NREL Hot-Wire Amorphous Silicon Deposition

R&D Partner

US DOE NREL THIN FILM PV PARTNERSHIP

The largest future (beyond 2000) growth in photovoltaic (PV) production capacity is likely to be in new thin-film devices—those with active regions less than the thickness of a human hair. Crystalline and polycrystalline silicon solar cell modules now sell for about $4 per peak watt ($W_p$). Future thin-film technologies are projected to cost less than $1 W_p. Achieving these prices would give a tremendous boost to sales of PV devices. Amorphous silicon (a-Si) has much appeal for several reasons. First, there is an established a-Si-industry that commands more than 5% of the PV market. Substantial production capacity increases (715 megawatt [MW]) are now in place and others are planned. This industry has achieved an exceptionally high manufacturing yield. Second, scale-up to large-area modules has already been demonstrated, with 4-ft^2 monolithic solar cells on steel substrates and 12.5-ft^2 cells on glass substrates. Finally, there is potential for improvement: theoretical efficiencies can surpass 15%. But achieving this potential efficiency is a difficult challenge and would require using the maximum fraction of the solar spectrum. To this end, tandem or triple cells (cells stacked one on top of the other) must be used, with the top and bottom cells usually incorporating alloy materials such as amorphous silicon carbide (a-Si:C) and amorphous silicon germanium (a-Si:Ge), respectively.

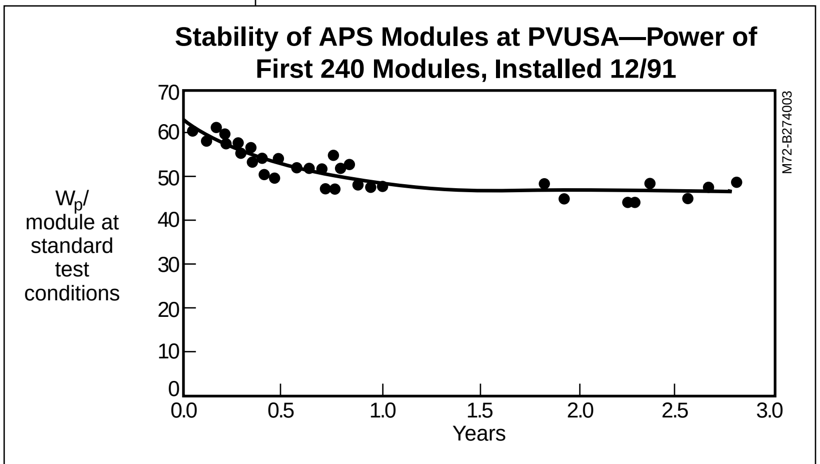

Figure 1. Amorphous silicon (a-Si) cells made with the conventional radio-frequency glow-discharge (GD) technique suffer from an initial degradation when exposed to light. The degradation is about 20%–40%. After the initial period of loss, the a-Si devices then stabilize. The hot-wire (HW) technique was invented to prevent this serious loss of initial efficiency.

A leader in a-Si technology—United Solar Systems Corporation of Troy, Michigan—has built a 5-MW manufacturing plant in Troy. In addition, Amoco's Solarex thin-film division, a pioneer in a-Si technology, established a joint venture with Enron Corporation of Houston, Texas, the largest U.S. natural gas producer. The new company, Amoco/Enron Solar, is building a 10-MW thin-film PV-module manufacturing facility expected to be operational in 1997.

However, the a-Si material produced today has two limitations. First, it suffers from a light-induced degradation mechanism that limits its ultimate efficiency. This degradation results in about a 20%–40% initial loss of efficiency followed by outdoor stabilization (see Figure 1). Second, the quality of the present alloy materials is inferior to that needed. Because of these two limitations, manufacturers resort to compromises that reduce cell and module efficiencies, with the result that the best stable module efficiency is 10.2% and the best stable cell is 12.1%. Although these numbers represent a significant advancement in the past few years, it is generally believed that new approaches are needed to achieve more ambitious long-term goals above 15%.

One approach lies with the efforts of the U.S. Department of Energy (DOE's) a-Si:H research program. For the past several years, industry has participated in the NREL-funded Thin-Film Partnership Program teams and has had a significant impact on the direction of the DOE-sponsored research. In addition to needing support for near-term goals, the industry participants have continually emphasized the need for innovative research to achieve the long-term goal of 15% for the efficiency of stable modules. Most of the industry presently uses the glow-discharge (GD) deposition process, which is analogous to a fluorescent light in that a strong electric field produces a charged plasma to decompose the source gases. However, the properties of films deposited by this technique (both a-Si and a-Si alloys) are inferior to those needed. As a result, studies of novel deposition techniques have become a high priority in the teaming effort.

One of the most promising of the new techniques is the hot-wire (HW) deposition technique (Figure 2). This technique, patented by an NREL researcher and a university researcher, has been under study for only the last few years, but it promises to be a significant step forward in the field. The HW process can be thought of as using a bright tungsten light-bulb filament to decompose the source gases. When a gas such as silane is physisorbed onto the hot tungsten wire, it decomposes into its atomic species. Because of the wire's high temperature, these species are then reevaporated, and make their way to the

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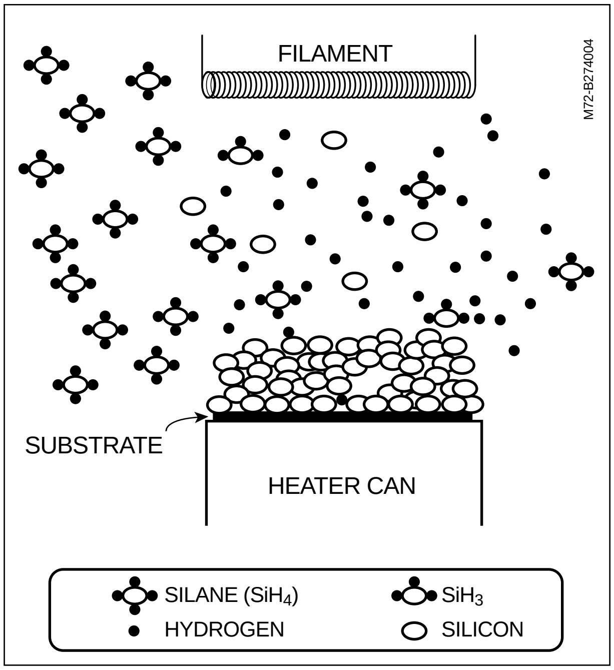

Figure 2. The HW technique uses a simple approach analogous to the hot filament in an incandescent light bulb. The hot filament breaks down the molecules of silane gas into usable silicon atoms that are deposited on the PV cell substrate to make a-Si.

substrate, forming the active solar-cell material, which is an alloy of silicon and hydrogen. This process works for other source gases (a-Si alloys) as well.

Technical Highlights

NREL researchers have demonstrated that the resulting HW material degrades significantly less than the corresponding material produced by the GD technique. More importantly, NREL studies of solar cells—in cooperation with United Solar, one of the largest industry partners—have demonstrated that the improved stability of the HW material is also observed in solar cells (Figure 3). If the HW method is eventually proven to be capable of depositing stable, high-efficiency a-Si devices, it may be considered an important step forward in the history of PV. As we attempt to verify and improve upon this result by fabricating high-efficiency solar cells, NREL will continue to work with industry to ensure that the full potential of these new materials is realized.

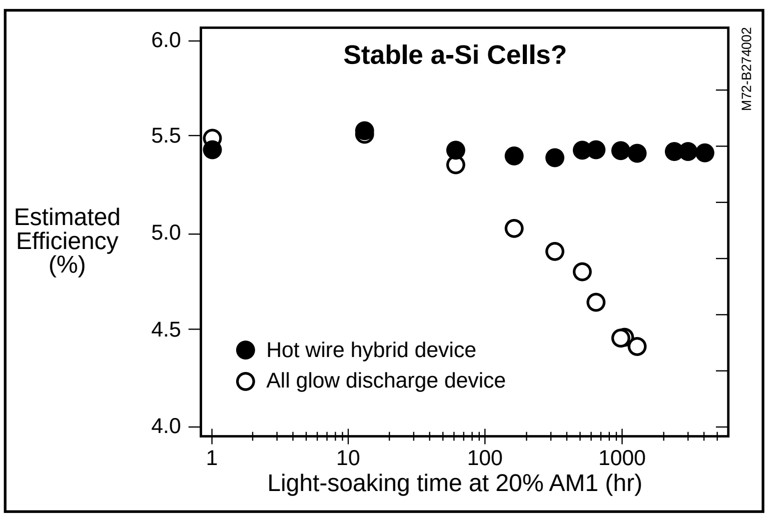

Figure 3. NREL has made and tested early HW, a-Si PV cells with very promising stability results. The figure shows a comparison between an HW cell and a GD cell control. As expected, the GD cell degraded with exposure to light. The HW cell, though, showed no degradation. This was an early design based on a palladium top-contact that allows less light (20%) to reach the active layers. However, even at the lower light level, the GD cell degraded, whereas the HW cell did not.

There are several advantages to the HW process: (1) The design is simple and easy to scale up. Many wires can be placed in parallel to enable deposition over large areas. (2) Because of a high growth rate for stable HW material, the time to grow a device is reduced nearly tenfold over that for the best GD material. (3) The HW process has a very high source-gas utilization, which is important when considering costly materials such as germanium. And (4) the HW technique has already demonstrated a-SiGe alloys with transport properties superior to those deposited by the standard GD technique.

Future Directions

Because of the initial success with HW device stability, work is proceeding to incorporate HW material into devices exhibiting higher efficiencies. In addition, new directions incorporating HW-deposited a-SiGe alloys in devices will be tried. While continued experimentation has reconfirmed many unique properties of this material, the incorporation into high-efficiency solar cells remains a challenge. High-deposition-rate microcrystalline and polycrystalline material, and low-temperature expitaxial layers, can also be made by HW deposition and can be attempted in the next generation of solar cells. These activities will be performed in close collaboration with the U.S. a-Si industry through the Thin-Film Partnership team structure. When and if the HW technique can be used to make high-efficiency (>10%) stable cells, NREL will work with U.S. industry to ensure that U.S. PV companies can use the knowledge and techniques to catalyze a major advancement in a-Si commercialization.

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