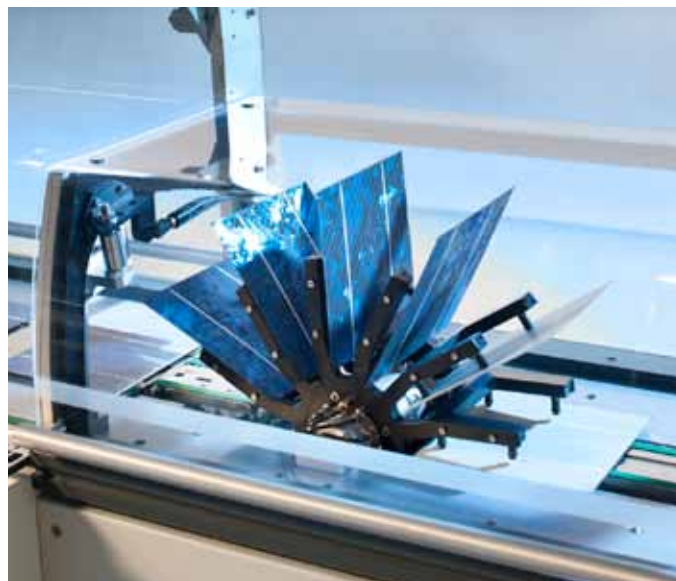


Introducing Print-on-Print to the solar industry



A progressive process that has nevertheless been utilised in other industries for several years, Print-on-Print involves the printing of one conductor grid directly on top of a previously printed and dried grid. PES asked acknowledged pioneers DEK Solar for an in-depth explanation of this revolutionary procedure.

A simple Internet search will reveal that the photovoltaics industry is working hard on higher aspect ratio frontside conductor grids as a route to increased solar cell efficiencies. This is because the silver energy-collecting conductors that are typically screen printed onto the frontside of a silicon-based solar cell actually block out sunlight, effectively stopping it from reaching the energy converting strata below. While it is important that these conductors are optimally distributed across the surface of the cell in order to mop up all the energy available, it is clear that the more surface area they cover, the more they will hinder cell functionality. Which is why the solar industry is putting such a lot of effort into reducing conductor widths. Currently in the region of 80-120 μm , these are expected to drop to 50-60 μm in the immediate future, reducing the shadow effect and improving cell performances considerably, while saving on materials costs.

In doing so, however, cell manufacturers must contend with a simple law of physics, and this is that a conductor's electrical resistance is directly proportional to its cross-sectional area. In other words, as width decreases, height must increase if the conductor is to maintain its current-carrying capacity. And this is where aspect ratio comes into its own. A simple enough equation describing a printed feature's height/width relationship, this metric, and more specifically, high aspect ratio conductors, will become increasingly critical as the solar industry pushes the limits on cell efficiencies.

Giving finer lines more height sounds straightforward enough, but the physical characteristics of printing screens, together with the release properties of standard silver screen printing pastes, effectively put a maximum height on 50-60 μm lines that is insufficient for the industry's needs. Special materials such as high aspect silver pastes have been instrumental in taking the industry

forward, and several deposition methods, described in numerous papers, also show a great deal of potential to do the same. Perhaps one of the most promising of these is a new metallisation process, already in commercial use in some leading cell manufacturers, which could deliver aspect ratios that, at between 0.4 and 0.5, were until now impossible.

Print-on-Print

Print-on-Print (PoP) is not a new idea, indeed, it has been used in other industries for years. Simply put, and as the term suggests, this technique involves the printing of one conductor grid directly on top of a previously-printed and dried grid.

Essentially there are two ways in which this can be done:

Top printing

In this case, the first, or base, print pass creates a grid pattern with relatively high, wide features. The second print, which is lower and narrower, sits directly on top

of, and within this first base print without coming into contact with the silicon wafer.

Encapsulation

Here, the base print pattern is low and narrow, and the second print pass is wider and higher. This top print pattern sits "over" the first, effectively encapsulating it and contacting both the first print pattern and the silicon wafer. This approach differs from Top Printing in that here, the second print has its confines on the wafer rather than on the base print pattern. For this reason, it is thought to create a somewhat finer line, enabling lines to be printed down to widths of just 60-70µm.

As we at DEK know from our experience with the PoP procedure for the semiconductor and biomedical sectors, repeatable accuracy is key in both cases. Primarily because without it, this degree of fine line work would simply be impossible. Furthermore, misalignment can wipe out the advantages of fine line PoP work by increasing line width and therefore increasing the shadow effect. In the Top Printing approach, accuracy is even more of an issue if we consider that the landing area for the second printing pass, which is formed by the base pattern, is extremely limited.

Print quality

Printing onto a printed base pattern is also complicated in terms of gasketing, as DEK's Senior Process Development Specialist Tom Falcon discovered when his team embarked on an in-depth study on the ways in which the efficiency of printed frontside silver conductors could be improved. The results of this ongoing work were first presented by Falcon in Hamburg at the 2009 European Photovoltaic Solar Energy Conference.

One of the many issues that emerged from the study was that, as the aspect ratio of printed features increases, the wire in the printing screens tends to become more obstructive, preventing the paste from properly filling the apertures, and it can even pull paste away from the apertures. This means that as aspect ratio rises, a conductor's height becomes increasingly uneven along its length. This was graphically visible in the team's analysis, which showed that the intervals between the highs and lows in any conductor mirrored the intervals between the knuckles in the screen mesh. The

industry has done a lot to reduce this problem, with today's 20-25µm standard wire diameters contributing to improved aspect ratios and conductor uniformity.

It is also possible to optimise screen emulsion thickness in order to achieve the best paste release properties for a given feature size, and paste manufacturers have done a great deal to improve silver paste formulations for high aspect ratio conductors. This notwithstanding, however, the non-uniformity issue still persists. Not only does this make the conductors less efficient, but it also introduces the significant challenge, when adopting the Top Printing approach, of creating an effective gasket between the printing screen and a very uneven base pattern.

meshes can go without using special but prohibitively expensive materials, especially given that they need to be robust. Screens for standard solar cell manufacture, for example, are typically expected to withstand up to 10,000 passes of a high-speed high-pressure print squeegee without distortion or breakage. And when we talk about distortion, we are talking about micrometers – the brief is to keep the print screen's dimensions, from corner to corner of a 15.6cm wafer, to within a tiny +10 µm!

The challenge becomes particularly clear if we consider how a printing screen is produced. Typically, the screen is made of a piece of woven steel fabric that is stretched and glued to a metal frame, then coated with a layer of photosensitive



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Optimising printing pastes...

A great deal of work is consequently underway by materials and equipment suppliers to improve deposition performance. Paste manufacturers, for example, have developed dedicated pastes for the two separate passes: the base pattern paste is optimised for low contact resistance to the silicon layer, while the top pattern paste is designed for its electrical conductivity. Both pastes can also be optimised for high aspect ratio work.

...and screens

Screen manufacturers, too, have done a great deal to improve printing uniformity, but there is a limit to how far fine wire

emulsion. This is then exposed, through a patterned phototool, to UV radiation that polymerises the exposed emulsion. The remainder stays soluble, and is washed off in water, after which the screen is dried. It may then be put into a cardboard box, flown halfway round the world, and go through substantial temperature changes en route before being fitted to the printer.

It may be handled carelessly, distorting the mesh or even the frame. The mesh wires may move within the screen structure as tension is applied and relaxed. Ambient temperature and humidity will affect the dimensions of the screen and the phototool in real time...

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the list goes on. The upshot is that there is a very real risk the print pattern that is finally fitted to the printer is in some way out of true.

These issues become even more critical when we deal with not one, but two printing screens that must be aligned not only to the silicon wafer, but also to each other. And that's before you even start printing – the wear and tear to which a print screen is exposed during its working life is considerable, and can cause loss of tension in screens, resulting in image stretch.

All of which, together with other challenges in fine line high-aspect ratio work, prompted Falcon's team to develop a new printing screen concept. Presented in Hamburg, this combines the advantages of conventional print screens with those of meshless electroformed stencils and could conceivably be a future solution for high-aspect ratio print patterning.

Repeatable accuracy

Thus the successful implementation of PoP in a high-volume manufacturing environment demands total accuracy. But this alone is not enough. That accuracy must come within the context of an optimised process where the print operations are finely tuned for maximum performance, both individually and in combination, and this must all be repeatable over many thousands of wafers.

Achieving repeatable accuracy requires a wealth of experience in process control and design. Consider for example, the critical issues around wafer handling. Up to a few years ago, wafer thickness was typically in excess of 300-400µm. Then as the solar industry started competing with the semiconductor industry for its limited supply of silicon, efficient ingot use became paramount and we saw wafers come down to 200µm, then 180µm in 2009. Today's standard is even thinner, at 160µm, and some manufacturers are even considering wafers just 120µm thick.

At the same time, wafers have gone from being 100mm² to 125mm², and they are now at an industry standard 156mm². Making the situation even more acute, there has also been a general move away from monocrystalline silicon to more economical, but much more fragile polycrystalline silicon. Add to this today's demands for increased yields,



and a standard industry beat rate of one wafer printed every three seconds and it becomes clear that wafer handling is now a completely different ballgame.

Today's wafers cannot withstand edge contacting, so edge grippers and the practice of driving a cell into a hard stop for alignment are completely out. This means that we can only use sensors and vision-assisted alignment techniques, and the wafer is picked up from the underside or is moved on belts.

As speeds increase, machine stability also becomes more critical. Printing systems are typically equipped with large mechanical parts such as work tables, print heads and handling systems that may go through extensive linear or rotational excursions, thousands of times a day.

As PoP, like many other novel approaches to solar cell metallisation, requires repeated alignment to within just a few microns, it is essential that such masses and their movements are minimised as they may cause the machine to vibrate during printing, compromising print accuracy and quality, or equally damaging, they can over time progressively knock print alignment accuracies out of true.

So the parameters that guide equipment and process design today are repeatable accuracy, speed, throughput and yield, together with the compact equipment footprint that fits with the needs of fast-growing fabrication facilities.

Solutions

This is where companies like DEK Solar come in. With 40 years of expertise in designing and supplying advanced printing technologies for demanding industries like solar, electronics manufacture and the semiconductor sector, DEK has been designing high-speed repeatable accuracy into the heart of its systems for decades. The result is that DEK's printing platforms are rated among the highest in the solar energy industry for process-control capabilities, guaranteeing the repeatable accuracy and print quality that are at the core of state-of-the-art printing techniques like PoP. And this, together with its industry-leading delivery times and world-class service, places DEK as an integral part of the success and long-term growth of its clients worldwide, and of their fast-moving, rapidly-growing global industry. ■

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