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The DOE Fundamental and Exploratory Research Program in Photovoltaics

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The DOE Fundamental and Exploratory Research Program in Photovoltaics

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ABSTRACT

This paper presents an overview of the Fundamental and Exploratory Research project within the U.S. Department of Energy's National Center for Photovoltaics (NCPV). The idea behind the project is to identify, support, evaluate and coordinate an optimal spectrum of complementary projects that either contribute to the fundamental understanding of existing PV technologies or to explore the less conventional, or far out, technological possibilities. Two other programs, one for close collaborative university/industry partnerships in crystalline silicon and an educational/research program involving undergraduates at eight historically black colleges and universities, are also managed under this same task. In sum, this effort represents directed high-risk, long-term basic research targeting possibilities for optimal configurations of low cost, high efficiency, and reliability in PV related devices whatever form they may ultimately take.

1. Introduction

In response to the need to explore all possibilities for the timely deployment of renewable energy technologies (RETs), whether they be within existent developing PV technologies or outside of the current array of solar electric technologies (SETs), there were three different projects initiated during the last two years; namely, the Future Generation, Beyond-the-Horizon, and Crystalline Silicon University Research initiatives.

2. Future Generation Project

Initiated in mid-'99, the Future Generation (FG) PV Technologies Project resulted from a consensus at an international meeting to review the potential viability of existing PV technologies and any research that might "leap frog" current technologies into the future. Through a better understanding of current material systems or through the explorations of wholly different SETs, or both, the driving force, the ultimate target, will always be a commercially viable SET. Representing the efforts of 18 different universities this program consists of a variety of investigations.

Specifically, in the III-V area, four universities are investigating different facets of novel growth methods and characterization of nitrogen-containing III-V compounds with the attending possibilities for bandgap engineering and a long-term goal of 40% efficient devices. For example, U.C. San Diego and N.C. State are combining varying N content in GaInNAs and strained superlattices for bandgap engineering for just such high-efficiency solar cells. A collaboration between U.C. Santa Barbara (MOCVD and MBE growth of GaInAsN) and Harvard (spectroscopic investigations of the subsurface interface electronic structure by ballistic-electron-emission microscopy) has shown increased understanding of band structure through good correlation between band structure and experiment at layer interfaces.

In amorphous silicon (a-Si) five universities are working on understanding the debilitating Staebler-Wronski effect via new characterization techniques and material studies. Using fluctuation transmission electron microscopy, the medium-range order, stability, and light-induced changes in long-range disorder in a-Si grown is under investigation at the U. of Ill.-Urbana. Washington State U. has developed two sophisticated, complementary characterization techniques and has applied them to the same a-Si samples. One technique, femtosecond spectroscopy, characterizes the ultrafast carrier dynamics occurring in a-Si in its transition from amorphous to microcrystalline Si and the other, positron annihilation spectroscopy, is used to characterize corresponding defect states. In another project, Cornell utilizes their unique double-paddle oscillator characterization technique to examine the intrinsic elastic properties of a-Si as yet another signature of the physics of the a-Si material under different growth and treatment conditions. And, using yet another different approach, the U. of Minnesota is coming to understand the light-induced changes in long-range disorder in a-Si by correlating the material's 1/f noise properties and its non-Gaussian statistics as a function of temperature.

In the study of crystalline Si itself, low-temperature, high-throughput processes for thin, large-grained Si using hot-wire chemical vapor deposition and modeling of the corresponding processes involved are being pursued at Cal Tech. In porous-Si studies, the U. of Rochester has already created a quite effective AR coating/textured surface for Si that is of interest to industry.

Exercises in the realm of less conventional material systems include the successful development of unique nanocrystalline composites at U.C. Berkeley. Nanocrystalline-based biomimetic solar electric devices that mimic nature's processes are under investigation at Vanderbilt University, while nanostructure arrays for potentially cost-effective multijunction solar cells are under development at West Virginia U., with already unanticipated spin-off applications. The aim here is to use low-cost organic materials while still having viable conversion efficiency. Another project that is both scientifically and commercially significant is the variety of p-type transparent conductive oxide (TCO) films produced at Northwestern via their NREL contract. On a different note work in the modeling of chemical reactions in PV module encapsulants and their devices is ongoing at Penn State as a topic with a very practical bearing on the devices as deployed.

In addition to the five cases already mentioned, the simultaneous ongoing development of measurement/ characterization techniques and their application is occurring on other fronts as well. One example is also at Penn State where they produce proto-crystalline Si (i.e., thin films containing areas of both of a-Si and nano-cystallites on the verge of crystallizing) with real-time monitoring of the optical properties, via ellipsometry and modeling. Synchrotron radiation studies of PV device interfaces, most notably of CdTe, have been carried out at SUNY-Buffalo. On a macro-scale, both a novel sequential mono-layering CIGS growth technique and an equally novel capacitance characterization technique to characterize these CIGS devices have evolved at Oregon U. in a joint effort between its chemistry and the physics departments. Finally, standards for these emerging technologies are under development at Arizona State.

3. Beyond the Horizon Project

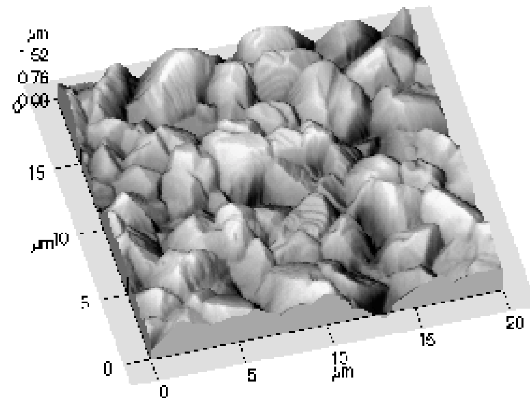
In mid-2002 and, to some degree, a variation and extension of the Future Generation project, was an initiative entitled Beyond-the-Horizon. The idea was to research possible materials, devices, and characterization techniques that might serve to ultimately go significantly beyond existing technologies that presently exist “beyond the horizon” of our current understanding and that may hold the key to our ultimate goal of 60% efficient / $ 0.50 / watt devices. Involving 11 universities and 5 companies, the ambition is to explore as much of this uncharted territory of possible as budget permits with the purpose of producing a new generation of SETs.. Alternatively, another goal is to provide the experimental and theoretical underpinnings for advances within existing technologies. Of the 16 awards, some examples are: liquid-crystal-based solar cells (Arizona), polymer solar cells (U.C. Santa Cruz), novel group IV solar cells (Iowa State), tandem organic solar cells (Princeton), molecular solar cells (Johns Hopkins), nanoscale silicon solar cell design (Iowa State), nonvacuum CIGS processing (Unisun) and low-temperature CIGS deposition (U. Ill.), a one-year optical rectenna solar cell feasibility study (ITN), nanoscale characterization of GaInNAs (Michigan), and a solid-state electrolyte for dye-sensitized solar cells (Dupont). The project just now beginning, we do not know how the games will turn out but we do know we have good players.

4. Crystalline Silicon University Research Project

Third, and also recently released, are awards for the Crystalline Silicon University Research Program. This effort brings seven universities and a number of crystalline silicon companies into a number of collaborations focused on increasing efficiency and reliability and lowering costs in the manufacturing environment. Emphases include screen-printed metallization, techniques for hydrogenation, handling of thin wafers, neutralizing bad areas, and developing new emitter technologies. We expect the collaborations to be very fruitful.

5. Historically Black Colleges and Universities (HBCU) Project

The HBCU project involves eight different universities where undergraduates participate in a number of PV experiments and research as well as summer internships at NREL. One purpose is to bring the students into the PV research community over time. A recent example is that of an undergraduate summer intern's published study of the effect of higher deposition temperatures on CdTe growth using atomic force microscopy (Fig. 1 below).



6. Conclusion

Overall, the program consists of 42 universities and 5 companies working on a wide spectrum of investigations of both existing and futuristic solar electric technologies. Much more than a number of isolated scientific investigations this project consists of directed basic research that is strongly encouraged to work in concert with other investigators, group efforts, and industry wherever possible. The idea is to regard the whole set of projects, the whole program, including all of the activities at NREL, such as the Measurement and Characterization Division, as one large network, one effort.

However, amid all of these efforts one might stand back and inquire why even have a fundamental and exploratory research program at this point? The answer is that it would be very imprudent to assume that our current menu of solar electricity technologies is anywhere near final. It is reasonable to assume that we may well yet find anything from a few to a number of new and exciting technologies both in the near term and out “beyond the horizon.”—that is, way out there. Clearly the most efficient access to, and development and subsequent deployment of, such technologies is a program specifically focused on pursuing just these possibilities as vigorously and as soon as possible and with funding commensurate with the pivotal role that basic research plays in the birth of a complex technology. Why, then, should it be largely university based?, it might be asked. Because our universities easily represent our greatest repository of scientific knowledge and innovation. The birthplace of bold new dreams, new thinking, new energy, and the next generation of technologists, our universities have been, and in all likelihood will continue to be, key to reaching our objectives. A number of the cases in this program represent high risk, long-term research but are also clearly worth investigating.