



HAL
open science

Blistering of Al₂O₃/a-SiN_x:H stacks: analysis of the submerged part of the iceberg by colored picosecond acoustic microscopy

Fabien Lebreton, Arnaud Devos, Etienne Drahi, Patricia de Coux, Francois Silva, Sergej Filonovich, Pere Roca I Cabarrocas

► **To cite this version:**

Fabien Lebreton, Arnaud Devos, Etienne Drahi, Patricia de Coux, Francois Silva, et al.. Blistering of Al₂O₃/a-SiN_x:H stacks: analysis of the submerged part of the iceberg by colored picosecond acoustic microscopy. 2017 IEEE 44th Photovoltaic Specialists Conference (PVSC), Jun 2017, Washington DC, United States. pp.464-466, <10.1109/PVSC.2017.8366749>. <hal-04779794>

HAL Id: hal-04779794

<https://hal.science/hal-04779794v1>

Submitted on 15 Nov 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization

Blistering of $\text{Al}_2\text{O}_3/\text{a-SiN}_x\text{:H}$ stacks: analysis of the submerged part of the iceberg by colored picosecond acoustic microscopy

Fabien Lebreton^{1,2,3}, Arnaud Devos⁴, Etienne Drahi^{1,3}, Patricia de Coux¹, François Silva^{2,3}, Sergej Filonovich^{1,3}, Pere Roca i Cabarrocas^{2,3}

¹Total S.A. Renewables, 2 Place Jean Millier, 92078 Paris La Défense cedex, France

²LPICM, CNRS, Ecole Polytechnique, Université Paris-Saclay, 91128 Palaiseau, France

³Institut Photovoltaïque d’Ile-de-France (IPVF), 8 rue de la renaissance, 92160 Antony, France

⁴IEMN UMR 8520, Dpt ISEN, 41 Bd Vauban, 59046 Lille Cedex, France

Abstract — Blistering of $\text{Al}_2\text{O}_3/\text{SiN}_x\text{:H}$ stacks has been regularly reported over the last decade. Despite several studies, it has not been possible to link blistering density and lifetime degradation. In this work we demonstrate the use APiC technique to probe the c-Si/ Al_2O_3 interface. It allows us to show that it might not be the delaminated surface fraction which rules the lifetime degradation but most likely the interface quality of non-delaminated areas. Blistering is the top of the iceberg; characterizing the interface with the high sensitivity provided by APiC is a breakthrough.

I. INTRODUCTION

Aluminum oxide (Al_2O_3) capped with amorphous silicon nitride (a-SiN_x:H) is nowadays a common passivation stack for p-type surfaces [1]. The combination of atomic layer deposition (ALD) for Al_2O_3 with plasma-enhanced chemical vapor deposition (PECVD) for the capping made its success. It is due to very high passivation properties provided by the first one and the good thermal stability ensured by the second one [2]. Performances of such stacks seem to be ascribed to the large amount of hydrogen released by the stack during post-deposition thermal treatments [3]. This hydrogen can easily diffuse to the c-Si/ Al_2O_3 interface passivating remaining dangling bonds. The main drawback of this gas release is the well-known blistering of the passivation stacks, which can deteriorate their optical and electrical properties [4, 5]. Up to now, it has not been possible to establish a direct link between blistering density and passivation quality [5, 6]. One way to limit blistering is to grow a thin silicon oxide layer prior to ALD deposition [7]. This layer is a good nucleation surface for the ALD process allowing a direct layer by layer growth mode rather than the island growth during the first ten cycles [8].

These observations reported in the literature and our own observations of non-homogeneously delaminated blisters (Fig. 1) let us to suggest an important contribution of the adhesion parameter. The proportion of delaminated surface due to blistering is generally lower than 10% [5], but it seems to be enough to deteriorate the whole minority carrier lifetime. We think that there is no direct relation between blistering density and lifetime. Passivation quality might be ruled by surface located between blisters, *i.e.* within supposed “healthy” areas. In this work we propose to assess these interface properties by colored picosecond acoustic microscopy (APiC) [9].

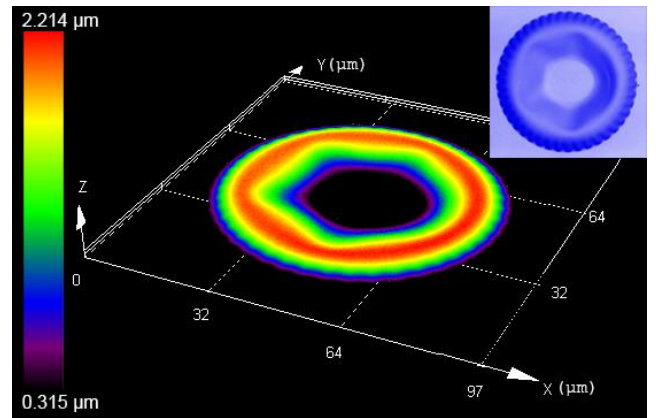


Fig. 1. Topography of a non-uniformly delaminated blister obtained by confocal microscopy. The colored scale indicates the height in the Z direction. Inset: Top view of the blister.

TABLE I

SUMMARY OF SAMPLES PARAMETERS AND MEASURED PROPERTIES. LIFETIME VALUES ARE DETERMINED BY QSS-PC. BLISTERING DATA ARE ACQUIRED BY OPTICAL MICROSCOPY.

Sample	Al_2O_3 thickness (nm)	Post-Deposition Annealing		τ_{eff} (μs)	Blistering		
		Duration (min)	Temperature ($^{\circ}\text{C}$)		Density (blister/ cm^2)	Average diameter (μm)	Delaminated area (%)
#1	30	-	-	1633	2760 ± 420	60 ± 7	7.8 ± 3.4
#2	30	10	380	1612	1820 ± 60	21 ± 4	0.6 ± 0.3
#3	6	10	380	3860	0	0	0

II. EXPERIMENTAL APPROACH

$\text{Al}_2\text{O}_3/\text{a-SiN}_x\text{:H}$ symmetrically processed c-Si samples were produced. Their process parameters and main numerical results are summarized in Table I. Al_2O_3 is deposited on both sides of the c-Si substrate in the same run thanks to a specific substrate holder which allows diffusion of precursors to both surfaces. An Al_2O_3 thickness of 30 nm was chosen to promote blistering on samples #1 and #2. A reference sample using a thickness of 6 nm to avoid blistering was chosen according to previous studies [10]. The c-Si wafers were double-side polished, float-zone, p-type, $\langle 100 \rangle$, with a resistivity of 1–5 $\Omega\cdot\text{cm}$ and a thickness of 280 μm . After HF dip, Al_2O_3 deposition was carried out at 250 $^\circ\text{C}$. Some samples received post-deposition annealing (PDA) in a forming gas atmosphere to activate hydrogen desorption. After this optional PDA, all samples received a 75 nm PECVD a-SiN_x:H capping at a substrate temperature of 300 $^\circ\text{C}$. A post-capping annealing for 20 min at 380 $^\circ\text{C}$ in forming gas atmosphere was then carried out to mimic the thermal budget of Ni/Cu plating metalization developed at IPVF [11].

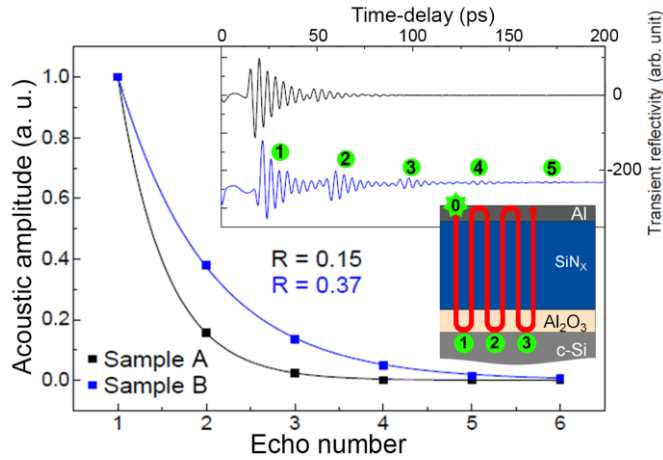


Fig. 2. Principle of APiC measurement. Inset graph and sample sketch: a thin aluminum layer is evaporated on top of the $\text{SiN}_x\text{:H}/\text{Al}_2\text{O}_3$ passivation stack. An acoustic wave is generated by a laser pulse on this Al layer (point 0). The wave propagates through the dielectric stack and is reflected back at the $\text{Al}_2\text{O}_3/\text{c-Si}$ interface (point 1). Depending of the adhesion between c-Si and the passivation stack, several reflections can occur (points 2, 3 and more). Main graph: acoustic amplitude as a function of the echo number. The reflection coefficient R is determined by fitting the mean echo number (n) with a power law R^n . The lower R , the better the adhesion. In this example c-Si/ Al_2O_3 adhesion of sample A is better than that of sample B.

Lifetime measurements have been done by photoconductance decay in quasi-steady-state mode (QSS-PC). Lifetimes are reported in this paper for carrier densities of 10^{15} cm^{-3} . High resolution lifetime maps have been obtained by QSS-PC calibrated high magnification photoluminescence. Blistering density has been determined by optical microscopy. The delaminated area has been estimated

assuming circular blisters [5]. In order to probe the c-Si/ Al_2O_3 interface between blisters, high resolution APiC microscopy mapping was used. This technique, rather new in the field of photovoltaics, is described in Fig. 2 [9].

III. RESULTS AND DISCUSSION

The high lifetime of sample #3 (3.8 ms) coated by 6 nm of Al_2O_3 could be partially ascribed to its blister-free surface. The presence of blisters on samples #1 and #2 directly decreases their lifetime by more than a factor of 2 compared to sample #3 (see table I). However samples #1 and #2 have different blisters sizes, densities and so delaminated surfaces by more than one order of magnitude.

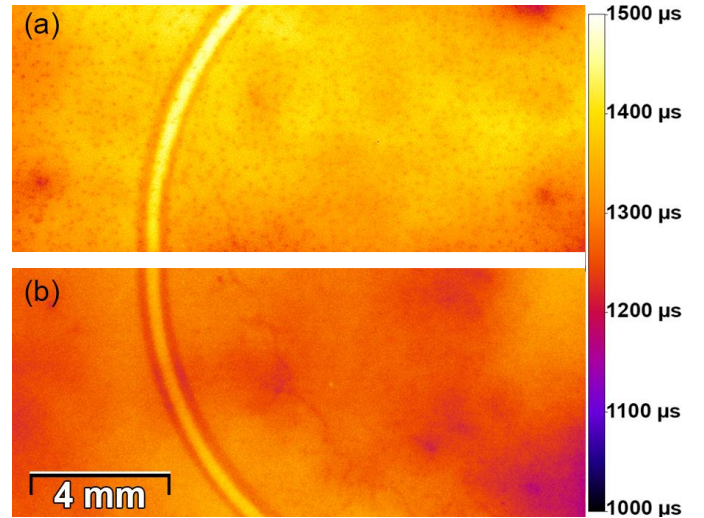


Fig. 3. High resolution QSS-PC calibrated photoluminescence of (a) sample #1 and (b) sample #2. Visible arc on both images is the Sinton stage sensor.

High magnification photoluminescence (Fig. 3) highlights a quite different response of these two samples. The sample having the lowest blistering density (Fig. 3-b) shows a rather homogenous photoluminescence response over its entire surface while on the other sample a spotted surface is visible (Fig. 3-a). This interesting pattern might not be visible on sample #2 because of the lower blistering density but also due to the average blister size, slightly smaller than a pixel of the detector. However, the average lifetime between blisters seems higher on samples #1 than on sample #2.

High resolution APiC map shows a very low and uniform reflection coefficient (R) for the reference sample (sample #3, Fig. 4-c). Sample #2 also presents a rather homogeneous R between blisters (Fig. 4-b) but its value is higher than for sample #3, highlighting a weaker interface. Sample #1 shows a mixed pattern of strong and weaker adhesion between its blisters. This contrast between delaminated and non-delaminated areas might be responsible for the higher photoluminescence signal observed on Fig. 3-a. In terms of

delamination, 4.5% and 0.45% of the APiC probed area are considered as defective for samples #1 and #2 respectively. These values are in good agreement with those determined by optical microscopy. Statistically, it can be seen on Fig. 4-d that the median value of the R is lower for sample #1 than for sample #2, underlining a better interfacial property between its blisters. However, the average value of these samples is similar, reflecting maybe more the QSS-PC lifetime which is an average value over the probed surface.

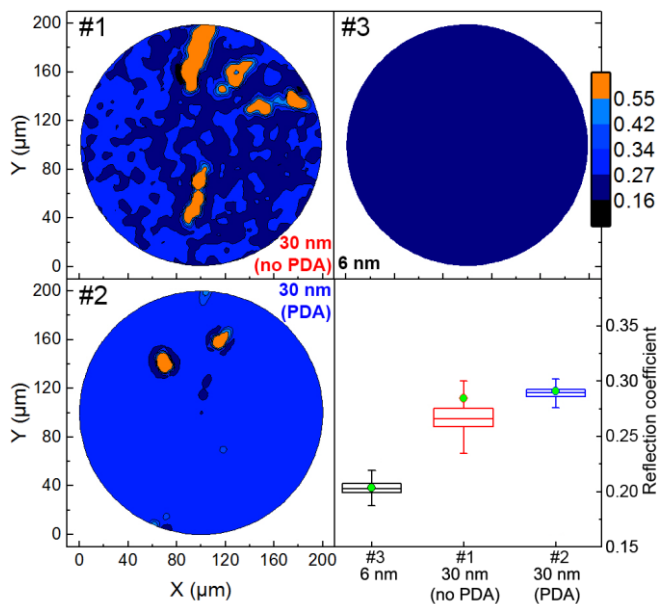


Fig. 4. High resolution APiC mapping of the reflection coefficient of samples #1, #2 and #3. Orange areas are blisters. Bottom right: Statistic distribution of the reflection coefficient for the 1330 measured points of each map. Lines in the middle of boxes represent the median values. Green dots represent the average value.

IV. CONCLUSION

Blistering is a visible macroscopic phenomenon highlighting delamination of the films. Like the visible part of an iceberg, blisters do not represent what is happening under the sea. Blisters are just a local manifestation of a broader interface degradation. Our results show that the acoustic reflection coefficient is the relevant parameter to evaluate passivation quality of a blistered surface. Its median value is representative of the percentage of delaminated area, while its average value seems to be more representative of the effective lifetime. APiC microscopy seems to be the key characterization to dive deeper into the understanding of blistering. As APiC requires metalization of the passivation stack, it can be the perfect technique to assess the passivation quality of PERC/PERT solar cells backside with full metalization.

ACKNOWLEDGMENT

This work was carried out in the framework of a project A from IPVF (Institut Photovoltaïque d'Ile-de-France). This project has been supported by the French Government in the frame of Programme d'Investissement d'Avenir – ANR-IEED-002-01. Fabien Lebreton thanks ANRT for CIFRE scholarship.

REFERENCES

- [1] V. I. Kuznetsov, M. A. Ernst, and E. H. A. Granneman, "Al₂O₃ surface passivation of silicon solar cells by low cost ald technology," in *40th IEEE Photovoltaic Specialists Conference*, 2014, pp. 0608-0611.
- [2] B. Veith, F. Werner, D. Zielke, R. Brendel, and J. Schmidt, "Comparison of the thermal stability of single Al₂O₃ layers and Al₂O₃/SiN_x stacks for the surface passivation of silicon," *Energy Procedia*, vol. 8, pp. 307-312, 2011.
- [3] A. Richter, J. Benick, M. Hermle, and S. W. Glunz, "Excellent silicon surface passivation with 5 Å thin ALD Al₂O₃ layers: Influence of different thermal post-deposition treatments," *physica status solidi (RRL) – Rapid Research Letters*, vol. 5, no. 5-6, pp. 202-204, 2011.
- [4] B. Vermang, H. Goverde, V. Simons, I. De Wolf, J. Meersschaut, S. Tanaka, J. John, J. Poortmans, and R. Mertens, "A study of blister formation in ALD Al₂O₃ grown on silicon," in *38th IEEE Photovoltaic Specialists Conference*, 2012, pp. 001135-001138.
- [5] L. Hennen, E. Granneman, and W. Kessels, "Analysis of blister formation in spatial ALD Al₂O₃ for silicon surface passivation," in *38th IEEE Photovoltaic Specialists Conference*, 2012, pp. 001049-001054.
- [6] P. Saint-Cast, D. Kania, R. Heller, S. Kuehnhold, M. Hofmann, J. Rentsch, and R. Preu, "High-temperature stability of c-Si surface passivation by thick PECVD Al₂O₃ with and without hydrogenated capping layers," *Applied Surface Science*, vol. 258, no. 21, pp. 8371-8376, 2012.
- [7] Y. Bao, S. Li, G. von Gastrow, P. Repo, H. Savin, and M. Putkonen, "Effect of substrate pretreatments on the atomic layer deposited Al₂O₃ passivation quality," *Journal of Vacuum Science & Technology A: Vacuum, Surfaces, and Films*, vol. 33, no. 1, pp. 01A123, 2015.
- [8] V. Naumann, M. Otto, R. B. Wehrspohn, and C. Hagendorf, "Chemical and structural study of electrically passivating Al₂O₃/Si interfaces prepared by atomic layer deposition," *Journal of Vacuum Science & Technology A*, vol. 30, no. 4, pp. 04D106, 2012.
- [9] A. Devos, "Colored ultrafast acoustics: From fundamentals to applications," *Ultrasonics*, vol. 56, pp. 90-97, 2015.
- [10] A. Zauner, F. Lebreton, P. Saint-Cast, M. Hofmann, J.-Y. Letellier, E. Urrejola, Y. Marot, F. Gouhinec, C. Charpentier, J. Hong, F. Coeuret, and S. Pouliquen, "PERC solar cells comparison of Al precursors for rear-side surface passivation," in *29th European Photovoltaic Solar Energy Conference*, 2014, pp. 1413-1416.
- [11] J. Couderc, H. e. Belghiti, D. Aureau, J. Dupuis, P.-P. Grand, É. Delbos, A. Etcheberry, and D. Lincot, "Study of one-step annealing for plated nickel-copper contacts on n-pert bifacial monocrystalline silicon solar cells," in *32nd European Photovoltaic Solar Energy Conference*, 2016, pp. 697-702.