A LARGE AREA PRODUCTION TECHNOLOGY FOR SOLAR CELLS – SPUTTER DEPOSITION OF SIN:H

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ABSTRACT: This paper summarizes aspects and investigations of the sputter process for industrial deposition of passivating SiN:H antireflection (AR) layers on multi-crystalline silicon solar cells. The motivation for this work was the existence of low cost mass products manufactured with sputtering technology such as coated architectural and display glass. In close cooperation with Applied Films, Fraunhofer ISE showed that sputtered nitride layers can replace the up to now used PECVD nitrides. The inherent advantages of sputtering technology such as excellent layer homogeneity, a silane-free process and long service cycles can be transferred to SiN:H deposition on solar cells. Operating figures for a newly designed inline sputter coater are presented.
Keywords: Sputtering, Silicon Nitride, Multi-crystalline

1 INTRODUCTION

In 2004, solar cell production worldwide exceeded 1.2 GW, an increase of over 65 % compared to the previous year [1]. In parallel, the capacity of new cell lines increases, being in the range of 50 MW or even higher. For 156 x 156 mm^2 cells this is an annual throughput of 14,000,000 wafers, corresponding to an area of about 340,000 m^2 of silicon wafers. Hydrogen containing silicon nitride (SiN:H) is commonly used as an antireflection and passivation coating on the front side of multi-crystalline (mc) cells. The deposition method mostly applied is plasma enhanced chemical vapor deposition (PECVD). Drawbacks of this technology are the use of silane, short service cycles and limitations for thickness uniformities in case of large scale inline coaters.

Sputtering is a coating technology for mass production of architectural, automotive and display glass [2]. Industrial inline coaters have an annual throughput of several million square meters and a service cycle of typically one week. Silicon nitride is one standard material in use for different applications [3, 4]. In a joint research project, Fraunhofer ISE and Applied Films showed that sputtered SiN:H layers have the same quality as PECVD coatings used as antireflection and passivation coatings on wafer based solar cells [5]. Applying sputtering technology in the solar cell industry is a step towards cost-effective mass production without dangerous process gases while maintaining quality and excellent layer homogeneity.

2 SPUTTER COATING OF ARCHITECTURAL GLASS

One typical industrial application of sputtered layers are coatings on architectural glass. The most important types are solar control coatings for reducing the heat load into buildings from the sunlight as well as low emissivity coatings for improving the thermal insulation of window glass. Standard float glass being coated in Europe has a pane size of 6.00 m x 3.21 m and inline coaters (fig. 1) have an annual throughput of up to 8,000,000 m^2 of glass.

Figure 1: Horizontal inline sputter coater for architectural glass; annual throughput up to 8,000,000 m^2

Shown in figure 2 is a scheme of a 5-chamber inline sputter coater for architectural glass. The washed substrates are rapidly transported into the entrance chamber (1), which is then evacuated to a pressure of approximately 10 hPa by high-capacity vacuum pumps. The glass pane is then transported into the buffer chamber (2) where further pumping takes place to a pressure of about $5 \cdot 10^{-2}$ hPa. Using two chambers for evacuation reduces the cycle time of the system. In the adjacent transfer section, the intermittent transport mode of the entrance and buffer chambers is synchronized to the continuous transport mode in the sputtering chamber (3).

In the coating region, there is a constant line of glass panes with small gaps in between. The sputtering chamber can be individually equipped with different sputter cathodes depending on the desired layer system. The material to be deposited onto the glass is fabricated into a plate (target) or a rotating cylinder and attached to the sputter cathode. The cathode is maintained at a negative potential, and a gas discharge is ignited when argon is admitted into the chamber. In the coating process, argon ions sputter the target. The ejected atoms form a film on the substrates.

After deposition of all films, the glass panes move through a second transfer section into the buffer chamber

(4) and into the exit chamber (5), which is then vented to atmospheric pressure; thereafter the coated pane can be transported out of the coater.

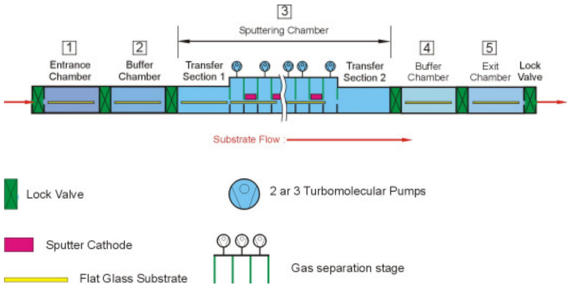

Figure 2: Scheme of a 5-chamber architectural glass coater for highest throughputs

The deposited layer systems can consist of up to ten sub-layers including metals and dielectrics. To achieve a uniform appearance of the product, it is necessary to maintain a layer thickness uniformity of approximately 2.5 % for every single layer. Even though the layer systems can be quite complicated, low emissivity and solar control coated glass is an inexpensive mass product.

In case of low emissivity coatings, the conductive functional layers in the layer system consist of silver, typically between 10 nm and 20 nm thick. The low emissivity of the coated glass surface reduces the radiative heat losses to the outside. Additional barrier layers are needed to protect the silver and dielectric layers are used to increase the light transmission in the visible range. For these dielectric layers, silicon nitride is one standard material in use.

3 SPUTTERED SIN:H COATINGS FOR SOLAR CELLS

On a prototype sputter system of the ATON series built by Applied Films and located at Fraunhofer ISE (fig. 3), sputtered nitrides were tested concerning their antireflection and passivation quality on multi-crystalline silicon solar cells. The coating area on the substrate carrier shown in figure 3 is 500 mm wide and 600 mm long. The substrates can be heated to temperatures up to 400° C. In the sputter process, solid silicon targets are the silicon source, making the use of silane unnecessary. The target is bombarded by argon ions and the sputtered particles react with nitrogen to silicon nitride. The index of refraction can be adjusted with the amount of nitrogen. Hydrogenation of the layers is realized by introducing additional ammonia. Thus, the index of refraction and the content of hydrogen can be controlled independently (fig. 4). Layer homogeneities of ±2.5 % or better were easily reached on the whole area of the substrate carrier. FTIR measurements demonstrate that Si-H and N-H bond densities of sputtered and PECVD SiN:H layers are nearly equal for optimum ammonia flows [5].

Figure 3: ATON 500 pilot coater for sputter deposition of SiN:H on wafers, located at Fraunhofer ISE

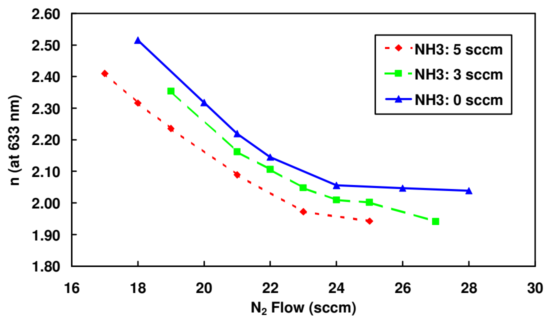

Figure 4: Index of refraction of sputtered SiN:H layers as a function of nitrogen flow for different NH_3 flows.

On standard multi-crystalline material, over 15 % efficiency are reached for standard industrial processing steps. IQE measurements in the long wave length range show that there is an effective passivation of bulk defects in case of multi-crystalline solar cells (fig. 5).

There has been much speculation about whether the ion energies present in sputter processes have a bad influence on the cell performance. For dark I-V measurements however, the determination of the saturation current in the depletion region (called I_{02}) proves that the emitter is not damaged by the process. The values are as low as for PECVD nitrides, when the ammonia flow and firing temperature are correctly adjusted [5].

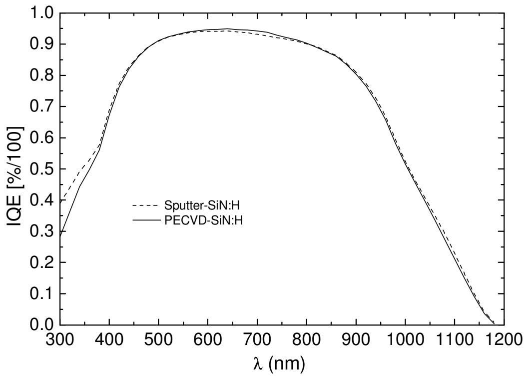

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Figure 5: Spectral response of a multi-crystalline solar cell with sputtered SiN:H AR coating. Also shown is the spectral response of a solar cell with a PECVD processed SiN:H layer. From [5].

4 INDUSTRIAL SIN:H SPUTTER DEPOSITION

Industrial sputter coaters for highest throughputs use the inline concept. In case of SiN:H coatings on wafer-based solar cells, the substrates are placed on a carrier and transported horizontally through the coater, moving continuously while passing one or more sputter stations. The throughput can be increased by enlarging the coating width or by increasing the number of sputter stations together with the substrate transport speed. By using the substrate carrier concept, all wafer sizes and geometries are possible.

In production, sputter processes typically run several days without maintenance break. When the sputter target erosion is complete, it has to be exchanged. In parallel, the coating chamber is vacuum cleaned and coated parts of the surroundings are replaced by clean ones. Cleaning can be done off-line by sandblasting. Maintenance and long-run tests showed that sputtered SiN:H coatings reach the necessary quality shortly after pumpdown of the coater (fig. 6) and maintain it throughout several days of continuous operation (fig. 7). The dynamic deposition rate shown is the layer thickness deposited at a substrate speed of 1 m/min. These tests were performed at the pilot coater at Fraunhofer ISE.

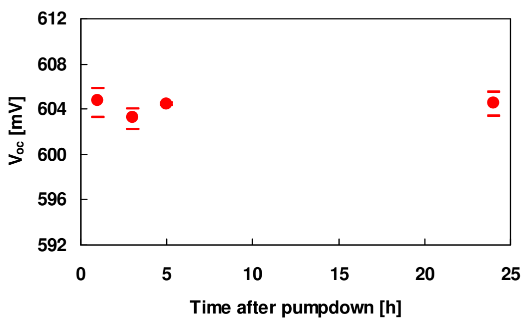

Figure 6: Measurements of open circuit voltages of mc cells show no bad influence of residual gases if SiN:H is deposited by sputtering shortly after pumpdown

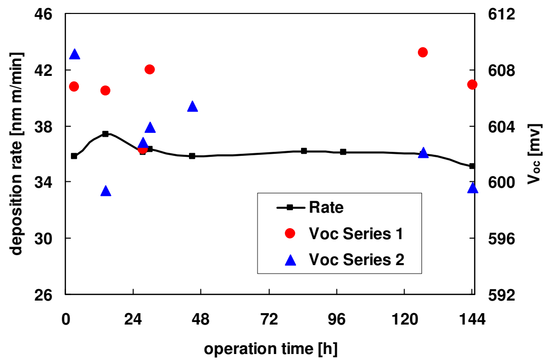

Figure 7: Sputtering processes can run several days without any maintenance break; open circuit voltages of mc cells show no trend in performance during the operation time of the SiN:H sputter deposition

Based on the experience collected with the pilot coater at Fraunhofer ISE, throughputs and costs of ownerships were calculated for an industrial coater with a coating width of 1600 mm ("ATON 1600"). In a coater with one single sputter cathode, already an annual capacity of 50 MW or 14.000.000 wafers (156 mm x 156 mm) can be reached. By adding a second cathode ("ATON 1600/2"), these values can be doubled to 100 MW or 28.000.000 wafers, respectively. Some operating figures are summarized in table I. At such throughputs, the estimated expected costs of ownership for sputtering are comparable or even lower than for PECVD, the current state of the art technology for SiN:H. Sputtering additionally features a silane-free process, long maintenance cycles and an excellent layer homogeneity.

	ATON 1600/1	**ATON 1600/2**
Number of sputter cathodes	1	2
Coating width (mm)	1600	1600
Wafers per carrier	45	45
Cycle time per carrier (s)	96	48
Throughput/h (156x156 mm^2)	1700	3400
Approx. Output (MW_p/year)	50	100

Table I: Operating figures of inline sputter coaters for the deposition of SiN:H as AR and passivation layer on multi-crystalline solar cells

The first industrial sputter coater (type ATON 1600, fig. 8) is momentarily in the commissioning phase and will go into operation in fall 2005.

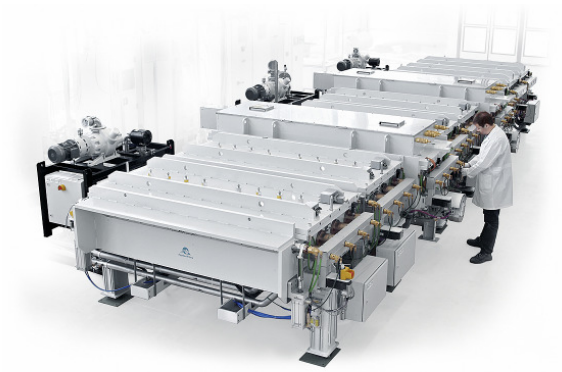

figure 8: Industrial inline sputter coater with a coating width of 1600 mm (“ATON 1600”); annual throughputs see table I.

5 CONCLUSION

Sputtering is an industrially proven coating technology used for mass production (e. g. architectural and display glass). Excellent layer thickness uniformities of 2.5 % on substrates and from substrate to substrate are reached.

Sputtered SiN:H AR and passivation coatings on wafer based solar cells yield the same quality as PECVD nitrides, whereas no silane is needed for the process. The index of refraction and the hydrogen content of the deposited SiN:H coatings can be controlled independently.

One week of continuous operation without maintenance break are typical for sputter processes; a quick production ramp up after maintenance is possible. With two sputter cathodes only, annual outputs of 100 MW at low cost of ownership are reached.

Sputtered SiN:H AR and passivation coatings have a high potential for use in future cell lines.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

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