DEVELOPMENT OF AN IN-LINE CAPABLE SPUTTERING PROCESS OF SILICON NITRIDE FOR CRYSTALLINE SILICON SOLAR CELLS

S. Scholz[1], S. Voser[2], G. Dovids[2], H. Haverkamp[1], G. Hahn[1,3]
[1] University of Konstanz, Department of Physics, 78457 Konstanz, Germany
[2] OC Oerlikon Balzers AG, Iramali 18, FL-9496 Balzers, Liechtenstein
[3] also with Fraunhofer Institute for Solar Energy Systems (ISE), Heidenhofstr. 2, 79110 Freiburg, Germany

ABSTRACT: The purpose of this work is to develop a high rate sputtering process for the deposition of silicon nitride antireflection coatings for crystalline silicon solar cells. Our goal is to achieve a cycle time that allows for the processing of single wafers without a reduction of the production line throughput. We have varied several processing parameters such as process gas composition and individual gas flows into the process chamber as well as different deposition rates. In order to assess the performance of the deposited layers with respect to their passivation quality complete cells were processed on monocrystalline Czochralski wafers (125x125 mm^2). We have found that the implementation of molecular hydrogen as a process gas has a detrimental effect on the passivation quality of the deposited layers. Furthermore, a clear influence of the sputtering rate on the overall cell performance can be seen. We have achieved a cell efficiency of 17.5% applying a standard screen printed process.
Keywords: Antireflection Coating, Silicon-Nitride, Sputtering

1 INTRODUCTION

The plasma enhanced chemical vapor deposition (PECVD) of silicon nitride (SiN_x) is currently the dominating technology for antireflection coating of crystalline silicon solar cells. The deposited layers generally show very little light absorption and a good passivation quality with regard to the cell surface as well as the bulk defects of multicrystalline substrates. The process technology however features some drawbacks: since the deposition can take up to several minutes only a batch process is suitable to maintain a high throughput, which in turn requires a considerable footprint in the production line design. The systems can involve expensive and intricate wafer handling systems limiting machine throughput and causing an increased breakage rate. Furthermore, the SiN_x layer is generated from an atmosphere containing ammonia (NH_3) and highly explosive silane (SiH_4). This requires additional safety measures to be taken for the entire installation driving up the process costs. Some PECVD systems that are commercially available additionally demand frequent cleaning of the wafer carriers as well as the deposition chambers. This reduces overall machine uptime and increases the maintenance costs.

Sputtering is a widely used technology for applying thin films of arbitrary materials on surfaces today, but it is still rarely used in crystalline silicon solar cell production.

Replacing the PECVD technology by using a high rate sputtering process yields two main advantages: silane can be avoided in the deposition process and the batch size can be reduced thus significantly simplifying wafer handling and reducing the machine footprint.

The broad spectrum of different coatings that can be applied makes the sputtering technology suitable not only for front side antireflection coating but several other applications like rear side passivation and metallization.

Based on results that have been presented by Wolke et al. [1] it is the goal of this work to develop an in-line sputtering process suitable for the formation of a SiN_x antireflection coating.

2 CELL FABRICATION PROCESS

Cells were fabricated on 125x125 mm^2 pseudosquare monocrystalline Czochralski wafers from Deutsche Solar with a specific resistivity of 1.5 Ωcm and a thickness of 210 and 240 µm. The sheet resistance of the phosphorus doped emitter was 50 Ω/sq.

All wafers were textured in an alkaline etch solution of KOH and isopropanol producing random pyramids on the surface. The metallization of the cells was done by screen printing and co-firing of conventional metal pastes.

Figure 1: Scheme of cell processing steps

3 DEPOSITION

The deposition system we used for the ARC layer is the new Oerlikon 'Solaris'. This new system is a high-speed single wafer-sputtering machine, which is designed similar to high throughput production systems used in the optical disk industry for the manufacturing of DVD and Blu-ray types of disks. The approach of this specific production technology is 'single substrate' handling combined with a high throughput – for the Solaris in this case 1200 wafers per hour.

Single substrate handling and processing has several advantages: first, substrate handling becomes simplified and only requires 2x3 m in footprint (including automation and handling), which is considerably less compared to current ARC production tools. Another advantage is that the target change times and shield cleaning are only a matter of minutes rather than hours , allowing to go back to cell production within a relatively short time.

Furthermore, each wafer is handled and coated in the same manner and therefore undergoes the same process, which helps to achieve narrow variation of several cell properties in the final product.

Figure 2: Oerlikon Solaris 6 system

The Solaris comes with six individual pulsed DC process chambers. The multi chamber design provides flexibility (up to six different layer materials possible) and will allow various configurations and processes as PVD (DC, DC pulsed, RF), CVD, PECVD, Etch, Annealing, etc.. Process conditions can be individually varied over a wide range for the optimization of the deposition process. The patented multi source cathode can hold up to four different target materials.

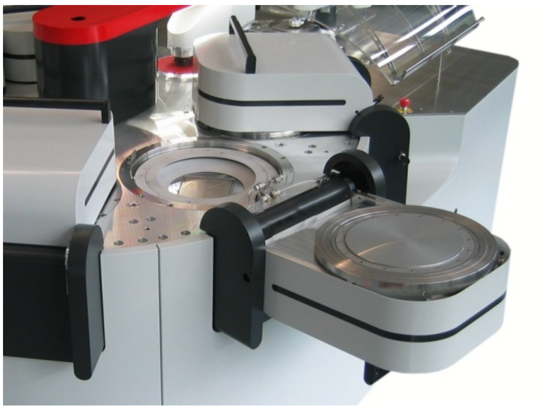

Figure 3: Opened process chamber with Si-target

Due to a simple carrier system design different substrate sizes and materials can be processed at minimum modification costs. Not only the front side of a wafer can be coated: backside passivation and metallization is another beneficial future application for this tool.

4 VARIATION OF DEPOSTION RATE

We observed an influence of the sputter rate on the quality of the SiN_x layer. It was found by Wolke et al. [2] before that lower sputter powers lead to better surface passivation. We measured a decrease in V_{OC} and accordingly in cell efficiency when increasing the deposition rate of SiN_x on the wafer, as shown in figure 2. Subsequent measurements of the internal quantum efficiency confirm that the front surface passivation properties of the SiN_x layer are dependent on the sputter rate.

The results of the IV-measurements are shown below in table I.

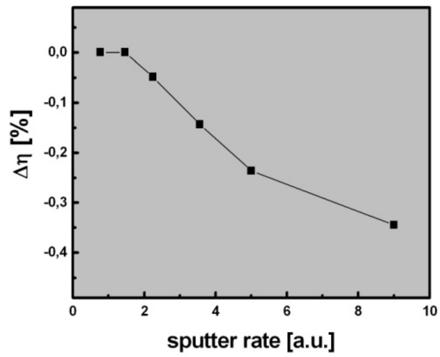

Figure 4: Losses in SiN_x layer quality with increasing sputter rate decreases the cell efficiency.

Table I: Results from IV-measurements for the best set of processing parameters (averaged over 6 cells).

	V_{OC} [mV]	J_{SC} [mA/cm^2]	FF [%]	η [%]
best cell	623.7	36.0	78.1	17.5
average	620.8	35.5	78.3	17.3

The applied layers of SiN_x did not contain significant amounts of hydrogen in this experiment.

5 IMPLEMENTING HYDROGEN

The passivation capability of hydrogen implemented in the SiN_x layer is well known. With the goal of introducing hydrogen into the layer of silicon nitride, molecular hydrogen was implemented as an additional process gas. The flow of molecular hydrogen into the process chamber was varied.

It was found that adding molecular hydrogen into the chamber has no positive effect on the passivation quality of the layer. Instead, a very high flow of molecular hydrogen into the chamber led to blistering of the SiN_x layer during contact sintering. Figure 5 shows the nearly proportional negative effect of adding hydrogen in molecular form as process gas.

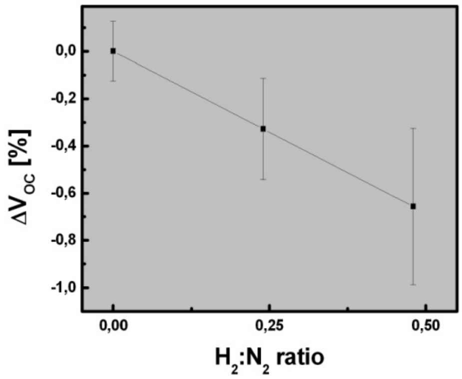

Figure 5: Losses in V_{OC} by implementing hydrogen in SiN_x with H_2 as process gas.

Implementing hydrogen in the SiN_x layer by adding NH_3 as process gas yielded better results. On the other hand, adding ammonia can lead to strong absorption of the SiN_x:H layer in the short wavelength regime. So finding the right process parameters is essential.

6 SUMMARY

In this paper we present the latest results in the development of a silicon nitride antireflection coating (ARC) applied by DC-sputtering. Tests have been performed on monocrystalline silicon substrates using a standard screen printed metallization approach. In a first set of experiments it was found that the applied deposition rate has a strong effect on the overall cell performance. A variation of the process parameters is able to significantly enhance the cell performance. The implementation of molecular hydrogen into the sputtering process was investigated. It was found that molecular hydrogen is not suitable for an introduction of hydrogen into the ARC coating. An increased content of hydrogen in the process atmosphere leads to blistering of the silicon nitride layer and a decrease of the open circuit voltage (V_{OC}). Without the implementation of hydrogen a cell efficiency of 17.5% was reached on 125x125mm² Czochralski wafers with a specific resistivity of 1.5 Ωcm with a fully screen printed metallization.

7 OUTLOOK

To develop a deeper understanding of the influence of the different process parameters a thorough investigation of the properties of the applied layers has to be done. Especially, FTIR (Fourier Transformed InfrarRed spectroscopy) measurements will enable us to further characterize the SiN_x coating and optimize it with respect to hydrogen implementation in order to further improve it for the application on multicrystalline substrates.

7 ACKNOWLEDGEMENTS

We would like to thank S. Ohl and B. Rettenmaier for partial processing and extensive technical support.

REFERENCES

[1] W. Wolke, A. Jäckle, R. Preu, S. Wieder, M. Ruske; Proc. 19th EU PVSEC, Paris 2004, 419-422.
[2] W. Wolke, J. Catoir, R. Preu, G. Emanuel, J. Liu, M. Ruske; Proc. 20th EUPVSEC, Barcelona 2005, 733-736.