

THERMAL STABILITY OF PECVD a-Si:H SINGLE AND PECVD a-Si:H + PECVD a-SiO_x:H DOUBLE LAYERS FOR SILICON SOLAR CELL REAR SIDE PASSIVATION

M. Hofmann¹, C. Schmidt¹, B. Raabe², J. Rentsch¹, R. Preu¹

¹ Fraunhofer Institute for Solar Energy Systems, Heidenhofstrasse 2, 79110 Freiburg, Germany,

² University of Konstanz, Fachbereich Physik, Photovoltaik-Abteilung, 78457 Konstanz, Germany

ABSTRACT

Hydrogenated amorphous silicon layers have been proven to potentially provide excellent passivation for crystalline silicon surfaces but typically show a sensitivity of the passivation effect to the thermal treatment of the samples after the deposition. This paper discusses the impact of different thermal processes in the range of 400°C to 850°C and of 3 s to 120 min on the passivation properties and on the hydrogen content of samples passivated with single a-Si:H and double a-Si:H + a-SiO_x:H layers. Furthermore, the hydrogen depth profile after deposition and thermal treatment at 400°C and 550°C was investigated by nuclear reaction analysis showing a hydrogen accumulation at the a-Si/c-Si interface for the high temperature. This is accompanied by a bubble formation at the interface at 700°C. Rehydrogenation of a-Si:H layers is performed and characterised by carrier lifetime and Si-H bond density analysis.

1. AMORPHOUS SILICON FOR SILICON SURFACE PASSIVATION

Hydrogenated amorphous silicon (a-Si:H) layers are in use for many years within the photovoltaic community. Thin film solar cells deposited on glass substrates or deposited amorphous emitters on crystalline silicon wafers as found in the HIT (heterojunction with intrinsic thin layer) structure [5] can be found in industrial production. Also for the passivation of crystalline silicon wafer surfaces, it has been shown that a-Si:H layers can provide an extremely effective means to enhance the minority carrier lifetime [1, 3, 4]. However, one typical characteristic of a-Si:H layers is their relatively low thermal stability. This limits the applicability of a-Si:H passivation in industrial production lines. This paper discusses the results of a few experiments on this topic.

2. FAST FIRING OF a-Si:H LAYERS

Typically, the industrial production of crystalline silicon solar cells includes the screen-printing of metal pastes on front and rear and the subsequent rapid thermal firing (RTF) that leads to the formation of local front contacts by etching through the anti-reflection coating and forming a contact to the underlying silicon emitter. Additionally, an Al back surface field is formed

at the same time. The peak wafer temperature used is typically in the range of 800°C ... 850°C. Hence, the surface passivation should withstand this step if it is deposited prior to the RTF.

When a PECVD a-Si:H was deposited at the surface of a crystalline Si wafer (FZ, p-type, Boron doped, 1 Ω cm, thickness: 250 μm, shiny etched surfaces) and fired in a metal belt furnace at a peak wafer temperature of 700°C, the formation of bubbles at the c-Si/a-Si:H interface was observed. See figure 1.

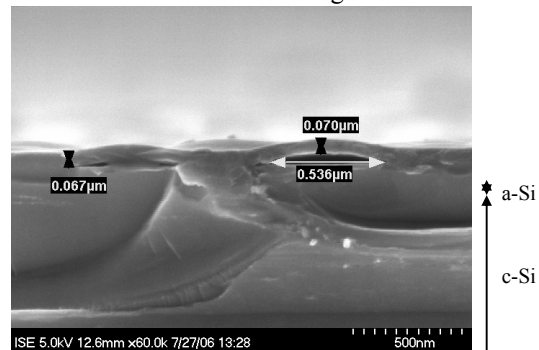


Figure 1: SEM image of the edge of a c-Si wafer with 70 nm a-Si on top after thermal treatment of 700°C for 3 s. Bubble formation (hydrogen) is visible.

In parallel to the bubble formation, an accumulation of hydrogen at the c-Si / a-Si:H interface was found by nuclear reaction analysis (NRA) with increasing post-deposition processing temperature [2]. See figure 2.

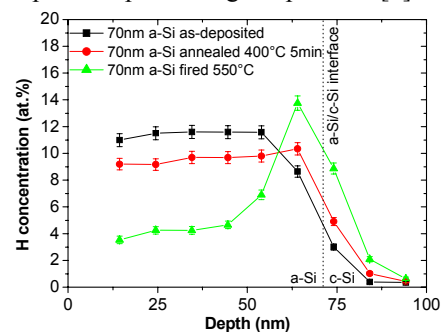


Figure 2: Hydrogen depth profile of a-Si:H layers as-deposited and after thermal treatment. Hydrogen accumulation at interface for fired sample accompanied by low passivation quality [2].

3. a-Si:H + SiO_x DOUBLE LAYERS

The incorporation of an additional PECVD a-SiO_x:H layer on top of the a-Si:H leads to an improved thermal stability of the passivation quality of a-Si:H at a c-Si

surface. See figure 3.

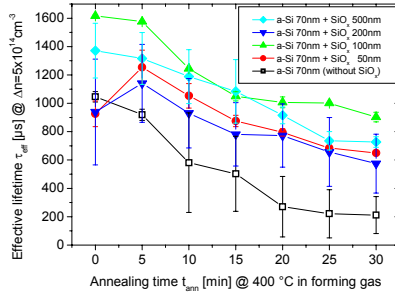


Figure 3: Carrier lifetimes of symmetric ($\text{SiO}_x/$) a-Si/c-Si/a-Si ($/\text{SiO}_x$) samples after stepwise annealing. a-Si + SiO_x systems show best stability [2].

The thickness of the SiO_x layer does not have a significant influence on the thermal stability. The main effect is due to the fact that a SiO_x layer is present.

Hydrogen depth profiling using NRA showed that the hydrogen accumulation at the interface after a low-temperature RTF at 550°C is lowered when a SiO_x layer is present. Also the measured carrier lifetime could be kept at a higher level compared to the single layer a-Si:H sample. See figure 4.

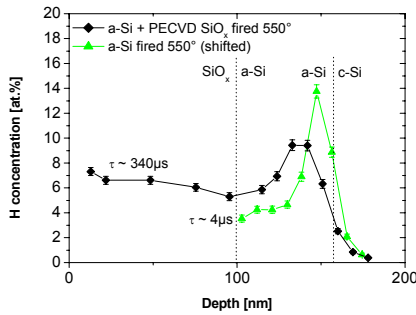


Figure 4: Hydrogen depth profile of a-Si:H and a-Si + SiO_x stack layers after thermal treatment. H peak reduced for stack system along with better passivation [2].

4. REHYDROGENATION OF a-Si:H LAYERS

Hydrogen plays a crucial role in the crystalline silicon surface passivation properties of a-Si:H layers. A rehydrogenation experiment according to figure 5 was conducted. First, the samples were subjected to 4 different thermal processes (FGA at 400°C for 30 min or 120 min and RTF at 550°C and 850°C) which led to a decrease of the hydrogen content. Next, additional hydrogen was supplied to the samples using a

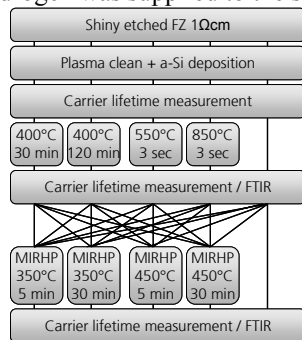


Figure 5: Process flow of rehydrogenation experiment.

microwave induced remote hydrogen plasma (MIRHP). The hydrogen content was close to zero for the RTF 850°C sample after RTF and after MIRHP. For the other samples holds the shorter the MIRHP process and the lower its temperature, the more hydrogen could be detected.

However, the additional hydrogen in the samples not always led to an increase of carrier lifetime. See figure 6. This can be attributed to the fact that typically only a small share of hydrogen is actively lowering the interface state density that helps lowering the recombination rate at the c-Si/a-Si interface. But one can state that starting with a certain amount of hydrogen only good lifetimes $>400\mu\text{s}$ were found.

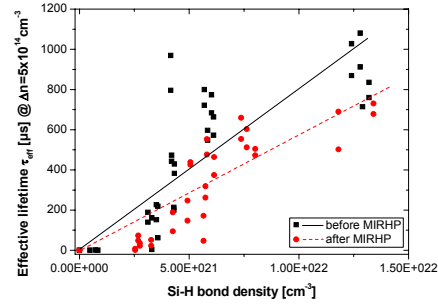


Figure 6: Dependency of lifetime on Si-H bond density before and after rehydrogenation (MIRHP).

CONCLUSIONS

Hydrogen is important for surface passivation. A sufficient amount is necessary to achieve a good passivation. A strong hydrogen accumulation at the a-Si/c-Si interface after a thermal treatment is found to be linked with a strong decrease of carrier lifetime. An additional PECVD SiO_x layer improves the thermal stability of a-Si:H.

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