Light Assisted Plating
A Novel Method of Electro-Deposition

Overview:

Light assisted plating, more commonly known as light induced plating (LIP), is a plating method that is unique to the photovoltaics (PV) industry. The LIP method is used to deposit plated metals directly on to the silicon surface of a PV cell. LIP has been in use in plating PV cells since the early 2000's and has only recently been adopted in large scale PV cell production environments.

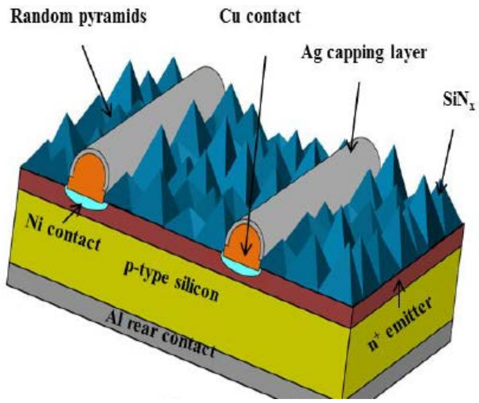
LIP is unique in electro-plating methods in that it utilizes the photovoltaic effect of the solar cell to assist in the deposition of metal onto the surface of the silicon. The photovoltaic effect was discovered in 1839 and is defined as the creation of a voltage or current when a material is exposed to light. As it relates to LIP metallization methods this PV effect greatly improves plating distribution across the cathode (PV cell) surface and enables higher current density plating.

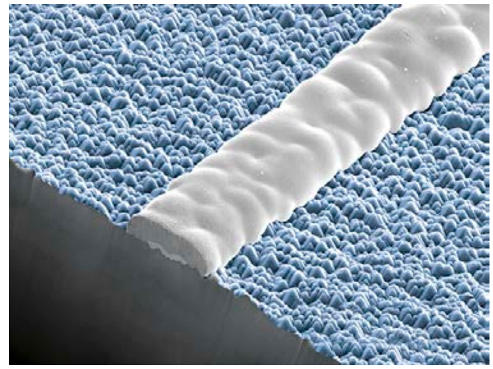
Background:

The vast majority of solar cells made today are made from a raw 156 mm2 silicon wafer that has been sawn from a silicon ingot. The silicon wafer then goes through a series of process steps to form a functional solar cell. Basic steps include surface texture, doping, application of anti-reflective coating, and finally screen printing of metal pastes to form the electrical conductors. Due to inherent limitations with screen printing it is expected that plating methods will replace screen printing metallization processes. Screen printing limitations include surface contact resistance to the silicon surface, high bulk resistivity, poor aspect ratio, and high cost. Screen printing metallization on PV cells is estimated to be approximately 35% to 40% of the overall manufacturing cost of a PV cell.

The LIP process can only be used on one side of the solar cell. The reason it is limited to one side is that a typical solar cell is essentially a p-n diode. This means the generation of the current from the photovoltaic effect travels in one direction in the silicon lattice. When photons (light) are absorbed in the silicon they will excite the electrons in the silicon and allow electrons to become mobile within the silicon semiconductor substrate. This mobility allows for the formation of "holes" where the electron formerly had a covalent bond. This then allows neighboring electrons to move into the holes created and thus results in holes being created throughout the silicon lattice. The back side of a typical solar cell is printed with a full covering of aluminum paste. This back-side layer is call the BSF or back surface field. This back-side surface field helps "push" the electrons generated within the silicon cell toward the opposite side to be collected by the conductors. LIP plating is utilized to form the conductor grid on the front side (sunny side) of the cell. Examples of a typical p-Type silicon solar cell with LIP plating are depicted below in Figure 1.

Figure 1.



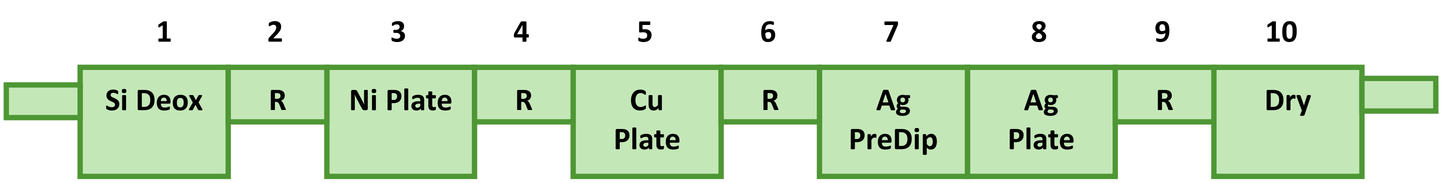


Conductor formation:

Before any plating can begin the underlying silicon must first be exposed. As previously mentioned, there is an anti-reflective layer that is applied to the front surface of the cell. This anti-reflective coating (ARC) is normally a thin layer of silicon nitride (SiNx). This ARC layer reduces surface reflection which allows more photons to enter the cell and ultimately results in higher conversion efficiency of the cell. The SiNx layer is not electrically conductive thus it can be utilized as a plating resist during the LIP plating steps. In this case, a laser is used to ablate the SiNx to form the pattern of the conductor grid and fully expose the silicon. It is important to note that the laser ablation process is critical to the overall success of the LIP plating process. Too much or too little laser energy will result in poor adhesion of the plated metals to the silicon. It is also important to use the proper type of laser to insure complete ablation of the SiNx layer but not induce damage to the silicon surface.

Once the silicon has been exposed and the conductor pattern is formed the cell is now ready for plating. In most PV cell designs a metal stack of nickel, copper, and silver are plated to form the conductor grid pattern. Each metal plays a specific role in overall structure. **Figure 2** depicts the normal process sequence for silicon solar cells that utilize plated conductor formation. It is important to note that in the process depicted below, only the nickel and copper utilize LIP plating technology. The silver plating step is typically an “immersion” or displacement process which does not require electrical contact or light to plate metal on to the surface of the copper.

Figure 2



The first step is to remove any silicon oxides that may have formed on the silicon surface. This pre-clean step is required to ensure good ohmic contact and adhesion of the subsequent nickel plating.

The nickel layer not only acts as the ohmic contact of metal conductor grid to silicon, it also acts as a barrier layer to the copper that is plated on top of the nickel. Under certain conditions copper can migrate into silicon and potentially destroy the p-n junction of the cell so a nickel barrier layer must be used between the silicon and copper. [1] Typical plated nickel thickness is about 1 micron.

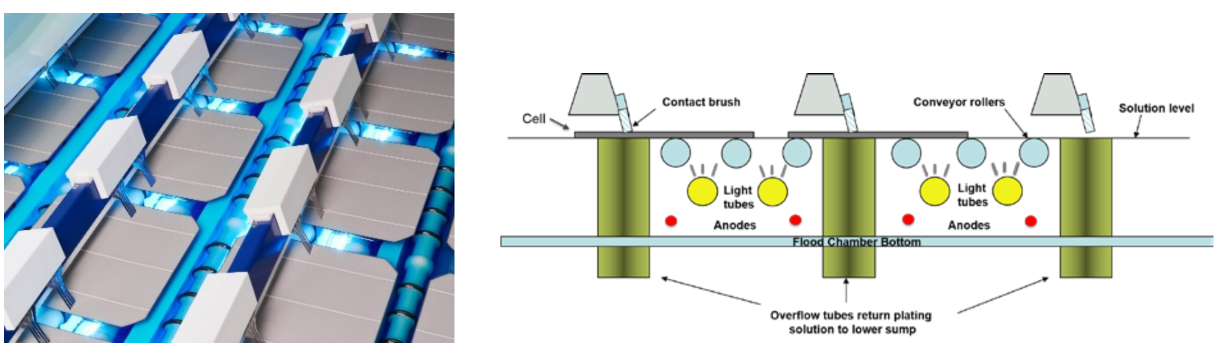
Copper is used as the bulk conductor of the fingers and buss bars that form the PV cell conductor grid. The plated thickness of the copper will vary depending on the number of buss bars used in the cell design. Typically, the more buss bars in the design the lower the plated copper thickness. Copper is the preferred bulk conductor metal because of its low resistivity and low cost.

LIP Plating

As described earlier the LIP process takes advantage of the photovoltaic effect within the cell substrate. To accomplish this, specialized plating equipment that incorporates light emitting sources within the plating tool are utilized. The light sources are typically high output LED tubes or arrays that are submerged in the plating chemistry. The light sources are pointed toward the cathode (PV cell) and are in close proximity to the cathode surface so the cell can absorb the maximum amount of light energy. Depending on the plating tool maker the conveyorized system may transport the cells in a horizontal fashion or in a vertical fashion. **Figure 3** depicts a horizontal LIP plating tool made by RENA GmbH. In this type of tool the cells are conveyed on horizontal rollers through the various plating, rinse, and dry steps. Unique to this plating tool, only the bottom side of the cell is wetted with chemistry and the top side stays dry throughout the plating process. Electrical contact is made via brushes that contact the back side of the cell which does not get plated. Light intensity is a very important aspect to LIP plating since brighter lights will result in more current generated within the cell. Ultimately brighter light enables higher current density plating and reduces the plating tool size.

Wavelength matching between the light sources and the chemistry absorbance wavelength has been researched but has proven to be of little benefit. The idea behind wavelength matching is to use light sources that emit light in a wavelength that has the least loss due to the related absorbance of the plating chemistry. All commercial LIP plating systems currently utilize white light and typical current density for copper plating is in the 20 ASD range.

Figure 3



One unique aspect to LIP plating is that metal content in the plating chemistry is usually run at lower concentrations than is typical in a normal electroplating application. For both nickel and copper LIP plating the metal content is kept at about 20 g/L. This lower metal concentration reduces “light blocking” from the metals in the plating chemistry which reduces the amount of light reaching the cell. All other chemical components such as acid normality, temperature, additive concentrations, and boric acid are maintained at what would be considered normal operating levels in a typical electro-plating system.

One of the main advantages of light assisted plating is the much-improved plating distribution across the surface of the cathode. Since the cathode has a uniform electrical field that is generated internally by the light energizing the cell, the effects of high and low current density variation is dramatically reduced. This is particularly important in the plating of metals directly on silicon since the silicon has inherently high electrical resistance. Without light assisted plating technology, uniform nucleation of metal deposits on the silicon would be problematic and large variations in plating thickness would occur.

Once the metal stack of nickel, copper, and silver have been plated the cells will go through an "annealing" process. This annealing process typically consists of a belt furnace that heats and cools the cells in a controlled manner. The anneal process purpose is to form an intermetallic layer of nickel silicide (NiSi) between the silicon and nickel. This nickel silicide layer performs two functions. First, it improves the contact resistance between the silicon and the nickel and secondly, it improves adhesion between the nickel and the silicon. [2] While some research has shown good results with elimination of the anneal step it is still the industry standard to perform it after plating.

The solar industry is unique compared to many other electronic markets because the product they produce is expected to have a minimum 20 year life span. In order to achieve this high level of reliability it is required that any technology or material change is closely scrutinized and tested to ensure reliability expectations are met. In order to ensure reliability, solar cells utilizing plating technology and LIP in particular have passed all standardized EIS testing for reliability. Testing consists of producing cells using the LIP plating technology, laminating those cells into a full sized modules, then testing the modules using various standardized impact and thermal cycling tests. Module testing is typically conducted at an independent third party laboratory. Modules produced using LIP plating have passed all testing conducted both by cell manufacturers and by many independent research institutes. [3]

While plating solar cell conductor grids has been in practice since the late 1990's there is still a relatively small number of solar cell manufacturers that utilize plating to form the conductor grids on the surface of the solar cell. There are five main types of solar cells produced today and the cell type determines whether plating technology is either required, or is an option to conventional screen printed conductors. Due to various inherent screen printing limitations it is expected that plated conductors on solar cells will continue to grow in market share going forward. [4]

1. Modanese et al "On copper diffusion in silicon measured by glow discharge mass spectrometry"
2. A. Mondon et al "Microstructure analysis of the interface situation and adhesion of thermally formed nickel silicide for plated nickel–copper contacts on silicon solar cells"
3. Bartsch et al "Simple and reliable processes for creating fully plated nickel–copper contacts"
4. 2017 ITRI PV Technology Roadmap page 30