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ATMOSPHERIC PRESSURE CHEMICAL VAPOR DEPOSITED ALUMINUM OXIDE / SILICON NITRIDE STACKS FOR PERC AND PERT SOLAR CELL CONCEPTS WITH HIGH PASSIVATION QUALITY

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ABSTRACT: PERC (Passivated Emitter and Rear Cell) cells based on p-type crystalline Si and PERT (Passivated Emitter, Rear Totally diffused) cells based on n-type crystalline Si are getting more and more attractive in the commercial solar cell market. As a result of the highly competitive market, a low-cost production reached by high through-put and low upkeep is necessary. Atmospheric chemical vapor deposition (APCVD) tools fulfill these requirements and provide necessary high layer quality for high-efficiency solar cell production. Aluminum oxide (AlO_x) layers may in certain situations reach a surface passivation quality higher than atomic layer deposition (ALD) based AlO_x layers. In this contribution we demonstrate excess minority charge carrier lifetime values τ_{eff} up to 15 ms (surface recombination velocity S <0.3 cms-1) on n-type Czochralski-Si for undiffused samples as well as emitter saturation current density values j0e down to 21 fA/cm^2 on a 65 Ω/sq p$^+$ emitter for fired AlO_x/SiN_y:H stacks, common to PERC and PERT solar cell designs, respectively. We also determined the influence of reaction energy depending on heat delivery during APCV-deposition on the layer growth leading to a high temperature stable, low-pinhole density and blistering free layer (stack).
Keywords: APCVD, Passivation, PERC, PERT, AlOx

1 INTRODUCTION

PERC (Passivated Emitter and Rear Cell) cells based on p-type crystalline Si and PERT (Passivated Emitter, Rear Totally diffused) cells based on n-type crystalline Si are getting more and more attractive in the commercial solar cell market. As a result of the highly competitive market, a low-cost production reached by high through-put and low upkeep is necessary. Atmospheric chemical vapor deposition (APCVD) tools fulfill these requirements and provide the necessary high layer quality for high-efficiency solar cell production. Based on trimethyl-aluminum and oxygen as precursors, aluminum oxide (AlO_x) layers [1,2] are deposited with the ability of reaching a surface passivation quality compared to atomic layer deposition (ALD) based AlO_x layers [3]. Due to higher deposition temperatures, APCVD AlO_x layers achieve higher temperature stability [4] preventing blistering effects [5] for peak firing temperatures up to at least 900°C. The blistering effect occurs when hydrogen accumulates at the layer interface at high temperatures (e.g. firing) [6] and may leads to a severe loss of passivation quality. Pin holes often occur in combination with an additional SiN_y:H layer due to high layer density or inhomogeneous deposition [7]. In addition to the reduction of passivation quality, pin holes may lead to shunting for metallized solar cells. Hence, the avoidance of these effects by investigating layer properties and the influence of reaction energy is necessary for the application of APCVD AlO_x/SiN_y:H layer stacks in PERC and PERT cell concepts [8].

2 EXPERIMENTAL

During sample preparation, the mono-crystalline Czochralski (Cz) Si wafers (n-type 1 or 7 Ωcm) are etched and cleaned. The samples are textured using a KOH based alkaline solution with alcohol-based additives or chemically polished using a HNO_3/HF solution.

Boron silicate glass (BSG) is deposited in an APCVD system in order to form a p$^+$ emitter for one of the sample groups. AlO_x is deposited by an atmospheric pressure APCVD roller system as well as by a plasma-assisted atomic layer deposition (ALD) tool on both, undiffused and emitter bearing, sample groups. The wafers are subsequently coated with SiN_y:H using a semi-remote plasma-enhanced (PE)CVD tool. The passivation quality is determined by applying photo conductance decay measurements to determine effective excess minority charge carrier lifetime τ_{eff}, the optical properties are investigated by ellipsometry measurement and optical microscopy imaging. The general process flow is schematically shown in Fig. 1.

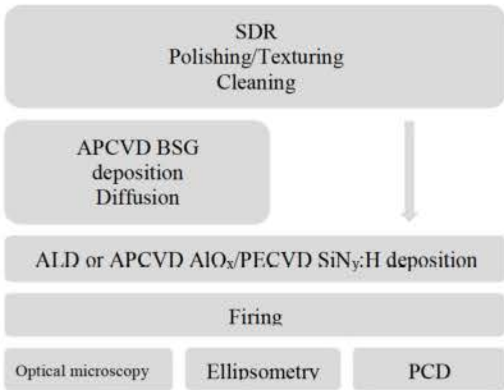

Figure 1: Schematic process flow of samples shown in the results section.

3 RESULTS AND DISCUSSION

3.1 Influence of reaction energy

The APCVD technique relies on highly exotherm reactions of the precursor gases and the substrate. Compared to other CVD techniques (e.g. PECVD [9]), the reaction energy for nucleation of the film on the substrate surface is only provided by the infrared-heated Si substrate temperature. Hence, the height of the deposition set temperature can impact growth and thus the properties of the layers.

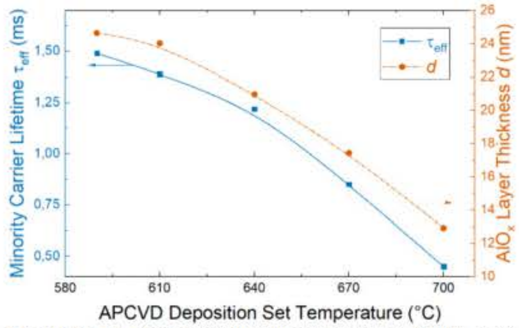

Figure 2: τ_{eff} (left axis) and layer thickness (right axis) dependent on the APCVD deposition set temperature.

To investigate the influence of deposition temperature on layer properties, APCVD AlO_x/SiN_y:H layers are deposited on textured 1 Ωcm n-type Cz-Si. As-deposited AlO_x layers on chemically polished reference wafers are prepared for measuring the layer thickness. Fig. 2 shows τ_{eff} as well as layer thickness dependent on deposition set temperature. For an increasing deposition temperature, passivation quality as well as layer thickness decrease. Literature shows that layer thickness values above a certain thickness (>10 nm) has no influence on the passivation quality of APCVD AlO_x [10]. A likely explanation for the reduced layer thickness in this case (Fig. 2) is a densification of the layer at higher deposition temperatures. H that could support surface passivation from the SiN_y:H on top of the AlO_x layer may thus not be able to diffuse as easily through the AlO_x into the Si wafer.

Note that there is no saturation behavior of layer thickness and effective lifetime below a set deposition temperature of 590°C in Fig. 2 since there is no AlO_x layer growth at lower temperatures.

3.2 Impact of firing step

High temperature stability of AlO_x layers is fundamentally necessary for most solar cell applications. Therefore, differently deposited AlO_x layers are capped by SiN_y:H and optically investigated after a high temperature firing step of 810°C set peak temperature. Fig. 3A shows the microscopy image of SiN_y:H capping on top of ALD AlO_x. For these deposition parameters achieving same layer thicknesses as for APCVD AlO_x, a large amount of blisters (ablation of layers due to H accumulation beneath) occurs. Due to high layer densities and comparably low deposition temperatures, the layer is thus deemed not temperature stable. In areas with less amount of blistering, pin holes are likely to be present. Hydrogen that would otherwise lead to a blistering is able to escape through the pin holes. The latter can also be seen in Fig. 3B which shows similarly capped APCVD AlO_x deposited at 700°C set temperature. Compared to Fig. 3A, there is no blistering. In Fig. 3C with AlO_x deposited at 590°C set temperature, neither blistering nor pin-holes can be observed. This shows the high temperature stability of APCVD AlO_x on the one hand, and confirms the higher density of the APCVD AlO_x layers at higher deposition temperatures.

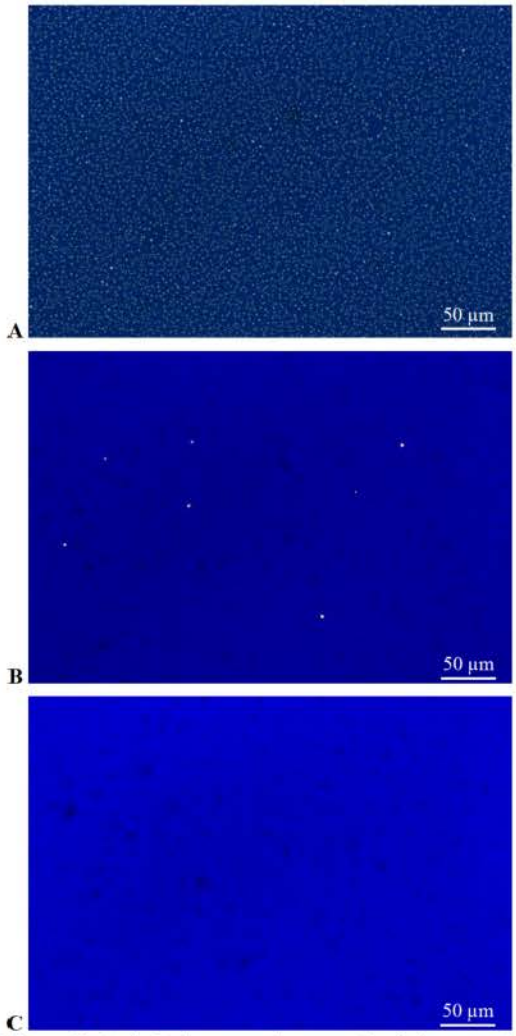

Figure 3: Optical microscopy images after firing step of AlO_x/SiN_y:H stacks deposited using ALD (A), APCVD at 700°C set (B) and APCVD at 590°C set (C) for AlO_x deposition. Blistering is only visible in (A), pin holes are seen in (A) and (B).

3.3 Passivation quality

For high-efficiency solar cells, well passivating layers leading to a low surface recombination velocity are crucial. For application in commonly used p-type PERC cells, an APCVD AlO_x/SiN_y:H layer stack on an undiffused sample group (7 Ωcm n-type Cz-Si) is analyzed regarding τ_{eff} at specified injection level of 10^{15} cm^{-3}. By determining τ_{eff}, a calculation of the maximum surface recombination velocity S is possible. Since in contrast for n-type PERT cells the passivation of the p^+ emitter is relevant, symmetrically processed samples are investigated to measure the emitter saturation current density j_{0e}.

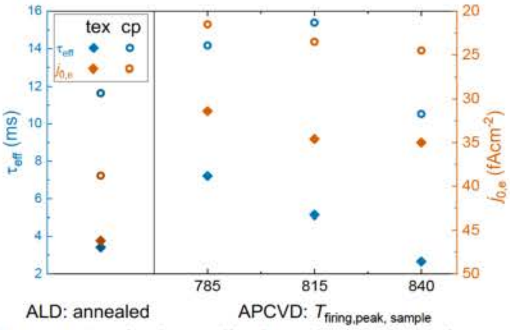

Figure 4: Passivation quality determined by measuring τ_{eff} for undiffused samples (left axis, blue symbols) and by measuring j_{0e} for samples with a 65 Ω/sq p^+ emitter (right axis, orange symbols). Annealed ALD AlO_x reference in the left part of the graph, at a variety of temperatures fired APCVD AlO_x/SiN_y:H stacks reference in the right part of the graph.

Fig. 4 shows these values for chemical polished (cp) and as a proof-of-concept for textured (tex) samples. Beside the ALD reference which has no SiN_y:H on top and has been annealed at 400°C sample temperature, the APCVD AlO_x layer stacks are fired at different temperatures. The ALD sample is called reference since this passivation technique usually achieves the best passivation values. Here, it is shown that except for a very high firing temperature APCVD AlO_x capped with SiN_y:H exceeds the ALD values. For the chemically polished samples which generally reach higher passivation quality, τ_{eff} values up to 15 ms can be achieved. From that, a maximum S of 0.3 cms^{-1} can be calculated. Also, j_{0e} values as low as 21 $fAcm^{-2}$ are reached.

Although the trend of passivation quality indicates a decrease of passivation quality with increasing firing temperature, the stability is very high for the investigated and PERT-typical firing temperature range. The layers can resist high temperature firing steps and therefore are well suited for high-efficiency solar cell processes.

4 CONCLUSION

In conclusion, APCV-deposited AlO_x/SiN_y:H stacks show high passivation quality. Surface recombination velocities of below 0.3 cms^{-1} and emitter saturation current values down to 21 $fAcm^{-2}$ make them very well suited for PERC and PERT cell architectures in addition to the advantages of the APCVD technique. The layer stacks show no blistering effect compared to ALD AlO_x. Minimizing the reaction energy leads to an increase in passivation quality and less pin hole formation during the firing step which can be attributed to the deposition temperature dependent layer growth and elemental composition.

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REFERENCES

[1] R. Hezel et al., J. Electrochem. Soc. 136, 518-523 (1989).
[2] L.E. Black and K.R. McIntosh, Appl. Phys. Lett. 100, 202107 (2012).
[3] K.O. Davis et al., Phys. Status Solidi RRL 7, 942-945 (2013).
[4] L.E. Black et al.,Sol. Energ. Mat. Sol. Cells 120, 339-345 (2014).
[5] B. Vermang et al., Sol. Energ. Mat. Sol. Cells 101, 204-209 (2012).
[6] L. Hennen et al., 38th IEEE PVSC, 2012, pp. 1049-1054.
[7] K. Domanský et al., Appl. Phys. Lett. 60, 2074-2076 (1992).
[8] B. Vermang et al., Progr. Photovoltaics Res. Appl. 20, 269-273 (2012).
[9] Q. Qiao et al., Appl. Surf. Sci. 305, 439-444 (2014).
[10] J. Engelhardt et al., 35th EUPVSEC, 2018, pp. 390-394.