Comment

Cost reduction in the solar industry

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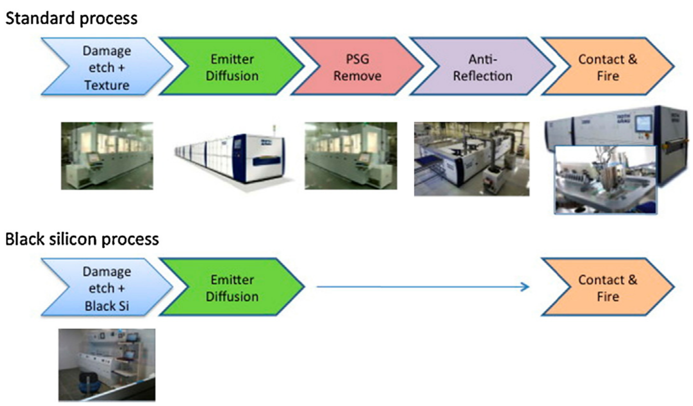
Andrew Barron discusses new processes as a route to attaining cost reduction targets for photovoltaic manufacturing



Schematic of the process flow for a traditional SiNx based AR coated Si cell and a b-Si equivalent.

For solar energy to become cost-competitive with energy derived from fossil fuels, we must either increase their efficiency or significantly reduce the cost of manufacture. In other words we need to consider the cost/kW hour as we do with coal, oil, gas, and nuclear power, rather than just quantum efficiency under ideal laboratory conditions. One area that has been focused on with regard to reduced manufacturing costs is to move away from silicon photovoltaic (PV) technologies to thin film (e.g., CIGS, CdTe) and 'third generation' solar (e.g., DSSC, OPV) devices [1]. While it is clear that these will remain intensely researched PV technologies, the infrastructure of the solar industry remains irrefutably based on the production of 'first generation' silicon cells. Irrespective of the adoption of potentially disruptive next generation PV manufacturing technologies, with 85–90% of a global PV market share worth ca. $100 billion, Si-based PV will continue as an increasingly prolific component of the World's energy security [2]. Government tariff incentives and low prices for PV have accelerated demand in China and the USA, while similar drivers across Europe and industry overcapacity have seen prices for Si solar modules drop to around $1 per watt without undue negative impact on manufacturers' operating margins. Advances in wafer, cell and module manufacturing, lower electrical conversion losses and improvements in cell efficiencies have also driven cost reduction. Despite these advances, both the US and China have a stated goal of further reducing the cost of solar-generated electricity. If we consider the manufacturing process of the cell alone (rather than the panel and the instillation) then there are two areas in which cost reduction could occur: raw materials and consumables or the process steps. It turns out that research into higher cell efficiencies may be the key to reducing the number of process steps and hence manufacturing costs.

A key requirement for an efficient solar cell is a low surface reflectance to maximize the amount of incident photons absorbed by the semiconductor to convert the incident light into electrical energy. The use of an anti-reflection (AR) coating is used to suppress the reflection of the solar cell surface by forming destructive interference of incident light. The most common AR coating for Si PV is plasma-enhanced chemical vapor deposition (PECVD) silicon nitride (SiN_x), which has a reflectance of about 2% as compared to 40% for a polished silicon wafer. Since their functionality is based on a quarter-wavelength coating, traditional AR

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layers are limited in use because reduction of the reflection occurs for only a narrow range of light wavelength and incident angle.

A potential replacement for the conventional AR coating, so-called ''black silicon'' (b-Si), was first reported by Jansen et al. [3]. Black silicon is a type of porous silicon whose surface morphology provides a graded refractive index between the silicon surface of the device and air, that results in a low reflectivity (~1%) and a correspondingly high absorption of visible light [4]. Black silicon has been successfully fabricated by several different methods including: laser chemical etching, pulsed electrochemical etching, reactive ion etching, and fast atom beam etching. However, these techniques need either expensive instruments with high energy consumption or complicated fabricating processes, making them unfavorable for industrial applications. As an alternative, metal-assisted chemical etching (MACE) methods were developed which generally includes two steps: metal deposition and electroless chemical etching. In the metal deposition step, a metal, such as Au, Ag, and Pt is deposited on the Si surface usually as nanoparticles (NPs) [4]. The metal NPs attract electrons from the silicon surface promoting the oxidation to SiO_2 in the presence of an appropriate oxidant. In the electroless chemical etching step, the as-formed SiO_2 is etched away by HF and a pit is produced under each NP. The remaining Si substrate forms b-Si that consists of a highly porous structure.

To further simplify the fabrication process of b-Si, one-step MACE methods based on the two-step method have been developed. However, developing a lower cost alternative metal precursor for the metal-assisted chemical etching method to further cut down the fabrication cost of b-Si is of interest. Cu NPs have been utilized for fabricating porous Si with a two-step Cu-assisted etching method, but instead of the desirable nanopores only shallow pits were formed on the Si surface limiting the effectiveness of the surface as an AR layer. Based upon results with the one-step Ag-catalysed system [4] it appeared that the shallow pit morphology was due to the lack of a component in the etchant solutions to reduce Cu^{2+} ions to Cu^0 and thus increase/maintain the size of the NPs. This is readily overcome by the replacement of H_2O_2 in the typical MACE system with H_3PO_3 as a reducing agent in a $Cu(NO_3)_2/H_3PO_3/HF/H_2O$ system [5]. The result is the formation of b-Si surfaces using low cost chemicals. Furthermore, if a b-Si process is used in combination with the phosphosilicate glass (PSG) films formed during doping to form the active n/p junction within the solar cell, then there is potential for the removal of several steps in the production process.

Figure shows a comparison of the process steps used in present Si cell manufacturing versus those that would be needed for a b-Si functionalized cell. As may be seen the number of steps can be decreased. It is in the removal of multiple steps in the manufacturing process and the associated costs of the chemicals, equipment and energy. Thus, b-Si could eliminate a lot of complexity and significantly reduce costs. Using a detailed, bottom-up manufacturing cost estimating methodology, as used by National Renewable Energy Laboratory (NREL) [6], which takes into account materials, labor and energy costs, an approximate cost for traditional processing (excluding the wafer substrate) can be made of \$0.17/watt. Through the replacement of PSG removal step and the typical SiN_x antireflective coating a cost of \$0.135/watt is estimated. While this difference may sound small it represents approximately 20% cost reduction saving. It is this type of cost saving through the development of new materials processes that offer the best route to grid parity of solar with traditional carbon based energy sources.

Further reading

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