EFFECT OF DIFFERENT ALOX PASSIVATION LAYERS DEPOSITED BY APCVD AND ALD ON LETID

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ABSTRACT: In this work the influence of AlO_x, acting as a barrier layer for in-diffusion of H from a H-rich dielectric layer, on the strength and kinetics of the LeTID (light- and elevated temperature-induced degradation) phenomenon is investigated. For this purpose, different AlO_x passivating layers deposited by different deposition methods, APCVD (atmospheric pressure chemical vapor deposition) and ALD (atomic layer deposition), are considered. Since the composition and material properties of the AlO_x layers fabricated in the two deposition systems are not exactly the same, the LeTID defect kinetics may differ. In the first experiment, by varying the AlO_x layer thickness, it could be confirmed that on Cz material the AlO_x layers grown by ALD and APCVD function as a barrier layer for H. In the second experiment, the comparison of the different AlO_x layers from APCVD and ALD is considered in more detail. The deposition temperature is varied for the respective methods, but the AlO_x layer thickness of 10 nm remains constant for all samples. To obtain conclusions on the LeTID behavior and the H content in the Si bulk, excess charge carrier lifetime and B-H measurements will be performed on the samples. Besides the AlO_x single layers, AlO_x/SiN_y:H stacks are also investigated. The results show that the APCVD AlO_x layer is more permeable to H than the AlO_x layer grown by ALD. Alternatively, the obtained results could also be explained assuming that the APCVD layer contains generally more H in the layer than the ALD AlO_x layer. The findings can help to better understand the origin of LeTID and find new processing sequences that can avoid or minimize the occurrence of LeTID, leading to higher stabilized efficiencies for high efficiency cell concepts.
Keywords: Degradation, Hydrogen, CVD Based Deposition

1 INTRODUCTION

Many high efficiency solar cell concepts such as PERC (passivated emitter and rear cell) are susceptible to degradation issues, reducing the efficiency over time. One of these phenomena is the LeTID (light- and elevated temperature-induced degradation) effect. The mechanism and the root cause of LeTID are not sufficiently understood yet. However, it has been shown that H plays an important role in LeTID [1-2]. The occurrence of LeTID was shown after firing of H-rich dielectric passivation layers such as SiN_y:H [3]. Since AlO_x layers represent a diffusion barrier for atomic H, the H content in the Si bulk can be affected by them [4].

The aim in this work is to investigate different AlO_x barrier layers that can influence the diffusion of H into the Si bulk in order to achieve a positive effect on the LeTID degradation behavior. Besides the variation of the layer thickness and the composition of the passivation layer, the deposition method can influence the LeTID effect. For this, the two different deposition methods APCVD (atmospheric pressure chemical vapor deposition) and ALD (atomic layer deposition) are investigated. In order to draw conclusions about the H content in the Si bulk, the concentration of BH pairs was determined via resistivity measurements.

2 EXPERIMENTAL

2.1 Sample preparation for AlO_x as diffusion barrier

B-doped Cz-Si wafers with a bulk resistivity of ~1 Ωcm serve as base material and were lasered to 5x5 cm². After saw damage removal and cleaning, the samples are gettered using a $POCl_3$ diffusion. The resulting emitter is removed in an etching step and the samples are cleaned again. Afterwards, the samples are deposited with AlO_x from ALD at 300°C and the thickness of the layer is varied from 10-25 nm. Since the deposition time is different for each layer thickness, the time was adjusted so that the samples have the same temperature profile. In addition, 75 nm SiN_y:H was deposited on the AlO_x layer. After firing at a temperature of $T_{sample,peak}$=813°C, samples were degraded at 80°C and at 0.9(1) suns. The effective lifetime τ_{eff} is determined using photoconductance decay (PCD) and evaluated at Δn=0.1·p_0, with p_0 being the doping density. To allow a better comparison of the degradation and regeneration behaviour, the lifetime equivalent defect density ΔN_{leq} is calculated from τ_{eff}.

2.2 Sample preparation for AlO_x from different deposition tools

Again, B-doped Cz-Si (~1 Ωcm) serve as base material. After saw damage removal and cleaning, AlO_x was deposited on the 5x5 cm² samples with two different deposition tools, APCVD and ALD. In addition to change of deposition methods, different deposition temperatures are also considered. With APCVD, AlO_x layers are deposited at 590°C and 690°C, and with ALD at 170°C and 300°C. However, the AlO_x layer thickness of 10 nm is the same for all samples. To investigate the influence of an additional SiN_y:H layer on LeTID and on the H content in the Si bulk, some of the samples were additionally coated on both sides with 75 nm SiN_y:H and fired at a temperature of $T_{sample,peak}$=813°C. The remaining samples, which are only coated with AlO_x, are also fired at the same temperature.
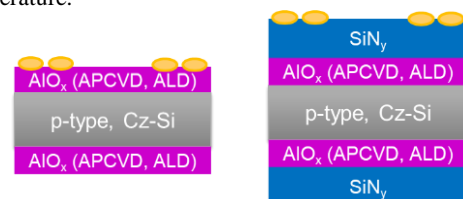

Figure 1: Schematic sample structure for B-H and lifetime measurements on fired samples with AlO_x (left) and fired samples with AlO_x/SiN_y stacks (right). Al contacts shown in orange.

For the determination of the BH pairs via resistivity measurement [5], aluminum was deposited on one side of the samples followed by laser fired contacting (LFC), see Fig. 1. For better statistics, two samples were processed for each variation. Analogous to the previous procedure, τ_{eff} is determined using PCD and the samples were degraded at 80°C and at 0.9(1). For the BH measurements the samples were annealed at 220°C in the dark.

3 RESULTS

Fig. 2 shows the resulting ΔN_{leq} of the samples, which are deposited with 0-25 nm thick ALD AlO$_x$ layers and an additional 75 nm thick SiN$_y$:H layer. As expected, the progression of ΔN_{leq} values shows a degradation and regeneration behavior. Within the first hour, ΔN_{leq} increases and reaches the maximum after about 0.5-2 h, followed by a decrease of ΔN_{leq}. It can be seen that the different AlO$_x$ layer thicknesses lead to a decrease in ΔN_{leq}. Compared to the 0 nm thick AlO$_x$ layer, the maximum value of the $\Delta N_{leq,max}$ decreases from 12 ms^{-1} to below 4 ms^{-1} for the 10 nm thick AlO$_x$ layer. Increasing the layer thickness to 15-25 nm does not lead to a further decrease of ΔN_{leq}. This could be due to a saturation value of AlO$_x$ with regard to H diffusion. These data confirm the results of [6].

The same experiment with variation of AlO$_x$ layer thickness was performed with APCVD. It could be shown that the APCVD AlO$_x$ layers also function as a barrier layer [7].
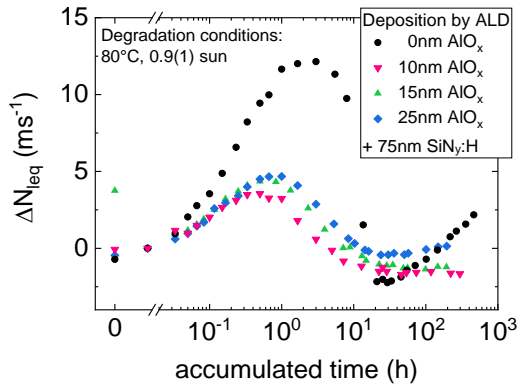

Figure 2: Lifetime equivalent defect density ΔN_{leq} over accumulated time (80°C, 0.9 suns) of AlO$_x$ layers of different thickness with an additional 75 nm SiN$_y$:H layer after firing.

When comparing the different AlO$_x$ layers from the two deposition methods, the layer thickness of 10 nm, which acts as a diffusion barrier (see Fig. 2), is the same for all samples. As mentioned earlier, the determination of the BH pairs is done by resistance measurement, but not every change in resistance can be attributed to the change in BH pairs. Depending on the treatment conditions, thermal donors could occur which can influence the change in resistance [8]. Since one hole is consumed for the formation of BH pairs from H2 in boron-doped silicon [9], the change in hole concentration -Δp is given. Thus, -Δp includes the change in BH pairs and the possible occurrence of thermal donors.
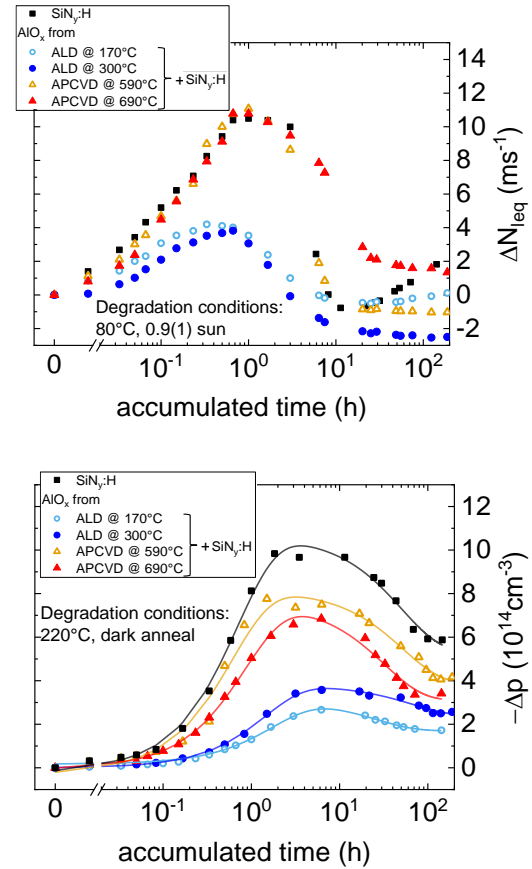

Figure 3: Lifetime equivalent defect density ΔN_{leq} (top) and change in hole concentration $-\Delta p$ with fit (bottom) over accumulated time of AlO$_x$ layers deposited by APCVD and ALD with an additional 75 nm SiN$_y$:H layer after firing.

Fig. 3 shows the defect density ΔN_{leq} and changing hole concentration -Δp over treatment time of the fired samples with AlO$_x$/SiN$_y$:H layers and SiN$_y$:H layer as reference. The ALD AlO$_x$ layers was deposited at 170°C and 300°C, and the APCVD AlO$_x$ layers at 590°C and 690°C. Also here, the progression of ΔN_{leq} shows a degradation and regeneration behaviour. The maximum of ΔN_{leq} lies for all samples around 1 h and as can be seen, that the maximum of ΔN_{leq} for the APCVD AlO$_x$ layers (~11 ms^{-1}) and for the SiN$_y$:H reference (~11 ms^{-1}) is higher than for the ALD layers (<4 ms^{-1}). During degradation the SiN$_y$:H reference and the APCVD AlO$_x$ layer have comparable ΔN_{leq} values but differs during regeneration. APCVD AlO$_x$ deposited at 690°C shows a flatter progression of regeneration compare to AlO$_x$ deposited at 590°C and SiN$_y$:H reference. Furthermore, except for the SiN$_y$:H reference and the ALD AlO$_x$ layer deposited at 170°C, the samples do not reach the minimum of ΔN_{leq} within 200 hours.

In the lower graph of Fig. 4 the changing hole concentration $-\Delta p$ is given. As mentioned in the experimental part, for the BH measurements two samples were processed for each variation, but since the data of the two samples is reproducible, only one sample per variation is shown in the graph. In the first hours $-\Delta p$ increases and reaches the maximum after about 2-10 h, afterwards $-\Delta p$ starts to decrease again before $-\Delta p$ starts to rise again after 200 h. Since it can be assumed that this second increase is not caused by the formation of BH pairs but by other

processes in the Cz-Si, e.g. thermal donors, the data are normalized to t=0. As can be seen, the maximum of -Δp for the APCVD AlO$_x$ layers (6-8·10^{14} cm^{-3}) is higher than for the ALD layers (<4·10^{14} cm^{-3}). Together with the results of the defect densities ΔN$_{leq}$ the APCVD layer appears to be more permeable to H diffusion from the SiN$_x$:H layer than the ALD layer. It could also suggest that the APCVD AlO$_x$ layer generally already contains more H than the ALD layer.

To get more insight into the influence of the different AlO$_x$ layers, AlO$_x$ samples with or without additional SiN$_x$:H layer are investigated. Fig. 4 shows the resulting ΔN$_{leq}$ and -Δp of the fired samples passivated either with AlO$_x$ only or with AlO$_x$/SiN$_y$:H. The AlO$_x$ layers are deposited with the ALD at 170°C and 300°C. Since the single APCVD AlO$_x$ layers have a very low effective lifetime (τ$_{eff}$< 1 µs) which affect the degradation behavior, the sample was not further analysed. Also here, the normalization was performed at time t=0.
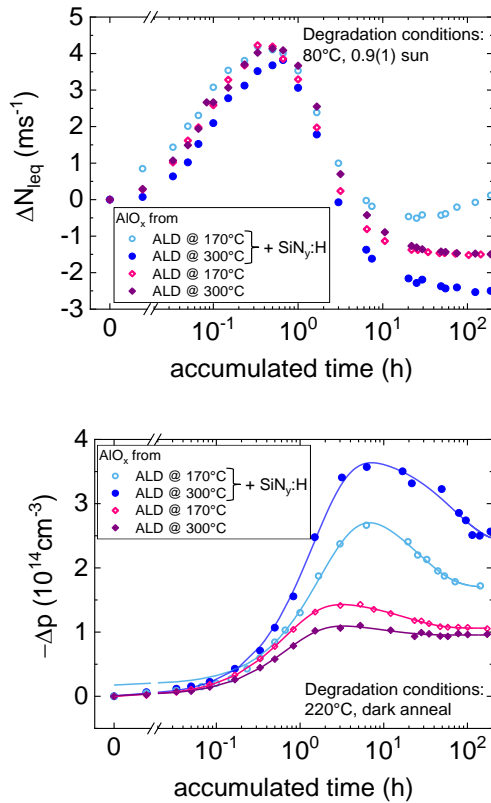

Figure 4: Lifetime equivalent defect density ΔN$_{leq}$ (top) and change in hole concentration –Δp (bottom) over accumulated time of single AlO$_x$ and AlO$_x$/SiN$_y$:H layers. AlO$_x$ layers deposited with ALD at 170°C and 300°C.

The ALD AlO$_x$ samples with and without SiN$_y$:H show the same defect kinetics. During degradation the deposition temperature does not seem to have any influence on ΔN$_{leq}$. However, the presence of an additional SiN$_y$:H layer appears to affect the regeneration kinetics. The minimum of ΔN$_{leq}$ is less than 30 hours for AlO$_x$/C stacks at ALD deposition of 170°C while the minimum is not reached within 200 hours for samples with single AlO$_x$ layer and for AlO$_x$/SiN$_y$:H stack at ALD deposition of 300°C. Thus, the deposition temperature seems to have an influence on the regeneration kinetics through the presence of a SiN$_y$:H

layer. In the lower graph of Fig. 4 the changing hole concentration –Δp is given. As can be seen, the maximum -Δp for the AlO$_x$/SiN$_y$:H layer (2-4·10^{14} cm^{-3}) is higher than for the single AlO$_x$ layer (<1.5·10^{14} cm^{-3}). Thus, as expected, an additional SiN$_y$H leads to more H in the Si bulk. Therefore, the additional SiN$_y$:H layer leads to a doubling of the hole concentration The deposition temperature does not appear to have a significant effect on -Δp.

4   CONCLUSION

Since the ALD AlO$_x$ shows lower defect density ΔN$_{leq}$ and changing hole concentration –Δp compared to AlO$_x$ deposited by APCVD, it seems that ALD AlO$_x$ has a stronger barrier effect than APCVD AlO$_x$. Besides the barrier properties, a general high amount of H in the APCVD AlO$_x$ layer compared to ALD AlO$_x$ can also be an explanation. The influence of different deposition temperatures of ALD or APCVD show no significant influence on the degradation kinetic but on the regeneration kinetic. Also, the samples with and without additional SiN$_y$H layer show comparable ΔN$_{leq}$ and –Δp values during degradation, but differ during regeneration. The influence of the temperature input during deposition is further described in [7]. Due to the thermal donors, the BH measurements on FZ material seem to be more suitable.

5   ACKNOWLEDGEMENT

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