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DYE SENSITIZED TITANIA PHOTOVOLTAIC CELLS ON FLEXIBLE SUBSTRATES—CONCEPT TO COMMERCIALIZATION

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ABSTRACT

Methods have been found for sintering titania nanoparticles at low temperature, e.g., <150°C, and for rapid sensitization of the sintered particles. This discovery means that dye-sensitized, titania solar cells can be made on flexible substrates, such as poly(ethylene terephthalate), in a continuous roll-to-roll manufacturing process. The ability to produce solar cells in a continuous fashion should substantially lower the cost of the cells compared to batch processed, on-glass cells. The combined attributes of spectral sensitivity, flexibility, light weight, impact resistance and low cost should find utility a variety of handheld appliances in both indoor and outdoor situations. In its most advanced state of development, this technology would find application in off-grid power generation and thus provide the opportunity of bringing solar generated electricity to rural areas of the world.

Key Words: Dye sensitized photovoltaic cells; Solar cells, Titania nanoparticles; Low temperature sintering

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INTRODUCTION

Over ten years ago, Graetzel and O'Regan demonstrated the utility of dye sensitized titania in solar energy conversion, but their sintering conditions require heating the titania nanoparticles to 450°C for several hours.[1] These conditions require that glass substrates be used as the substrates in a batch processing operation. The plates, being previously patterned and coated with a transparent semi-conductor such as indium-tin oxide (ITO), are then coated and patterned by silk screening, for example, with a suspension of titania. The plates must then be placed in an oven and heated to temperature for several hours to affect sintering of the nanoparticles. After sintering, in order to avoid breakage, the plates must be cooled slowly for several hours before applying the sensitizing dye. Sensitization is followed sequentially by the application of an electrolyte (potassium iodide/iodine), the application of an adhesive/sealant and lamination of a patterned counter electrode, the substrate for which may be either glass or plastic. The fact that sintering is an extremely slow process and, in addition, breakage significantly decreases manufacturing yields, in analogy to batch processed, glass liquid crystal displays, the cost of dye-sensitized solar modules will be fairly high.

In 2000 Sukant Tripathy began the process of creating a company based on the successful demonstration of low temperature sintering of titania nanoparticles and their use in a photovoltaic cells.[2] This discovery offers the potential of low cost manufacturing of solar modules for the first time. His primary goal was the creation of a company whose products would have a beneficial impact on people in third world countries where electricity is a scarce commodity. At his memorial service in January, 2001, at the University of Massachusetts, Lowell, his wife Susan suggested to all those in attendance that the greatest honor they could afford Sukant would be to keep his dream alive by continuing to develop the technology and to create the company that he had been working toward at the time of his death in December. His colleagues and friends took up this challenge by making this company a reality.

In the Spring of 2000, H. Berke became the Chief Executive Officer, P. Wormser was named the President/Chief Operating Officer, and a commitment to provide ''seed funding'' was made by Zero Stage Capital. A Board of Directors was formed which included Berke, Wormser, B. Stevens (Zero Stage), and A. Heeger (Nobel Laureate in Chemistry, 2000) a long time friend of Sukant's. Last July, the Company, Konarka Technologies, Inc., began operations with 5 employees, three of whom are co-inventors of the low temperature sintering technology and co-founders, namely, S. Balasubaramanian, K. G. Chittibabu, and L. Li, the CEO and the President.[3] In August, the Vice President of Research and Development (RG) was hired, and by December Konarka had grown to 16 full-time members. Over the four month period from August to December, many additional discoveries in sintering, sensitizing, and electrolytes were made which led to new intellectual property, and due to significant technological advances in patterning and assembly, the Company is on a path to full-scale manufacturing of solar modules.[4]

In this paper I will highlight the progress that has been made at Konarka Technologies toward the commercialization of dye sensitized solar cells.

DISCUSSION

The worldwide photovoltaic market has experienced 30% growth every year for the past several years; Japan and Europe represent the largest proportion of that growth with the US market showing modest gains (Fig. 1). Unfortunately, all of the third world countries combined represent a very small percentage of total worldwide usage of solar energy, and growth has been very slow in spite of the fact that, currently, 30 billion people have no electricity.

Typically when one thinks of solar power the most obvious and familiar use is architectural, examples of which are windows and rooftops of office buildings and homes. These are large surfaces that can generate a significant amount of power and can be used to supplement grid power. The high rate of growth eluded to above combined with large area deployment represents a significant opportunity for companies that are able to supply solar cells which embody performance, convenience of installation and maintenance at low cost.

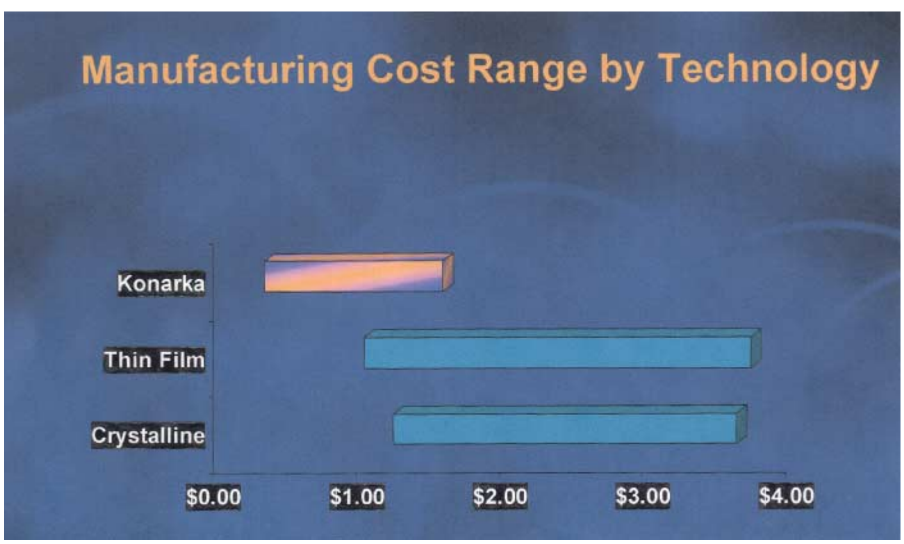

Figure 1. Photovoltaic market growth (%) vs. year (Source: PV News, Paul Maycock, editor, February, 2001).

One of the most practical uses for solar power is its application in remote locations where the electric power grid is nonexistent. However, only a small percentage of the worldwide population of off-grid, remote villages currently use solar energy. Where solar modules are available, they are used for running water pumps and small appliances; they are also used for charging batteries for night-time lighting.

Although there are many factors contributing to slow growth and limited distribution of solar power in the third world, two of the most important are the lack of sales and maintenance infrastructures and, even more importantly, the high cost of the solar modules. One path to low cost solar power is a continuous roll-to-roll, high speed coating process that will reduce the cost of the product to levels not attainable by conventional manufacturing processes as currently practiced.

In regard to cost, crystalline silicon, amorphous silicon, cadmium indium sulfide (CIS), and cadmium telluride (CdTe) are all either inherently high cost materials or require complex manufacturing processes which also add to the cost. This is due primarily to the slow processes, i.e., crystal growth for silicon, vacuum deposition for the others, and complex interconnection procedures, by which these materials are converted to solar modules. In addition, when glass plates are used as the substrates, the modules are produced in a batch process, which adds additional process time. When flexible substrates are used, vacuum deposition is the process method of choice, but it is slow due to low coating speeds and long pump down time. In addition, since high temperature is required for evaporation of the photoactive material, the substrate of choice is metal foil, and the finished cell is laminated with a transparent sheet for protection. This makes the cells somewhat stiff, very heavy, thick and fairly expensive.

From a performance standpoint, crystalline silicon is the most efficient (15–20%[5]) and has the most robust of all of the photovoltaic materials. Amorphous silicon, CIS and CdTe exhibit around 5–7% efficiency and have shorter lifetimes. Dye sensitized titania cells (DSSCs), processed at high temperature, exhibit 10–11% efficiency, and have stability at least as good as a-silicon, CIS and CdTe.

For DSSCs, the materials are inexpensive and readily available, with the exception of the sensitizing dye itself which is required only in extremely small quantities, and the assembly is done at atmospheric pressure–both contribute to lowering the cost. On the other hand, the cells are assembled in a series of spin coating operations which requires batch processing. Furthermore, the titania must be sintered at high temperature (450°C) for several hours which is the major drawback to realizing low cost processing. This high temperature requires that the cells be made on glass plates or metal foils further increasing costs. In the final analysis, manufacturing costs of high temperature DSSCs should be lower than the other technologies but not significantly lower.

Manufacturing processes which truly represent significant cost savings will only be realized when high speed, roll-to-roll coating operations are devised. This requires low cost, flexible polymer film, and therefore rapid, low temperature deposition techniques for titania. The research group at the University of Massachusetts (Lowell), directed by Sukant Tripathy, discovered a means of interconnecting titania nanoparticles at low temperature by heating a suspension of titania and titanium alkoxide to 150°C for an hour.[2] More recently, this process has been modified by Konarka so that the coated suspension on ITO/PET film base requires heating to 110°C for less than one min.[6] Furthermore, the dye sensitization step has been reduced from 30 min or more to less than 30 sec. Utilizing these new developments and subsequent discoveries regarding electrolyte formulations, new dyes and dye additives, and additional process improvements, the estimated cost per watt of Konarka's initial products should be as low as the lowest estimated costs for amorphous and crystalline silicon, and at high speed, full scale manufacturing the cost should be as low as \$0.5/W (Fig. 2).

Utilizing the current best processes developed in our laboratories, the efficiency of photovoltaic cells (area $= 0.5\,cm^2$ at AM 1.5) is constantly >5%. Over the next several months the research and process development teams will attempt to understand the factors affecting cell performance, create solutions to enhance performance, and modify and optimize existing procedures so that the goal of 7–8% cell efficiency is realized.

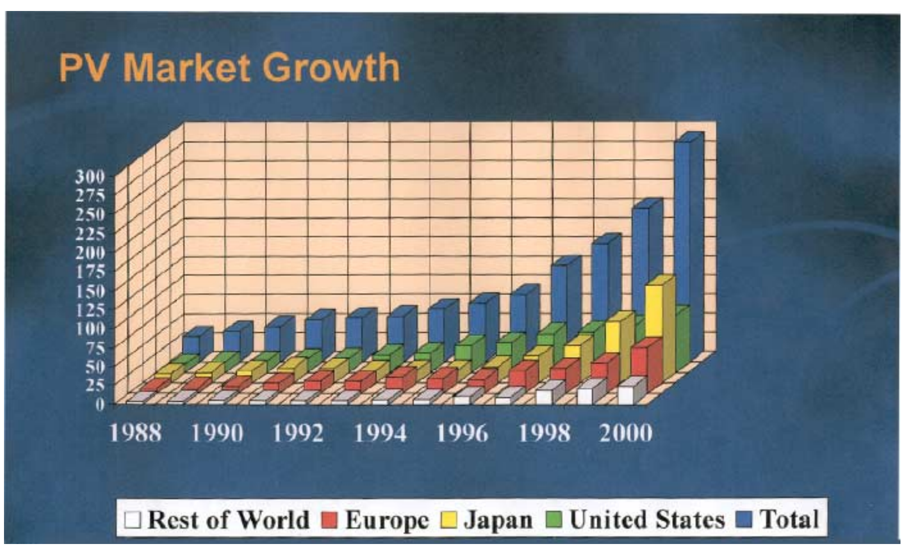

Figure 2. Estimated and actual manufacturing costs for crystalline silicon, thin film technologies (A. D. Little for 2010) and Konarka's roll-to-roll process.

For a detailed description of the Dyed Titania Solar Cell, and related photoelectochemical cell technology, the reader is directed to numerous review articles.[7] Konarka's technology will be described in detail in forthcoming publications.

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