Inline processing of crystalline silicon solar cells: the holy grail for large-scale manufacturing?

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ABSTRACT

Lowering the cost of production of solar cells requires higher throughputs and higher production yields for thinner and more fragile silicon wafers, and inline processing could hold the key. However, current processes used in production do not enable full inline processing and often require a substantial amount of handling between process stations as the throughputs per station and tray requirements differ greatly. It will take many years before a full inline process flow is available and if it comes, wafers will most likely be positioned on a single tray throughout all process stations. This paper will discuss the current processing methods for all individual process steps and will provide an outlook on inline processing in view of the three cost reduction strategies: thinner wafers, higher throughput, and higher efficiency cell designs.

Introduction

The solar industry needs to reduce production costs of solar modules by at least a factor of two in the coming years. For silicon wafer-based solar modules, the largest cost savings can come from reducing silicon wafer thickness, since silicon feedstock, crystallization, and wafering make up 50% of the direct manufacturing costs. Large cost savings can also be obtained by upscaling production lines [1]. The challenge is then to obtain high throughput processing while maintaining yields for very fragile wafers and cells. Further cost reductions can be achieved from increasing the efficiencies of solar cells with developments such as the Interdigitated Back Contact cell design (IBC) [2] recently making it to market. These solar cells have design requirements that are more difficult to meet and need more and new process steps, as illustrated in Fig. 1.

Inline processing promises high throughput manufacturing of silicon wafer-based solar cells while maintaining high yields, and has the advantage of minimum wafer handling and a continuous flow of cells through a production line on a belt (Fig. 2). The method involves a continuously running process with wafers flowing through equipment to obtain the specified treatment. During batch processing, the wafers are first placed in a cassette or boat before being loaded into the process chamber (see Fig. 3). All wafers get the required treatment in one position in the equipment, after which all wafers are offloaded. This has the advantage of very dense wafer packing, which reduces space requirements for equipment. However, wafers require substantial handling as they are placed in and out of cassettes, especially when all process stations have different cassettes or boats.

Inline and batch compare to each other in the following qualitative manner:

	Inline process	Batch process
Handling	Minimal	Maximum
Floor space	Large	Minimal
Process time	Short	Long

Deciding whether a process should be batch or inline depends very much on the existing process conditions and requirements. Therefore, solar cell factories will often use a combination of batch and inline processing. The following is a breakdown of processing methods for all individual steps, as well as an insight into the possible cost reduction strategies of producing thinner wafers, achieving higher throughput and developing higher cell efficiencies.

Surface damage removal, texturing, and cleaning by wet processing

The majority of wafers used in the industry are grown in large ingots and separated by wire sawing, both of which are batch processes. During separation, the wafer surface is damaged and covered with small cracks, leading to high recombination

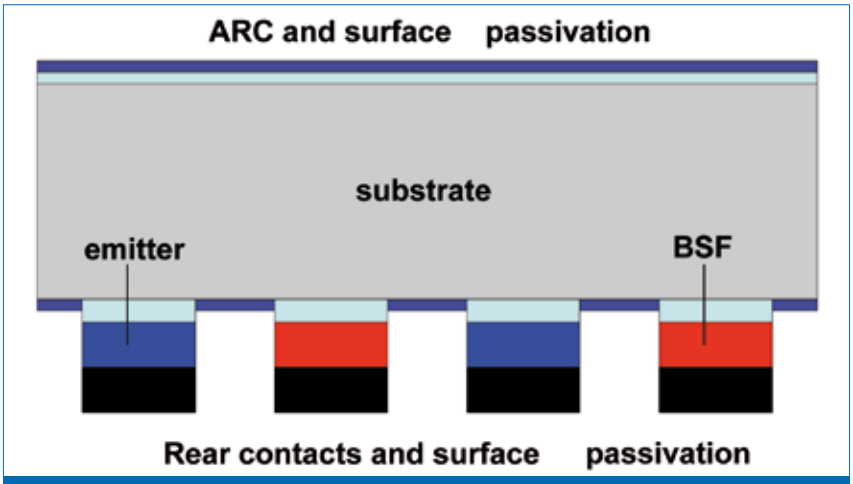

Figure 1. Interdigitated back-contact cell – a high efficiency cell concept.

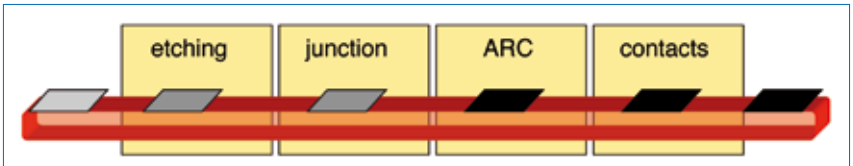

Figure 2. Optimal inline processing from process to process on a moving belt.

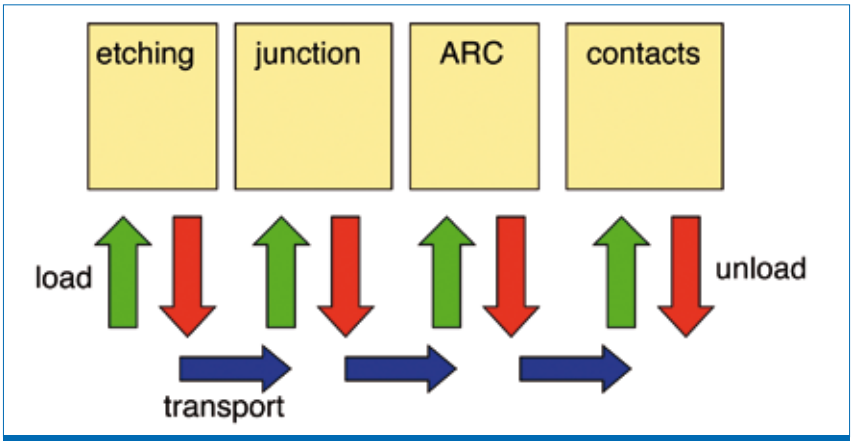

Figure 3. Typical industrial processing with loading and unloading at every process step.

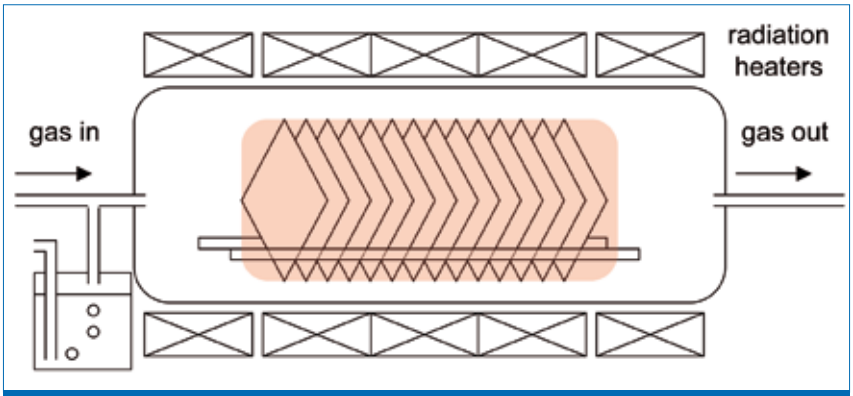

Figure 4. Quartz tube furnace layout for emitter junction fomation.

in these regions that will have a negative impact on solar cell efficiency. The wafers are textured at this point, giving them superior light coupling compared to a smooth surface. Optical reflection is reduced from ~35% (polished surface) to in the best case less than 10% (random pyramids), with the wafer texture increasing the light absorption by up to 40%.

Processes currently in use

Two fundamentally different processes are dominating the industrial market. One process is inline, based on acidic etching and used almost exclusively on multi-crystalline wafers. The second process is batch, based on alkaline etching of mono-crystalline wafers.

The acidic etch is based on the chemical reaction between silicon and a mixture of hydrofluoric acid (HF), nitric acid (HNO_3) in the presence of additives (e.g. water). In a process taking less than three minutes, between 4 and 6µm of silicon is removed from each side of the wafer, resulting in a random texture with a reflection of 20-25% at 1000nm. Process temperatures are, depending on the additives used, between 6°C and 30°C.

During alkaline etching, silicon is dissolved by an endothermic reaction with hydroxide (OH^-). The process is in most cases a two-step etch: the damaged surface is removed at high temperatures and high alkaline concentration. Random pyramids are then grown by the slow anisotropic reaction between silicon and hydroxide. This second step is normally performed at a lower concentration and temperature and in the presence of an additive (e.g. 2-propanol) to increase selectivity for different crystal lattices.

Pros and cons of inline versus batch and on-substrate

The selection of inline or batch texturing is not one of preference, but is determined by the wafer material being used. Acidic etching is a relatively fast process and therefore inline processing is possible at a lower cost of ownership than batch processing. Acidic etching can be used on mono-crystalline wafers, resulting in higher reflectivity than with alkaline etching and subsequent efficiency loss of about 0.5% absolute.

Alkaline etching is strongly dependent on temperature and composition of the etching mixture. A short process time is possible, but for good light coupling a structure of random pyramids is necessary. This structure can only be obtained when there are large differences in etch rates for different crystal lattices (anisotropy). To obtain a high difference in etch rates, it is necessary to use additives, a lower temperature and a lower concentration – all of which result in slower reaction speed and longer etch rates. Therefore, inline alkaline texturing etch is, at the moment, not used on an industrial scale.

Future developments and outlook

To make inline alkaline etching and texturing possible, the processing time must be reduced to times comparable to those of inline acidic etching. This reduction can be achieved for the initial saw damage removal step, but new reaction mixtures (different alkaline sources or additives) must be sourced that have an as high or higher anisotropic etching preference at a higher reaction rate.

Acidic etching can be performed both in inline and batch processes. The next breakthrough will have to be an acidic etch with a reflection comparable to that of mono-crystalline wafers with random pyramids. An example of this etch already exists [3] and ECN is working on upscaling this process, which could potentially replace alkaline texture etch for mono silicon wafers.

Wet texturing may be replaced by gaseous techniques (RIE, plasma) for structural etching, but should remain the only cost effective process for saw damage removal. For high efficiency concepts, the texture is important; however the cell design does not impose extra process requirements.

Cleans

Only two different post-emitter cleans are used in the industry: standard PGS removal with an aqueous solution of HF and ECN-Clean, consisting of an additional cleaning step/surface modification using Bakerclean PV-160 [4]. Both cleans can be applied during inline and batch processes. The choice will mainly depend on the stations before and after the clean.

Emitter formation

Emitters provide the driving force in the solar cell. During emitter processing, a dopant is provided at the surface and diffused into the silicon. In this way, a layer with opposite doping is made and a p-n junction is formed.

Processes currently in use

Batch process – quartz tube furnace

When the solar cell industry came on the scene in the 1970-80s, production technologies were transferred from the semiconductor industry. Emitter formation processes, also known as the phosphorus diffusion process, was one of these technologies, and saw the introduction of the quartz tube furnace. This type of furnace is still dominant in the production of silicon wafer-based solar cells. Nowadays, a single quartz tube of a typical horizontal furnace can process 400 wafers at a single batch and each process can take up to 2.5 hours including the loading and unloading steps (see Fig. 4).

Typically, machine throughput can be increased in a number of ways:

- increasing the number of wafers to be loaded in a single batch process using a longer tube

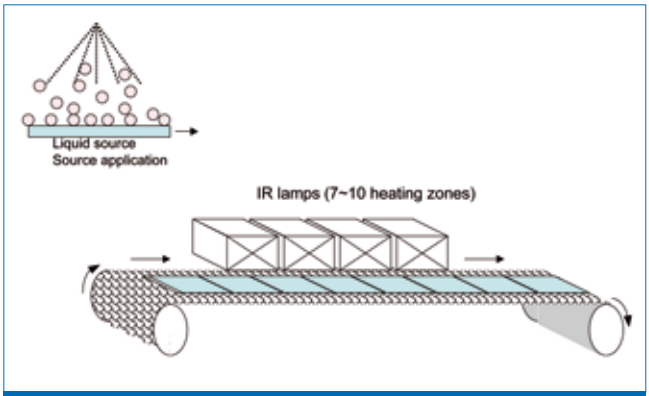

Figure 5. Inline phosphorus emitter junction formation with a sprayed phosphorus deposition and diffusion in a belt furnace.

- narrower spacing between wafers
- back-to-back processing by loading two wafers in one single slot. The wafers contact each other on the back-side and the front-side of each gets diffused
- shortening process duration with faster replacement of the chamber with ambient, intensive cooling
- loading/unloading at higher temperatures, and
- reducing machine floor space by stacking tube furnaces vertically.

However, almost all of these solutions – with the exception of stacking – have an impact on the doping profile, diffusion uniformity within a wafer, and diffusion uniformity from wafer to wafer. Careful investigation is required when any of these solutions is introduced into production. The maximum throughput will be determined from the point of view of device performance rather than mechanical limitation.

As a phosphorus diffusion source, two types of sources were developed: gas source application and coating source application. A typical gaseous source is $POCl_3$ (phosphorus oxychloride), which is introduced into the furnace by N_2 or Ar bubbling. It is quite popular these days because of its relatively easy handling and the self-cleaning effect of Cl_2. However, its byproduct being corrosive and harmful to humans, the chamber ambient should be isolated and correctly replaced when wafers are unloaded. For coating source application, the source is normally supplied as a liquid and spun on wafers. It has been less popular for tube furnace diffusion because it requires coating and pre-baking before being heated, while the coated film is prone to incorporate contaminations.

Inline process – conveyor belt furnace

Recently, the inline conveyor belt furnace has been used for emitter formation. As shown in Fig. 5, silicon wafers are spray-coated with a liquid diffusion source and are then transported horizontally by conveyor belt and heated. This simple concept of conveying wafers originally came from metal sintering for semiconductors. The spraying method could be replaced by spin-coating, screen-printing or dipping, while the conveyor belt can be constructed using a metal mesh belt, ceramic rollers, walking beams, etc.

Inline furnaces were originally not used for diffusion because there was widespread agreement in the semiconductor industry that metal elements such as the belt should not be used for diffusion processes to prevent metal contamination, which can harm the reliability of the manufactured semiconductor device. On the other hand, a heavily-doped phosphorus layer was known to capture metal impurities like Fe, Cr, Ni etc. which exist within the original wafer material. This capturing – or gettering – effect was also expected to be valid when such metal impurities exist in the doping material or the diffusion furnace itself.

ECN has shown that no degradation occurs in minority carrier lifetime of the wafer material that was treated with phosphorus diffusion in an inline metal conveyor belt furnace [5]. The results even suggested that contamination level is equivalent as that of quartz tube furnace diffusion using $POCl_3$ source.

Pros and cons of inline versus batch

Contamination

The inline conveyor process is more likely to cause metal contamination than the quartz tube batch process. This effect is negligible during phosphorus diffusion due to the metal gettering effect. For other very high temperature process steps, thermal oxidation and boron diffusion, the quartz tube process might be better suited. This is because for these processes the gettering effect is small or absent and the wafers become contaminated with metal impurities reducing silicon quality and solar cell efficiency.

Diffusion source application and process controllability

The phosphorus diffusion source is applied as liquid before wafers are heated in the inline conveyor furnace, while the source is applied as vapour after the wafers are heated in the quartz tube furnace. This enables the use of open chamber, often leading to shorter process duration per wafer. However, process control parameters have less flexibility, which makes it difficult to optimize the proper doping profile for higher device performance.

Handling wafers and floor space

Silicon wafers are transported horizontally during the whole process of diffusion for the inline conveyor furnace, while they have to stand vertically in the quartz tube furnace. Horizontal transportation requires minimum handling when the wafers are removed from one process machine to another, and it can distribute the stress caused by the wafers' weight. The wafers undergo more thermal stress when they are heated in the quartz tube furnace because they are supported at several points on their edges, which greatly impacts the breakage yield. Horizontal wafer transportation requires more floor space than vertical wafer placing in furnaces; stacking the inline furnaces vertically has little benefit. For batch furnaces, stacking vertically allows the expensive loading/unloading system to be shared.

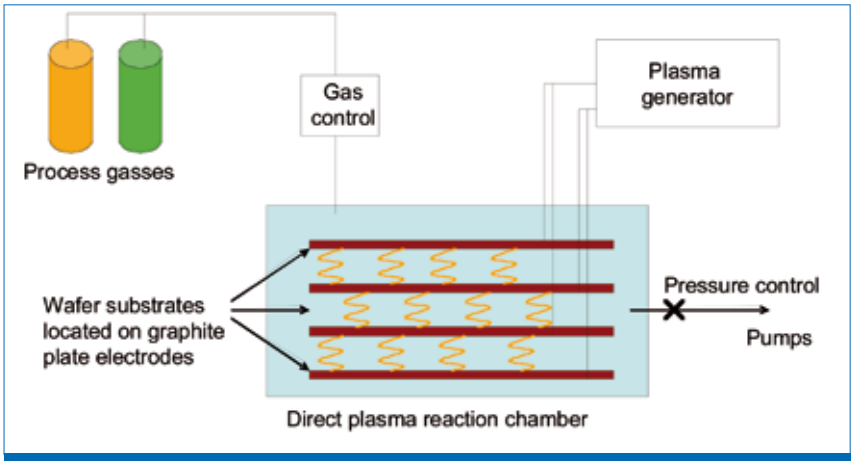

Figure 6. Schematic showing a direct PECVD system.

Operation and maintenance

Recent developments in automated technology have almost eliminated the difference in the practical operation of both types of furnaces, but troubleshooting an inline conveyor furnace is easier. A typical example concerns the heaters used by the quartz tube furnace. When the furnace accepts the group of wafers, the temperature inside decreases rapidly, though the heater should keep the whole wafer group at the same temperature, ramp up to the process temperature, and cool down to the unloading temperature. Even though recent technology is robust, troubleshooting this part requires specialized skills.

The inline conveyor furnace uses static heaters, the output of which is almost constant once the set point is adequately settled. If an IR-lamp breaks, the machine users can replace it and readjust the set point with appropriate maintenance training.

Limiting factors for increasing throughput

There are several solutions to increase throughput for both types of furnaces. However, most solutions for the quartz tube furnace impact diffusion quality and care must be taken if any of these avenues is brought into play. For the inline conveyor furnace, the maximum throughput is limited by mechanical factors like belt strength, conveying speed, and homogeneity of the line heater. This contrast suggests the future technological and mechanical improvement may give more room for throughput improvement to the inline conveyor furnace.

Future development and outlook

Improving device performance at larger throughput is not easy. Inline conveyor or quartz tube? Both systems appear to experience setbacks in reaching larger throughput and higher efficiency, and some technology breakthroughs will be necessary such as Centrotherm's 'inline-tube furnace' concept [6]. Although the effectiveness of the concept has not yet been proven, such an attempt is really stimulating the PV sector and encouraging others to tackle technology innovations.

	Inline	Batch
Typical process time per single wafer incl. load / unload	20 ~ 40 minutes	1 ~ 2.5 hours
Contamination	Most contamination can be prevented by metal gettering effect of phosphorus.	No metal contamination.
Diffusion source application	As liquid & before being heated Pros: Use of open chamber enables quicker process. Cons: Less control of process chamber	As vapour and after being heated Pros: More control of process chamber Cons: Closed chamber required which causes longer process duration.
Wafer handling	Horizontal transportation throughout the process Pros: Minimum handling and lower breakage rate Cons: Larger floor space needed	Vertical wafer location during the process Pros: Small floor space Cons: Higher breakage rate due to the handling and thermal stress
Maintenance & troubleshooting	Operators can solve most of issues with appropriate maintenance training.	Help of skilled engineers is sometimes needed
Limiting factor to increase throughput	Belt length and width (the belt material should be strong enough to support the length and width) Conveying speed against breakage yield Homogeneity of the line heater	Adequate doping profile Diffusion uniformity within a wafer Diffusion uniformity from a wafer to another

Table 1. Pros and cons comparison of inline and batch method with typical constructions.

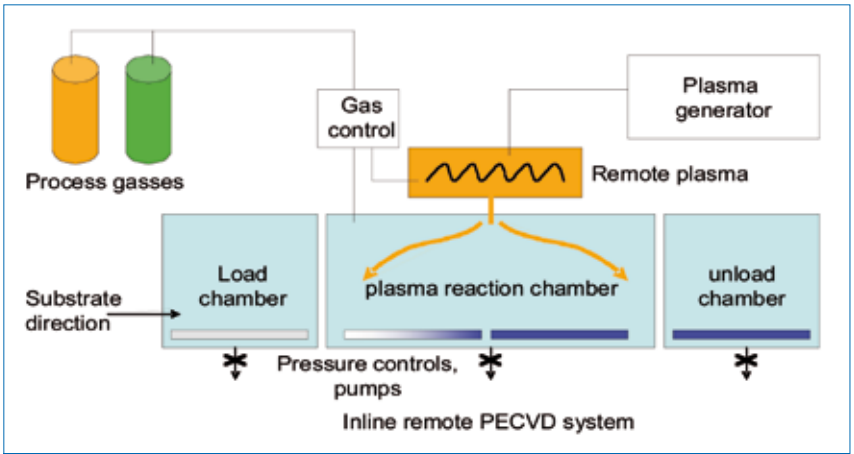

Figure 7. Schematic drawing of an 'inline' remote PECVD system.

For high efficiency concepts, the diffusion process must be adapted to allow for both n-type and p-type regions to be formed on the back of the solar cell (see Fig. 1). Therefore, local diffusion is necessary. Local diffusion sources can be applied by printing methods; local heating can be applied with laser doping; local diffusion masks can be deposited. Diffusion masks are currently being used in production to form the interdigitated diffused regions. Boron diffusion has to be applied, which requires higher temperatures and longer times than for phosphorus diffusion to obtain the optimal doping profile. On the other hand, boron diffusion does not provide the same gettering effect as phosphorus diffusion; therefore, quartz tube diffusion is preferred for these cell designs.

Dielectric coating deposition

Reducing the reflection of incident light on solar cells requires coating with anti-reflective coating, such as metal oxide layers like TiO_x or SiO_x. However, since the first application in 1981 [7], the use of silicon nitride (SiN_x) as an anti-reflective coating has become dominant in crystalline Si PV technology. The refractive index *n* of silicon nitride can be tuned between 1.9 and 2.5, which enables excellent anti-reflective properties both for solar cells in air and behind glass in a module. Furthermore, SiN_x passivates the surface of the solar cell by reducing the defect density and by creating a positive field effect [8].

The third function of SiN_x is the supply of bulk passivation by means of hydrogen diffusion. This property is especially important for mc-Si solar cells, which are used in more than 50% of total crystalline Si cell production. By using hydrogen-containing gasses like SiH_4 and NH_3 as precursor gasses for the SiN_x layer deposition, hydrogen atoms will be integrated in the SiN_x layers by diffusing into the bulk of the mc-Si solar cell during the high temperature firing step, providing passivation for crystal defects (dangling bonds) and impurities (C, O, metals).

While the anti-reflection properties of the SiN_x layer are determined by the optical constants *n* and *k*, the surface and bulk passivating properties are found to depend strongly on the mass density and bond densities (Si-N, Si-H, N-H) of the SiN_x layer [9,10]. Both need to be optimized to reach high cell efficiencies [11].

Processes currently in use

In most solar industries, the SiN_x coating is deposited using plasma enhanced chemical vapour deposition (PECVD), which is based on ionizing the precursor gasses (usually NH_3 and SiH_4) using an electric field. Ionized molecules – or radicals – will react and deposit on the surfaces creating an amorphous SiN_x layer. By changing process parameters like pressure, temperature and silane or ammonia gas flow, the plasma properties change and the optical and physical properties of the deposited layers can be tuned to optimal values.

There are essentially two forms of PECVD:

Direct PECVD: In this case, the plasma is in direct contact with the substrates. This principle has worked, up to now, only in batch mode since the substrate carrier itself is used as one of the electrodes for the electric field (see Fig. 6). The EM-frequencies range from 40 to 440kHz. Industrial applications consist of several stacked chambers into which the substrates are loaded and processed, and subsequently unloaded. During loading and unloading of the substrates the plasma is, naturally, turned off.

Remote PECVD: In this case, the plasma is excited some distance away from the substrates. Several types of remote PECVD have been developed, such as: microwave PECVD (2.45MHz), pulsed PECVD (13.56MHz – 100kHz) or expanding thermal plasma (DC). These applications can run both in batch and in inline mode. In the inline case, the plasma stays turned on while substrates are loaded, processed and unloaded from the process chamber (see Fig. 7). Recently, other deposition methods like sputtering of SiN_x from a solid silicon source have been developed [12].

Pros and cons of inline versus batch and on-substrate

Both PECVD and sputter processes involve low pressure conditions and ionized dangerous gasses (i.e., silane and ammonia). Due to the nature of these processes, so far the processing itself has been batch or hybrid (a 'batch' process, enveloped in an inline machine). The process itself runs continuously in the process chamber, with large batches of samples transported in and out of the chamber by means of load locks. The batch (or so-called tray) is heated in the load lock chamber before it enters the process chamber.

Compared to batch, inline processing, even in this 'hybrid' manner, provides a better process stability. This is due to the fact that the plasma is continuously turned on and the temperature in the process chamber is kept constant. Hybrid inline processing is only possible for remote PECVD or sputtering processes where the plasma is controlled separately and independently from the substrate transport.

Besides this, remote PECVD has several other advantages compared to direct PECVD methods:

- There is less influence of substrates (size, mass, etc.) on the plasma conditions as

Courtesy: Asys.

Figure 8. Rotary printing for faster printing.

the substrates do not act as one of the electrodes.
- The substrates will not be heated additionally by the plasma.
- Moreover, as the ionized particles are formed some distance away from the substrates, the ion impact on the substrates will be less. This will decrease the damage done to the surface of the substrates, which will be important for high efficiency processing.

However, direct PECVD has the advantage of a low energy density, point-of-use activation and less downstream loss of activated reactants. Furthermore, the lower frequencies allow for a larger deposition area.

SiN_x layers of good quality can be deposited with both PECVD systems. Furthermore, optical parameters and densities can be tuned to optimal values. Recently, a comparison for bulk passivation was made between a direct and an indirect plasma source using both n- and p-type mc-Si, and p-type string ribbon and EFG material [13]. The authors found that although the different wafer types could react slightly differently to the two different systems, overall with both remote and direct PECVD good bulk passivating layers can be deposited.

Future developments and outlook

Both batch and hybrid PECVD (or other SiN_x deposition) systems can be integrated very well in an inline production line. This is already happening on a large scale in industrial solar cell manufacturing lines. However, these processes will always require handling of the thin wafer substrates before and after processing of the SiN_x layers. Should the wafers become even thinner in the future, this will lead to more and more breakage.

For PECVD (or other) processes to become truly inline, they would have to work at atmospheric pressures. This way, no load locks are necessary and the substrates can be transported directly inline through the deposition chamber. Although such a PECVD system was mentioned some years ago [14], no cell results were published at that time and to the authors' knowledge the system has not yet been industrialized.

For new cell designs, coatings will likely need to be deposited on both sides. This will require a redesign of the trays, since trays are now designed for single-side deposition. The first commercial systems are now available for this process, while for IBC cell designs, thermal oxide passivation is used, which requires quartz tube furnaces.

Metallization

In the metallization process steps, the electrical contacts are fabricated onto the solar cell. For standard type cells, this means a front side H-pattern using silver, rear-side silver contacts as pads or bars, and further full aluminum coverage on the rear side.

Processes currently in use

Already 30 years old, thick-film screen-printing and contact-firing is the leading manufacturing technology for all three contacts on the crystalline silicon solar cell. In screen-printing, metal conductor paste is transferred onto the cell through a framed screen mesh with a patterned emulsion. The printed paste is dried prior to a next screen print step. After all contacts have been printed and dried, the cells pass in-line through an IR lamp conveyor-type firing furnace. Here, the actual contacts are established: the metals are baked and electrical and mechanical contact with the cell surface is made.

Co-firing or triple firing is standard since it became possible to fire front contacts through the SiN anti reflection coating, realizing direct contact with the emitter, in conjunction with BSF formation on the back-side using aluminium. At first, multiple lanes were used in a firing furnace to obtain throughput, then single lane fast firing furnaces with more emphasis on peak firing became necessary to realize good contacts. Dual- or even triple-lane fast firing are or will soon become available.

A main advantage of screen-printing is that it allows the deposition of a high volume of material (the thick film) in complex patterns in one stroke. In addition, screen print pastes allow dispersion of the highest metal fractions. Furthermore, screen-printing technology has gained considerable momentum, since it has been and is applied for most crystalline silicon solar cell manufacturing [15]. Only a few alternative technologies were or are being used.

For non-flat silicon wafers, such as EFG silicon material and string ribbon material, pressure as applied by transferring metal paste through the screen gives rise to breakage of the ribbons, which led to demand for non-contacting or low-pressure methods. This group includes dispensing of paste, decal transfer and pad printing. Another approach is plating technology, e.g. such as that used for the Saturn-type cells of BP. The method applies various plating in laser-buried grooves on the front-side of the cell, focusing on improved efficiency through enhanced contacting and low shadowing. Today, some manufacturers use variations on printing and plating, again in a proprietary manner.

Pros and cons of inline versus batch and on-substrate

Screen-printing is considered a batch-type and on-substrate process. A wafer is positioned on the print table, accurately aligned, moved under the print station and then paste is printed onto the cell. After repositioning the table, the cell is removed. The handling takes time, as does the printing stroke itself. For faster handling, e.g. the rotary table platform is established, as shown in Fig. 8. The print speed dictates the movement of the squeegee, pressing and transferring paste through the screen. The print stroke takes up the most time in the various steps and is therefore pushed up to gain throughput, at the cost of the desired fine line high aspect ratio.

Over the last decade the design of screen printers and their cell handling were improved such that throughputs of more then 1200 cells per hour became possible. Although some current screen printers can do ~1500 cells per hour [16], this still limits total throughput of the manufacturing line, since other, full inline equipment can easily double that number. As a solution two parallel lines of printers and dryers – and sometimes firing furnaces – are added. Today even triple lanes of screen printers are available, thus increasing throughput to ~4000 cells/hr [16]. A multi printing lane approach is also beneficial for the extra attention that screen-printing needs in terms of throughput and yield. Stopping one machine for screen exchange, for example, will not have to affect throughput.

The printing of two cells, which was selectively used for some time, has recently been introduced in commercial equipment, and, though it will double the throughput, it will not resolve the issue of stopping the printer for screen exchange, etc. It must also be demonstrated that printing two cells using one screen will not affect the desired fine line high aspect ratio printing.

To comply with the industry's needs, ECN Solar Energy carried out research into the applicability of rotary screen-printing for solar cell metallization. Rotary screen-printing is a well established technology for such processes as fabric printing. The method is a true inline process, and for PV application would easily increase throughput. Yet the special screens that are needed in this approach were found to be unsuited to realizing the required pattern definition.

RTP firing has been a topic of research for some time, and has shown encouraging results, but never made it as a real-world application due to its batch-type character. Firing in belt furnaces is a true inline process and throughput is not a real issue here. For cost purposes, the footprint, energy consumption and yield are important, but do not directly limit future manufacturing.

Future developments and outlook

Alternatives for screen-printing are under research and/or in the industrial test phase. The alternatives focus on improvement of the electrical front contact together with less shadowing, as well as high throughput. Fraunhofer ISE has carried out a large body of research on a hybrid method of metallization that involves deposition of seed layers with additional plating [17]. Industrial prototype equipment, such as various types of ink-jetting, is currently undergoing industry testing, as is research on full plating of the front-side contacts. Ink-jet seems

perfect for the in-line depositing of fingers. Although the substrates can move inline and continuously, the method is still semi-continuous because of the stopping and starting of the deposition of paste at the beginning and end of a finger. A second process step is needed for the application of the busbars perpendicular to the fingers. Non-orthogonal patterns, such as the ECN pattern for metallization wrap-through cells (MWT), are difficult to align to the ink-jet approach [18].

The greatest challenge with these alternatives is that the equipment has to comply directly not only with the high throughput demands of the industry, but also with the accurate positioning of the cells for e.g. selective emitter-type cells, but also for the fine-line high aspect ratio requirements for both front-contacted cells and rear-contacted cell demands.

Together with the development of new approaches and equipment, the overall solar cell concept is evolving. New concepts, such as IBC, MWT, etc. apply back contacts, and lead to different requirements for metallization. Opening the dielectric layer with lasers can lead to other contact schemes such as direct plating, sputtering and laser contact firing.

A very important aspect of all new metallization development and other process steps is that it will not only have to increase efficiency of the cells, but also throughput at increased yield and at overall lower costs.

Conclusions and outlook

True inline processing of silicon wafer-based solar cells is not currently available for all processes. Inline processing could become very relevant when wafers get very thin and fragile and any wafer handling should be avoided. Particularly for vacuum processes such as PECVD of dielectric coatings and the metallization process, a full inline process will not become available in the near future.

It is likely that more processes will be performed on the same tray; for instance, the wet chemical cleaning step might be replaced by a dry cleaning step. In this case, the same tray could be used during diffusion, cleaning, coating deposition, and maybe even metallization. For new cell designs such as IBC, full inline processing is even more difficult since processes are needed that at the moment cannot be performed inline, such as boron diffusion, inkjetting, and laser processing.

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Yuji Komatsu received his Ph.D. in electrical engineering at Kyoto University, Japan. He joined Sharp Corporation in 1994, and was involved in R&D of high efficiency c-Si solar cells until he left the company in 2005. Since then, he has been working at ECN, where he is now responsible for R&D of dopant diffusion processes.

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