points.

Proposed budget information does not require detailed cost development, but should highlight a non-binding estimate of the major features of the anticipated costs including labor, materials, equipment, travel, tuition and miscellaneous categories. Cost sharing is not required, but is encouraged as cash or in-kind support enhances the productivity of the effort. Non-binding commitments for cost share will be considered as a policy factor in the evaluation.

The single cover slide provides a very brief summary of the proposed project and should be delivered in the format shown in Attachment B. Use fonts no smaller than 12 points.

Attachments or appendices to the proposal will not be considered.

8. Evaluation

Proposals submitted in response to this solicitation will be screened for relevance to photovoltaic industry needs by BAPVC Management and then reviewed by technical experts from BAPVC member companies. No more than two Proposals will be accepted from any Principal Investigator for investigations led by a single PI. There is no limitation on number of proposals from multiple-PI teams.

All reviewers will treat all proposal information and materials as confidential in accordance with the BAPVC Non-Disclosure Agreement (NDA) which can be viewed in the Industry Membership Agreement located in the BAPVC site http://bapvc.stanford.edu

Reviewers at all levels will be asked to focus specifically on the extent to which the Proposal addresses the following criteria:

1. Technical Impact:
   a. Industry relevance supported by presentation of data, process descriptions and design factors used to assess potential to scale and to analyze process costs.
   b. Extent of improvement on factors fundamental to module performance, capital equipment cost, throughput, materials consumption or reliability.
   c. Probability of successfully achieving the project objectives and BAPVC goals of transferring the technology to industry within three to five years
2. Technical Merit:
   a. Awareness of the technology status and benchmarks
   b. Soundness of technical approach.
   c. Identification of technical risks or barriers to project success and plan for mitigation.
   d. Clarity of project plan including quantitative, achievable milestones.
3. Coordination with BAPVC Projects:
   a. Discussion of past performance supporting proposed enhancement of existing projects or evidence supporting strength of planned collaborations within BAPVC
   b. Benefit of enhancement or collaboration toward accelerating progress of the existing technologies toward industrial adoption

9. Proposal Selection

The BAPVC management will evaluate the recommendations from the industry review and factors impacting achievement of the objectives of this procurement in order to select projects for award. The BAPVC Executive Board will review the evaluation and approve the portfolio of proposals for award.

In the event that a project is selected for award, Stanford University will request a complete proposal and cost estimate to initiate negotiations for award. The educational institution must execute the BAPVC Membership Agreement for Research Members that describes plans for management of intellectual property and consortium operations. This agreement can be viewed in the BAPVC site http://bapvc.stanford.edu. Negotiation of the Sub-Award agreement will also require completion of U.S. Department of Energy forms including SF424A budget summary, PMC123.1 budget justification, justification of indirect rates, and NEPA EF-1.

10. Submission Procedure:

Submit proposals by e-mail to jpbenner@stanford.edu with copy to npacheco@stanford.edu. Confirmation of receipt will be delivered by e-mail reply.

Questions should be addressed to jpbenner@stanford.edu. Responses, if deemed appropriate, will be posted to the BAPVC web site with the question and distributed to all known potential respondents by e-mail.

Attachments

A. Proposal Template

B. Summary Slide Template