NEW COMPACT SILICON NITRIDE DEPOSITION SYSTEM FOR 1500 SOLAR CELLS PER HOUR

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ABSTRACT: OTB Solar uses the expanding thermal plasma technique on its high throughput PECVD tool, the DEP_X, for the deposition of a silicon nitride antireflection coating on silicon solar cells. These films are deposited at very high rates (>5 nm/s) from an Ar-NH_3-SiH_4 plasma at a substrate temperature of around 400 degrees Celsius. The ETP source technology was already adapted in the DEPx1000 platform, but now the high deposition rate capabilities are extended into the DEPx1500 family, without compromising the footprint of the tool.
Keywords: Silicon-Nitride, PECVD, Passivation

1 INTRODUCTION

In this paper the DEPx1500 is introduced. This system is used for plasma enhanced chemical vapor deposition (PECVD) systems for silicon nitride deposition on crystalline silicon solar cells. Similar systems are nowadays widely available for industry. The throughput of such systems is mostly limited by the deposition rate. As a consequence, throughput enhancement is very costly since it involves up-scaling of the process chamber and plasma generating assembly.

OTB's DEPx1000 system [1,2] uses an expanding thermal plasma which is generated in a very small area (0.5 cm^2) at high power (10 kW), making the plasma sources and therefore the process chamber very compact. Due to the expansion of three plasmas the effective area is increased to 0.3 m^2 and a uniform deposition rate is achieved by choosing the proper positions of the induvidual plasma sources. Up-scaling of the DEPx1000 to the DEPx1500 system (for 1500 solar cells/hour) has been achieved without any increase in foot print. In figure 1, an overview of the new deposition tool is shown.

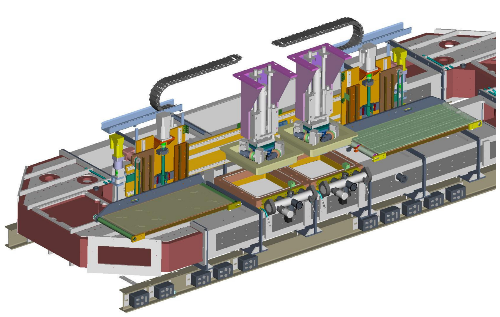


Figure 1: Overview of the DEPx1500 platform in which the belt handlers and the load lock section is shown.

In order to facilitate a 50 % increase in thoughput, modifications were needed on the handling system and the LoadLock operation, the Linear Motion System in terms of carrier speed, as well as the deposition speed of the process.
The DEPx1000 uses compact wafer carriers for only four solar cells each. The tact time is only 15 seconds [1], and consequently only 10 seconds on the DEPx1500. The fast load-lock design has been optimized by using two load-lock units simultaneously for both unloading and loading of eight solar cells on two carriers, and by integration of the load-lock lid and Bernoulli-handler. The pumping down time is 3.5 seconds, due to a specially designed dust filter and pump system that covers a pressure range of 1000 mbar down to 1E-1 mbar. Also, the DEPx1500 uses a closed single-track carrier transport system in stead of a two track/ferry system. This way the carrier transportation speed can be increased by 50%. The cariers however can be made compatible with the DEPx1000/1500 family.
In order to facilitate a similar ramp up temperature profile, due to the increased carrier speed, the prehat section needed to be increased from 6 to 9 lamps. The same heater concept hoewever is used as in the DEPx100 platform.

Furthermore it is wothwhile to mention that the DEPX1500 handling platform can be equipped with external handlers based on robotics as well as integrated vision systems. They can handle both casettes of any commercial type available up to 100 counts as well as operate as coin stackers. In this sense they are universal ans called as such.
The plasma sources have been improved to operate at higher power (15kW per three sources), reaching a deposition rate of over 4 nm/s on wafer level. The quality of the silicon nitride layer in terms of hydrogen passivation is maintained, as will be demonstrated in section 3.

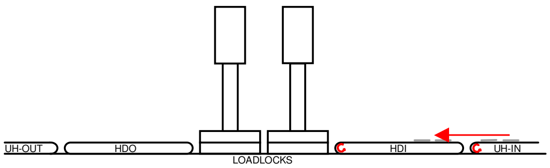
Lastly, it is interesting to mention that the pump stand which is used for the process gases is delivered optionally with an integrated scrubber system.

2 DETAILED DESCRIPTION OF THE DEPX1500

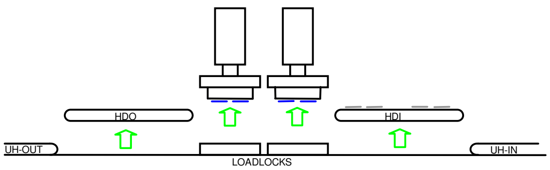
In an earlier paper, it was described how the DEPx1000 produces 960 solar cells per hour in a footprint of only 4.5 times 2.5 meters. In the following sections, the working principle of the DEPx1500 will be described in terms of wafer transport in and out the tool, Linear motion system (LMS) of the carriers inside the vacuum vessel, load-lock operation and sources.

Wafer transport
The DEPx1500 machine uses belt handlers to transport wafers in and out the machine as well as integrated Bernouilli grippers in the load-lock covers. So upon opening the load-lock covers, the wafers are already transported in the *z*-stroke of the lids. This enables a moving belt transport mechanism to handle the wafers in and out the load-locks.

The handling and load-lock sequence is schematically shown in figure x (a till g). The following abbreviations are used: Handling in (belt) HDI, handling out (belt) HDO, belt from the Universal handler in (UH-in) and Universal handler out (UH-out).



(a)



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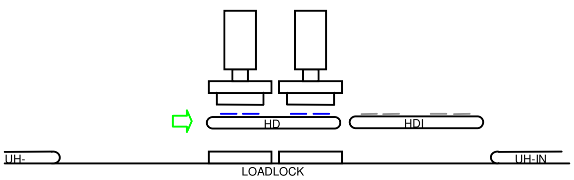

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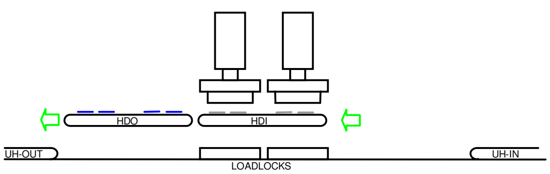

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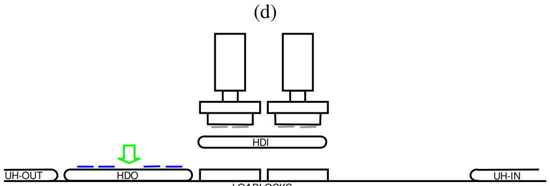
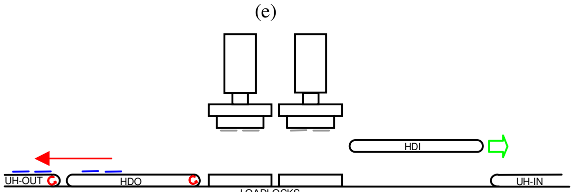
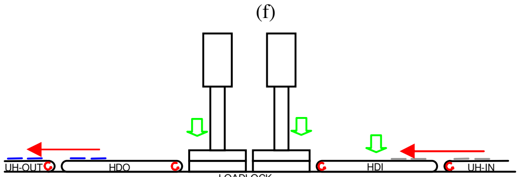


(e)



(f)



(g)

Figure 2 (a) till (g): Sequence of the handling belt actions in order to transport wafers in and out the machine. See text for explanation of the transport sequence.

In figure 2(a) the sequence starts with two closed load lock covers and a Universal handler in belt transporting wafers onto the handling (HDI) belt unit. After that, in figure 2b, the two load lock covers will open simultaneously, accompanied by the *z* stroke of the HDI and HDO belt units. Note that the 8 wafers (indicated by the blue color in figure b) are transported as well. Then, in figure 2c, the wafers from the load-lock covers are taken over by the HDO assembly, by moving to the right. In figure 2d, both the HDO and HDI are moving to the left, enabling the HDI belt assembly to deliver 8 new wafers to the load-lock lids. In figure 2(e) the HDO belt moves down again, in order to facilitate a transport movement to the UH-out belt. In the meantime (figure 2f), the HDI can also move toward the original position in order to take 8 new wafers as depicted in figure 2(g).
One of the most challenging aspects of designing such a wafers transport system is the intrinsic ability to cope with broken wafers, both mono type who scatter in only a few pieces as well as multi-crystalline wafers which break in many pieces. A number of preventing actions were implemented in this system:
1. In the UH a robot hander *first* determines the integrity of the wafer (broken of corners, shape of the wafer, etc), before placing it in a pre-aligned position on the UH-in belt.
2. The HDI belts are partly open, so in case a wafer breaks, the fragments are collected underneath the belt in a controlled bin.
3. Both the HDI as well as the HDO are *closed* belts. So in case a wafer breaks, the belt can remove the wafers which are not picked up by the load-lock Bernoulli grippers, or are placed on the HDO belt already in pieces, in a controlled way, namely in a broken wafer bin at the end of both the HDI and UH-out.
4. In case a wafer is broken inside the machine, an integrated cleaning system in the load-lock becomes active, as soon as the covers are in the upright position.

Linear Motion system
Wafer transport inside the vacuum tool comparable to the DEPx 1000 platform [See Roel Parijs], except that the ferry is now replaced by a semi-sphere track. This enables the carriers to develop a higher carrier speed train through the deposition area. The constant velocity of a carrier depending on throughput is easily calculated via the formula: $v = \frac{1}{2} n \cdot l / t$ in which n the number of wafers per carrier, l the length of the wafer plus the wafer distance, and t the load-lock cycle per n wafers. Note that the throughput of the machine in wafers per hour equals $N = 3600 \cdot t/n$.
In total, 11 carriers are transporting 4 wafers each from the load-lock area trough the deposition zone. With minor adaptation, the carriers are backward compatible with the earlier DEPx family. In figure 3, the Human Machine Interface (HMI) is shown for the two DEPx variants; in figure 3(a) the DEPx1000 LMS configuration is shown, and in figure 3(b) the DEPx1500 one. The semi sphere track is clearly observed, as well as the higher carrier speed.

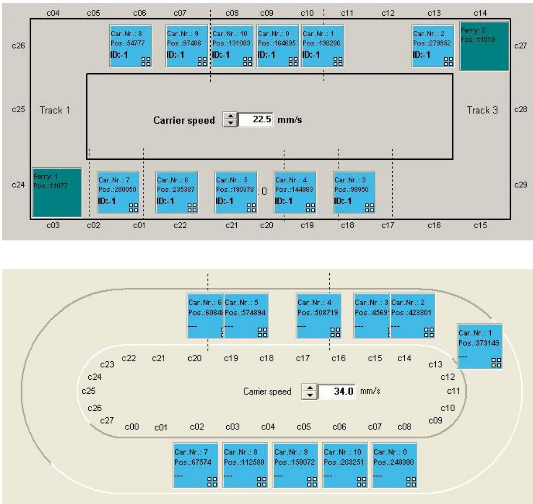


Figure 3: carrier transport system with two single tracks and ferries of the DEPx1000 (top), and closed single-track of the DEPx1500, enabling a 50% increase in carrier speed (bottom).

ETP Sources

In order to be able to increase the throughput of the DEPx1500 platform, the current that is carried by the source is a primary parameter to enhance the deposition rate *without* increasing the silane gas flow too much. In figure 4 the effect of increased power (i.e. current) is shown upon the deposition rate. Increasing the argon flow by 8% adds to this effect as is observed from figure 4 as well. In section 3 more detailed results are discussed regarding the increase of the amperage, silane flow and film density [3, 4].

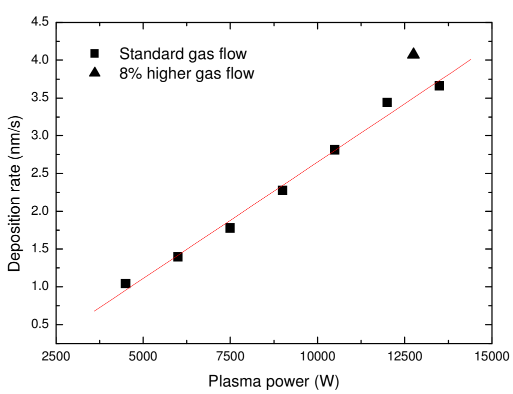


Figure 4: deposition rate of silicon nitride on the DEPx1500. The increase in deposition rate with plasma power can clearly be seen. Increasing the gas flow by 8%, results in a further increase without decreasing the layer quality. Note that the deposition rate is defined on wafer level.

Load-lock operation

The load-locks are minimized for volume as well as conductivity to the vacuum pumps. On the DEPx product family the On Tool Booster (OTB) pumps are used. These pumps are extensively described in reference [5]. In figure 5, a typical pump down curve is shown of a Load Lock pump down cycle. After initial pump down in which the pressure varies with V/S, the desorption regime sets in.

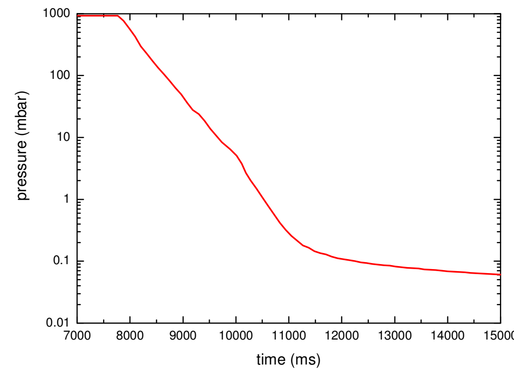


Figure 5: pump down of DEPx1500 load-lock with new booster pump. Within four seconds, the pressure has decreased to 1E-1 mbar, sufficient for further wafer transport.

In figure 6 the drop in rotational speed of the shaft is shown versus time. On t = 0 seconds, the angle valve between the OTB pump and the load lock volume is opened. The nominal rotational frequency equals 1000 Hz, dropping to about 900 Hz in about 2.75 seconds. Then this frequency recovers in linearly towards the 1000 Hz level again in about 10 seconds. Note that the entire load lock cycle is 20 seconds, well within the recovery time.

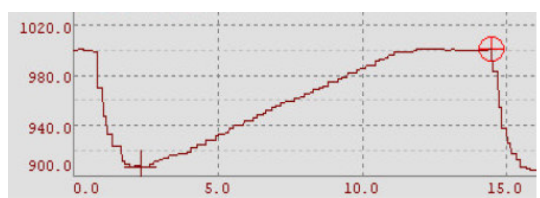


Figure 6: Rotational speed of the pump shaft after opening the valve at t = 0 [s] at the start of a load lock cycle. The horizontal scale represents time in seconds and the vertical scale the rotational frequency in [Hz].

3 PROCESS RESULTS AND DISCUSSION

In this section, the layer quality is assecced in terms of (n,k) plot as well as the mass density, as determined by FTIR. In figure 7 the (n,k) plot is shown for two cases namely a total of 10 kW applied to three sources as well as 15 kW. This is mainly due to the increase in source current from 70 A to 100 A. The trend of (n,k) is evident: with increasing refractive index n, the number of Si-Si bonds increases, resulting in a higher absorption k in the UV range (in this example at 360 nm). However, if the mass density increases, the same refractive index n can be obatined with a lower Si/N ratio, also resulting in a lower absorption. It has been shown that a high mass density of silicon nitride gives improved hydrogen passivation and therefore a higher cell efficiency. Evidently, a plasma power of 15 kW (100 A) gives a better silicon nitride quality.

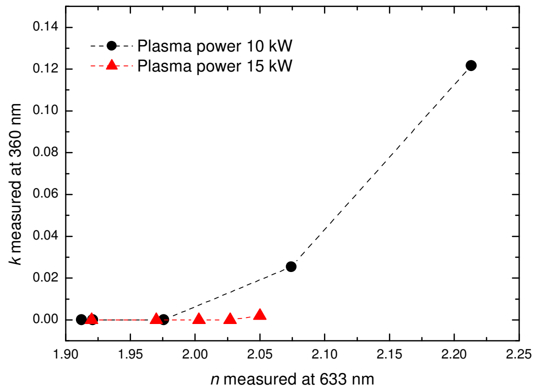


Figure 7: absorption of silicon nitride for different indices of refraction. It is clearly visible that a higher plasma power of 15 kW results in a lower absorption, indicating an increase in mass density.

In figure 8, the mass density of the SiNx layers deposited at either 70 or 100 A is shown for increasing silane flow. The refractive index is always in the range of 2.06 to 2.08. At 70 A, it can be seen that the mass density suddenly drops at a silane flow larger than 0.8 (Note that a silane flow of 1.0 corresponds to a throughput of 1500 wafer/h). However, at 100 A, the optimal mass density shift towards a higher silane flow, which is sufficient for producing 1500 wafers/h. It should be noted that the process pressure increases gradually with increasing silane flow. Therefore it is expected that the mass density can be improved even further (normally a lower process pressure results in a higher mass density), especially at high silane flows.

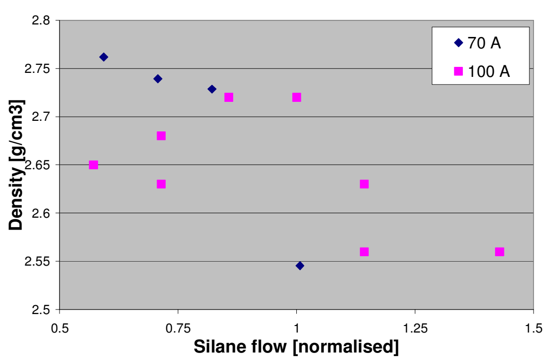


Figure 8: Mass density of SiN layers versus the normalized silane flow for layers deposited at a source current of 70 and 100 A respectively.

4 CONCLUSIONS

The DEPx1500 has been successfully developed. One of the most pronounced results is the increase of throughput, but maintaining the small foot print. Wafer handling speed has been increased by using simultaneous load locking combined with belt transport handling and load-lock lids that act as wafer handlers. Fast pumping down of the load-locks is done by a special type of booster pump. Wafer transport speed has been increased by using a closed-track carrier system without the use of additional ferries.

The deposition rate of silicon nitride has been increased by using high-power ETP plasma sources. The mass density of the silicon nitride layer is still sufficiently high at these high deposition rates of well above 4 nm/s, indicating that a good silicon nitride layer quality is maintained.

5 REFERENCES

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