Manufacturing Solar Cells — Assembly & Packaging

The trend in packaging has shown a serious shift: attendance at assembly and packaging conferences has been dwindling over the past few years. At the same time, solar power shows have been celebrated with lots of fanfare, aisles crowded. More and more electronics assembly and packaging companies are appearing at solar expos. The shift is on and there are significant opportunities for electronics engineers in the fast-growing solar business.

Solar cells grew out of the 1839 discovery of the photovoltaic effect by French physicist A. E. Becquerel. However, it was not until 1883 that the first solar cell was built, by Charles Fritts, who coated the semiconductor selenium with an extremely thin layer of gold to form the junctions. The device was only about 1 percent efficient. Subsequently Russian physicist Aleksandr Stoletov built the first solar cell based on the outer photoelectric effect (discovered by Heinrich Hertz earlier in 1887). Albert Einstein explained the photoelectric effect in 1905 for which he received the Nobel Prize in Physics in 1921. Russell Ohl, working on the series of advances that would lead to the transistor, developed and patented the junction semiconductor solar cell in 1946.
Thin film solar cell annealing furnace.

Today's solar cells can be described as the co-existence of three different generations: crystalline silicon, thin film, and dye. Along with the development of solar cells, there has also been a parallel development of solar cell manufacturing technologies. Assembly and packaging engineers have played a significant role in developing these manufacturing techniques, creating incredible potentials in every generation of the solar business.

FIRST GENERATION

Elemental or crystalline silicon is the principal component of most semiconductor devices, most importantly integrated circuits or microchips. Silicon's ability to remain a semiconductor at higher temperatures has made it a highly attractive raw material for solar panels. Silicon's abundance, however, does not ease the challenges of harvesting and processing it into a usable material for microchips and silicon panels. At least three standard manufacturing processes mean that there are technical opportunities for assembly and packaging engineers.

1. Phosphorus diffusion.

There are two main layers that are essential to the solar cell's function. One is a p-type layer, which means that the wafers are boron doped, and an n-type layer created by introducing phosphorus. The silicon wafer usually already starts off by already being doped with boron. In order to form the n-type layer, phosphorus has to be introduced to the wafer at high temperatures of around 870°C for 15-30 minutes in order for it to penetrate into the wafer. The excess n-type material is then chemically removed.

These diffusion processes are usually performed through the use of a batch tube furnace or an in-line continuous furnace. According to BTU, detailed cost of ownership models have shown that in-line diffusion can deliver per wafer costs of as low as one third the cost of a batch diffusion furnace. The basic furnace construction and process are very similar to the process steps used by packaging engineers.

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2. Silicon wafer metallization.

Electrical contacts are formed through squeezing a metal paste through mesh screens to create a metal grid. This metal paste (usually Ag or Al) needs to be dried so that subsequent layers can be screen-printed using the same method. As a last step, the wafer is heated in a continuous firing furnace at temperatures ranging from 780 to 900°C. This completes the metallization process, removes solvent and binder, and forms electrical contacts. Metallization is the most critical step. The challenge of reducing wafer thickness for higher efficiency has created stringent requirements for both the equipment and the process itself.

Si Wafer metallization line

3. Solar module assembly.

Solar module assembly usually involves soldering cells together to produce a 36-cell string (or longer) and laminating it between toughened glass on the top and a polymeric backing sheet on the bottom. Frames are usually applied to allow for mounting in the field, or the laminates may be separately integrated into a mounting system for a specific application such as integration into a building. The basic process is very similar to the SMT process assembly that packaging engineers are already familiar with, albeit on a larger scale. The packaging industry's lean manufacturing methodology can be applied directly to solar module assembly.

SECOND GENERATION

Second generation solar cell, also known as thin-film solar cell (TFSC) or thin-film photovoltaic cell (TFPV), is made by depositing one or more thin layers (thin films) of photovoltaic material on a substrate. The most advanced second-generation thin film materials in use today are amorphous silicon (aSi), cadmium telluride (CdTe), and copper indium gallium selenide (CIGS). The thickness range of such a layer is wide and varies from a few nanometers to tens of micrometers. Is thin-film now the way to go? There are certainly many good reasons for moving to thin films for the solar cell manufacturing process.

1. Thin film deposition.

Copper indium gallium selenide (CIGS) is used for the thin film active layers in CIGS solar cells, commonly formed using sputter deposition. During this vacuum-based process, a plasma of electrons and ions is created from inert argon gas. These ions dislodge atoms from the surface of a crystalline material which is then deposited to form an extremely thin coating on a substrate. Depositing thin film by sputtering is the same process used in semiconductor manufacture and in packaging.

2. Thin film annealing.

After sputtering, the thin film needs to be annealed to achieve optimum results. It is also possible to inject additional chemicals during the annealing process. An annealing furnace is similar to the brazing furnace commonly used in packaging industries. The muffle is typically made of SUS 316L material to ensure good corrosion resistance for the thin film solar panel's corrosive environment. A typical belt furnace can anneal up to 600 x 1200mm (23.6 x 47.2-in.) thin film solar panels after thin film deposition.

Thin film solar cell annealing furnace

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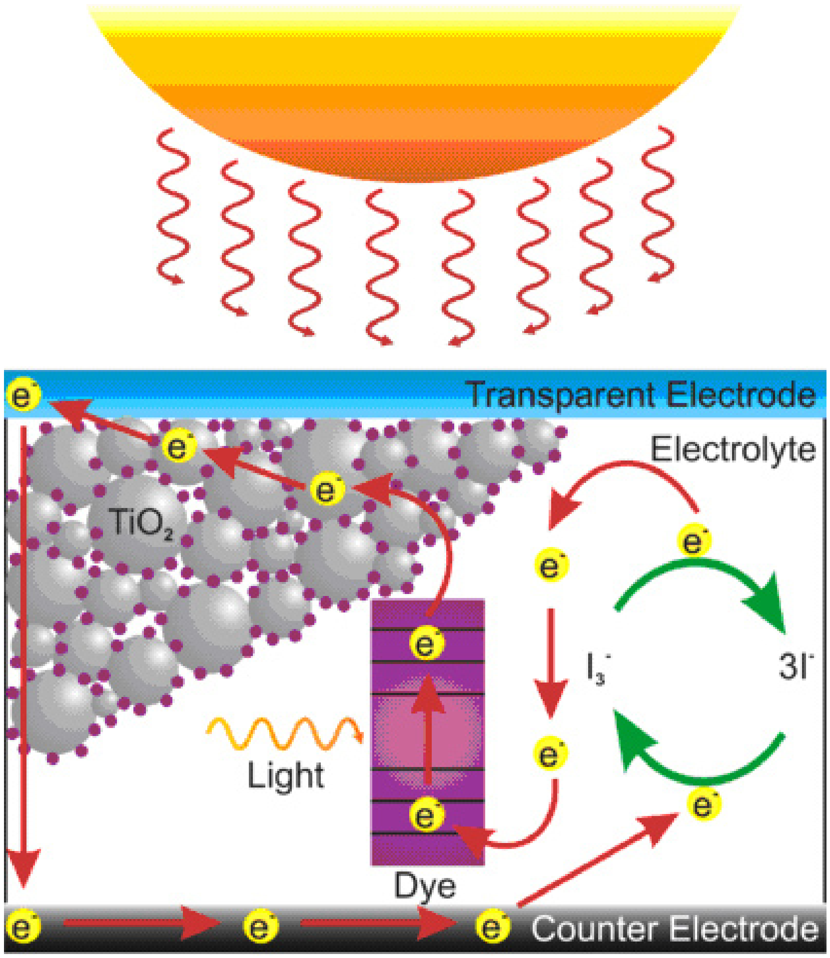
3. Metallization.

Like its first generation cousin, the manufacture of thin film solar cells need Al or Ag screen printing metallization, originally invented for the thick film process. Such metallization pastes or inks can be used on both rigid (glass, silicon) and flexible (polyimide, polyester, stainless steel) substrates. The metallization can be accomplished through either thermal curing or firing.

THIRD GENERATION

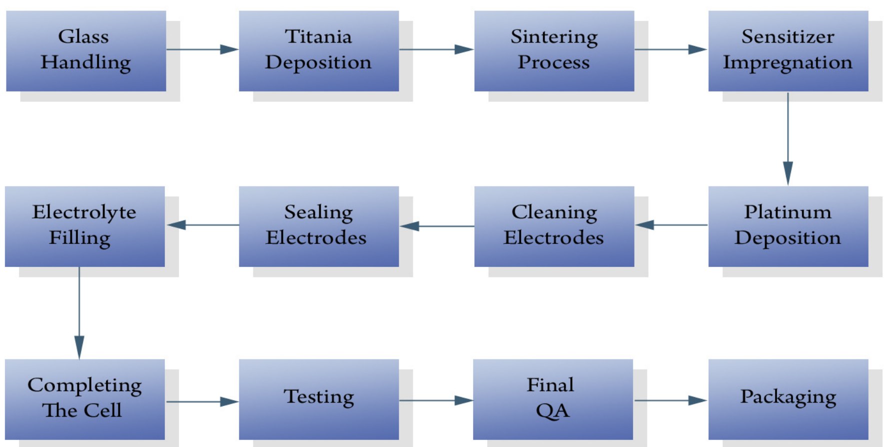
The electrochemical dye solar cell was invented in 1988 by Professor Graetzel of Lausanne Polytechnique, in Switzerland. The "Graetzel" dye cell uses dye molecules adsorbed onto the nanocrystalline oxide semiconductors such as TiO2 to collect sunlight. Dye cells employ relatively inexpensive materials including glass, Titania powder and carbon powder.



Schematic diagram for dye sensitized solar cell

Graetzel's cell is composed of a porous layer of titanium dioxide nanoparticles, covered with a molecular dye that absorbs sunlight, like the chlorophyll does in green leaves. The titanium dioxide is immersed in an electrolyte solution, above which is a platinum-based catalyst. As in a conventional alkaline battery, an anode (the titanium dioxide) and a cathode (the platinum) are placed on either side of a liquid conductor (the electrolyte). Sunlight passes through the cathode and the conductor, and then withdraws electrons from the anode, at the bottom of the cell. These electrons travel through a wire from the anode to the cathode, creating an electrical current.

Dye Sensitized Solar Cell Manufacturing Process Flow



SIMILAR TO SEMICONDUCTORS

The basic dye cell manufacturing steps also resemble the approaches taken by the semiconductor and packaging industry. For example, a screen printer is typically used to apply titania and other layers to the Transparent Conductive Optical (TCG or TCO) glass. Nanocrystalline TiO2 pastes are screen printed onto the TCO glass, then dried and fired in a continuous belt furnace. The sintering process allows the titanium dioxide nanocrystals to partially "melt" together, in order to ensure electrical contact and mechanical adhesion on the glass. All these furnaces are typically modified from standard thick film furnaces.

After dye staining and anode side application of proprietary current collectors, platinum catalyst is obtained by using the Pt-Catalyst T/SP product which can either be squeegee printed or screen-printed using a polyester mesh of 90. The solar cell needs to be dried at 100°C for 10 minutes before being fired at 400°C for 30 minutes. During the assembly, sealing and filling processes, TCO glass with the completed Titania layer is mated to the cathode current collector, protective glass plate, sealed, busbar attached to the cell and then the cell is filled with electrolyte. Custom designed, fully automated and efficient cell assembly, sealing and electrolyte filling machine sets are required for these production steps.

At one time, Torrey Hills Technologies sold in-line continuous furnaces mostly for thick film and brazing applications. Several years ago, in response to the growing demands of the solar manufacturing industry, the company's engineers reinvented the original technology and adjusted it to different types of solar cell processing. A critical step in solar cell manufacturing is metallization through screen printing. By changing the specifications of thick film drying and firing furnaces, the company stepped comfortably into the solar cell market.

Solar technologies have created compelling technical challenges and business opportunities for assembly and packaging engineers. The traditional thick film, thermal treatment and assembly techniques play key roles in solar cell manufacturing. Many skill sets possessed by electronics engineers can be easily reinvented and applied to the solar cell industry.

For more information on belt furnaces and solar cell manufacturing, please go to http://www.beltfurnaces.com for details.