PASSIVATION OF LASER-DRILLED VIA HOLES FOR EMITTER-WRAP-THROUGH-CELLS

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ABSTRACT: A high speed via-hole drilling laser process for emitter-wrap through cell production is investigated concerning the removal of induced crystal damage by a subsequent alkaline etching step. The etching time necessary for damage removal is identified. Further the passivating properties at the via-hole surface of two passivation layers are compared. The passivating effect of a PECVD-SiN layer deposited on both sides of the wafers is confronted to thermal oxide passivation by lifetime measurement. A theoretical frame work using the analogy of via-holes and dislocations is applied to extract values for the surface recombination velocity at the via-hole wall. Both analysis indicate that the passivating effect of the PECVD layer depends on the via hole radius whereas the passivation quality of the SiO_2-layer saturates for an etching time of equal or greater 240 s. For the highest etching times surface recombination velocities of down to 60 cm/s are found for SiN.

Keywords: EWT, laser processing, laser damage analysis, passivation

1 INTRODUCTION

One of the key features of the EWT (emitter-wrap through) cell concept [1] is an emitter via that connects the front side emitter with the back side emitter, where the contact metal is deposited. State-of-the-art laser processes allow drilling a plurality of via-holes within a processing time appropriate for industrial application. Since the drilling process is expected to harm the Si crystal around the borehole, material must be removed in a subsequent etching step to avoid detrimental effects on EWT-cell performance, caused by recombination or increased via-hole resistance. In this work we investigate a state-of-the-art process as described elsewhere ([2], [3]) concerning the removal of crystal damage induced by alkaline etching with SEM and lifetime analysis. Since a sensitive damage analysis requires a passivation of the via-hole wall two passivation layers, namely thermal oxide and silicon nitride deposited by plasma enhanced chemical vapour deposition (PECVD) are compared in this regard.

2 EXPERIMENTAL

2.1 Sample Preparation

A disc laser system was used in "on the fly"- mode [2] to drill honeycomb patterns of different numbers of via-holes per unit area (Figure 1) into 4 Ωcm polished FZ-samples of 330 µm thickness. The wavelength emitted by the Yb:YAG crystal is 1030 nm, whereas a diode current of 42 A, a pulse frequency 15 kHz and 12 repetitions per hole were used. The via-hole densities were chosen to be between N^i_{via} = 200...1850 cm^{-2} to achieve a strong influence of the via-holes on the investigated parameters. At the sample center no via-holes were drilled in order to measure the background lifetime. At the via-hole positions the samples were not in contact with the laser chuck. Subsequently the samples were alkaline etched in 30% KOH at 80°C, varying etching time sample wise from 5s…960 s, starting at very low values since the laser process is expected to induce little damage. After a cleaning step a thermal oxidation process was applied aiming at 105 nm thickness to a part of the samples. On the remaining samples SiN_x with a refractive index of n (λ = 632 nm) = 2.8 and a thickness of 70 nm was deposited by means of PECVD. Finally all samples were annealed in a forming gas atmosphere.

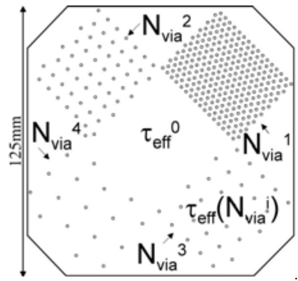

Figure 1 *Lifetime sample design. τ_{eff} (N_{via}^i) is measured on 4 areas of different via-density surrounding a reference area without via-holes.*

2.2 Results

2.2.1 SEM-analysis

In order to analyze the surface structure of the via-holes the same drilling process and etching steps were applied to Cz – material with saw damage. Cross sections were prepared with a wafer saw. Figure 2 to Figure 4 show cross sections through different via-holes with varying etching time, whereas the laser incident side of the sample as well as the via-hole wall are visible. The cutting depth d_{saw} was chosen to be smaller than the wafer thickness d_{wafer}, thus the lower part of the cross sections with less smooth surface is a broken edge. After drilling, the via-hole wall appears to be smooth and slightly wavy, and laser debris is visible on the wafer surface. After 60s etching in aqueous solution of 30 % KOH_{aq} debris on the original wafer surface is nearly removed (Figure 3). The via-hole wall exhibits brighter stripes in <110> directions, indicating that the anisotropy of the alkaline bath is beginning to play a role. Thus at this stage the material is of at least partly crystalline structure. Figure 4 finally displays a via-hole that was etched for 240s. The surface topology in <110> and <100> direction is clearly different. The <100> part is rather smooth with few steps whereas the <110> directions exhibit a corrugated surface and several steps. In a top view one would expect an octahedron of decreasing size moving from the laser incident side to the back. Figure 5 displays the (equivalent) radius vs. the etching time (FZ-samples) measured on front and back side with a microscope, where required calculated from the area enclosed by a polygon to account for the deviation from a non circle shape.

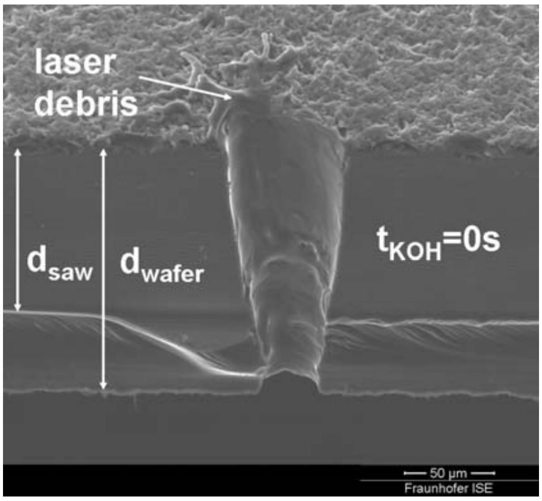

Figure 2 *Cross section of via-hole in Cz-wafer after drilling. Laser debris is present on the surface. The via-hole wall appears to be smooth.*

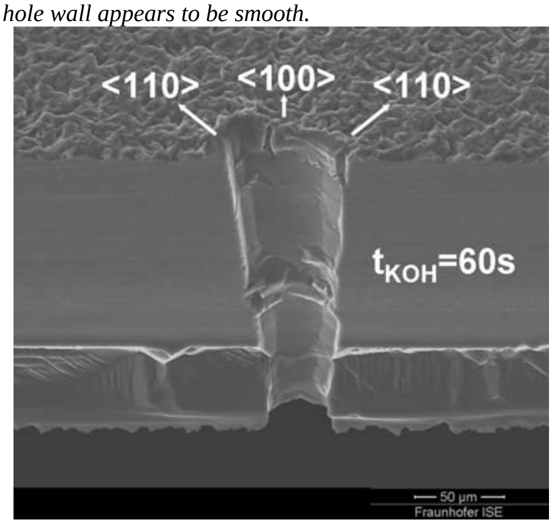

Figure 3 *Cross section of via-hole in Cz-wafer after t_{KOH}=60s. The anisotropy of the alkaline etch is visible.*

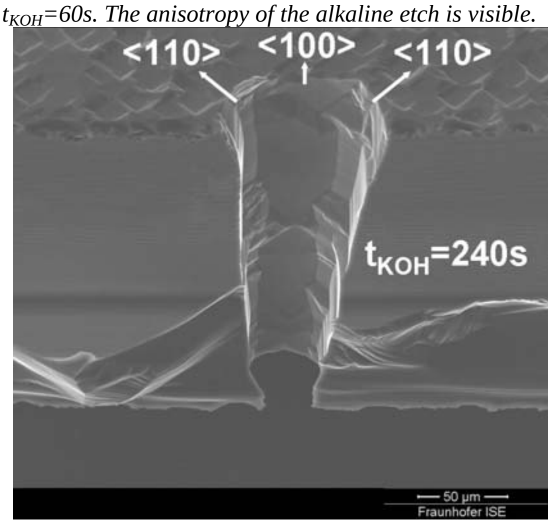

Figure 4 *Cross section of via-hole in Cz-wafer after t_{KOH}=60s. The anisotropy of the alkaline etching leads to a direction dependence of the surface topology. In <100> direction the surface is smooth with some steps whereas in <110> direction the surface is corrugated and exhibits several steps.*

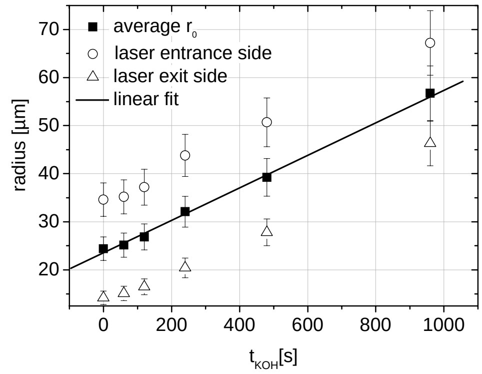

Figure 5 *(Equivalent) radius vs. etching time microscopically measured on both wafer sides. If necessary an equivalent radius was calculated from the area enclosed by a polygon to account for deviations from the circle shape.*

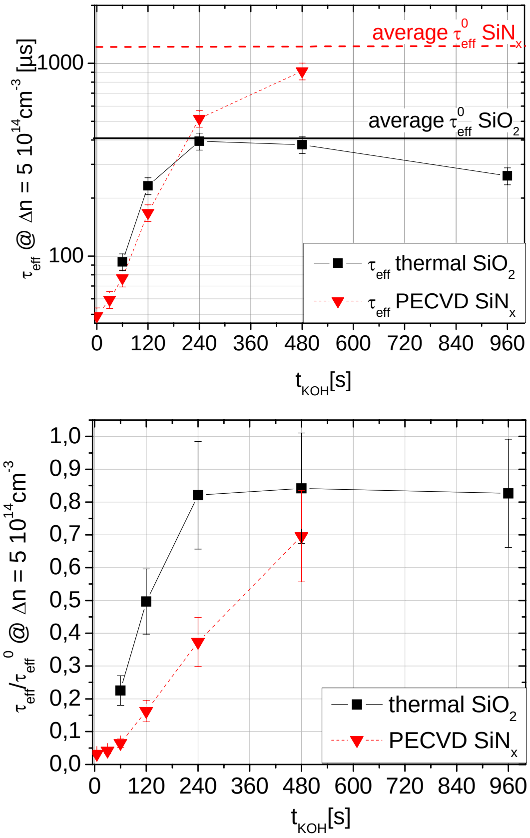

Figure 6 *upper part: absolute lifetime dependence on etching time for PECVD-SiN and thermal SiO_2 for N_{via}=295cm^{-2}; lower part: ratio of effective lifetime to background lifetime for both layers for N_{via}=295cm^{-2}*

2.2.2 Lifetime Analysis

For lifetime measurement a WCT 120 QSSPC-set up by Sinton Consulting was used illuminating the samples on the side of smaller diameter of the conical via hole. For the case that the area fraction of the via-holes exceeded 5% this was accounted for in the optical factor assuming the light entering a via-hole not to be absorbed. Lifetimes were evaluated at the injection density Δn = $5x10^{14}$ cm^{-3}. Figure 6 displays results of lifetime measurement for both sample types at a via-hole density of N_{via} = 295 cm^{-2}.

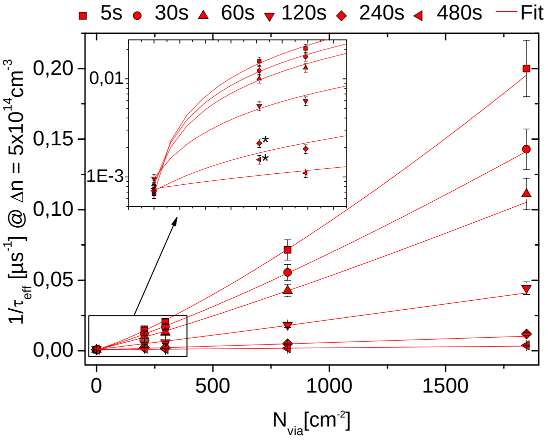

Figure 7 *Inverse τ_{eff} vs. N_{via} for different etching times with fits according to Opdorp et al. for SiN layer. Recombination decreases with etching time as well as decreasing via-hole density. The extracted S_{via} ranges from 18200cm/s to 60cm/s (Table 1).*

The lifetime measured on the samples with thermal oxide increases with etching time, reaches a maximum value at t_{KOH} = 240s and then slightly decreases. Considering the ratio of effective lifetime and background lifetime τ_{eff} / $\tau_{eff}^{\ 0}$ a clear saturation starting at t_{KOH} = 240s can be observed. Thus the passivation cannot be improved by further etching leading to the conclusion that the via-hole is laser damage free.

Lifetime for the SiN-samples increases even for the lowest etching times, whereas it is lower than for the oxide samples for t_{KOH} = 60s and 120s and and exceeds the lifetime of oxide samples above 240s. Hence the layer has some passivating effect inside the via-hole as has already been observed in previous work ([3],[4]). The ratio however increases and remains at lower values than for the oxide samples for all etching times realized, and no saturation with etching time nor a maximum can be observed. Thus the passivation quality of PECVD-SiN improves with increasing via-hole radius.

In order to compare the samples further it is helpful to extract a parameter that describes the recombination activity independently of background lifetime. A model originally derived to describe recombination activity of dislocations by Opdorp et al. is applied, resulting in a lifetime attributed to “via-hole-recombination” ([3], [4]):

$$\tau_{via}(N,r_0,S) \approx \frac{1}{2\pi DN}\left[-\ln(r_0\sqrt{N}) - 1.17 + \frac{D}{Sr_0}\right] \qquad \textbf{eq. 1}$$

The term reduces to the first two summands for diffusion limited recombination (S >> D/r_0) and to the third for boundary rate limited rcombination (S << D/r_0). In the latter case the recombination depends linearly S, r_0 and N. The effective lifetime τ_{eff} is assumed to be determined by a surface, bulk and via-hole contribution:

$$\frac{1}{\tau_{eff}} = \frac{1}{\tau_{via}} + \frac{1}{\tau_S} + \frac{1}{\tau_b} = \frac{1}{\tau_{via}} + \frac{1}{\tau_{eff}^0} \qquad \textbf{eq. 2}$$

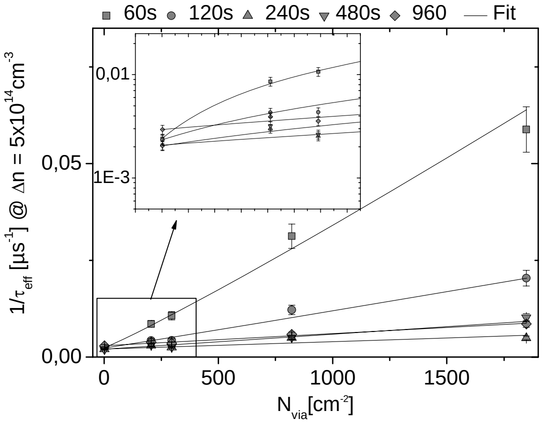

Figure 8 *Inverse τ_{eff} vs. N_{via} for different etching times with fits according to Opdorp et al. for SiO layer. The values of S_{via} of the oxide samples is about half of the values of the SiN-samples.*

Figure 7 displays the inverse lifetime measured on the SiN samples. Recombination systematically decreases with etching time and increases with via-hole density to a large extent. The recombination value at N_{via}= 0 was measured at the sample center. The data points marked with asterisk exhibited lifetime dips in spatially resolved measurements not correlating with the shape of the via-hole area, and were therefore not considered in the following fit. Error-weighted fitting of the data according to eq. 1 with S_{via} as free parameter results in values starting with 18200 cm/s up to 60 cm/s (Table 1) whereas average radius values from the microscopic measurements where used. The error is estimated to be about 30%. The background surface recombination velocity was calculated to range between 10…15 cm/s assuming the bulk lifetime to be Auger-limited.

It is interesting that S does not tend to the thermal velocity of electrons for very low etching time as has been found for different laser processes in previous work [3]. A possible interpretation is that a passivating effect of the SiN-layer is present even for the lowest etching time meaning that the near surface bulk of the via-hole is only moderately damaged so that the physical surface does play a role in the recombination dynamics of the via-hole. On the other hand the sensitivity of the method is limited for very high recombination velocities.

Figure 8 displays the same graph for the SiO-samples. Recombination generally decreases with etching time, however for t_{KOH} equal or greater 240s there is no improvement. Further it can be observed, that for low etching times the inverse lifetime depends in the expected manner on via density, however for t_{KOH} equal or greater 240s this is partly not the case. In spatially resolved lifetime measurements the oxide passivation was found to exhibit lateral inhomogenities affecting the areas of N_{via}^2 and N_{via}^4 for higher etching times, since background recombination plays a significant role in this etching time regime. Since the change in background lifetime cannot be quantified it was neglected in the fits (Table 1). In Figure 9 the extracted values for the two passivation layers can be compared. S_{via} of the SiO_2 samples decreases up to t_{KOH} = 240 s whereas for higher etching time it does not change significantly indicating that all damage detectable with this method is removed.

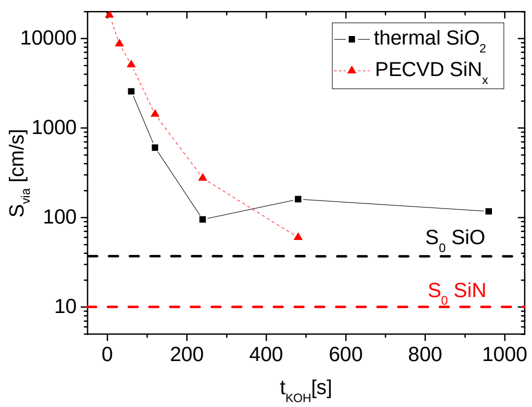

Figure 9 *S_{via} values extracted from fits vs. etching time for both sample types. For the SiO-samples saturation for t_{KOH} equal or greater can be observed. The SiN-samples show lower values up to 240s indicating the radius-dependence of the passivating effect.*

However, the average surface recombination velocity on the original wafer surface S_0~40 cm/s calculated assuming the bulk lifetime to be Auger limited is not reached. Considering that the via-hole surface is partly rough and a larger fraction of the surface consists of {111} planes (Figure 4) it can be expected that the passivation layer is less effective.
Svia-values for SiN do not exhibit saturation within the considered etching time, and are lower than for the SiO_2-samples up t_{KOH} = 240 s. As could already be concluded from the lifetime measurement this indicates that the passivating effect of PECVD-SiNx depends on the via-hole radius. For the highest etching time Svia= 60 cm/s are extracted, however S0 is not reached as well as for SiO2 samples.

Table 1 *Values for S_{via} extracted from fits. The error is estimated to be 30%. The values for the nitride samples are significantly higher and exceed the values for the oxide samples by a factor of about two.*

t_{KOH} [s]	S [cm/s]	
	SiO_2	SiN_x
5	-	18200
30	-	8700
60	2600	5100
120	600	1430
240	100	260
480	160	60
960	90	-

3 CONCLUSION

A state of the art laser drilling process has been investigated concerning the removal of crystal damage by alkaline etching. It is found that an etching time of equal or greater 4 min in 30% KOH @ 80°C is sufficient for damage removal. Further the passivation of the via-hole of thermal SiO_2 was found to be more effective than PECVD-SiN for low etching times. The passivating effect of the latter layer increases with the via-hole radius. The coverage of the PECVD-SiN_x-layer depends on via-hole geometry, qualifying thermal silicon oxide for damage analysis, though the passivation quality that can be reached and thus the sensitivity is lower. Extracting S_{via}-values from the data, one finds that the values for silicon oxide passivation are lower than for silicon nitride passivation for low etching times. The values SiO-layer reach around 100cm/s whereas for the SiN-layer 60 cm/s are reached for the highest etching time of t_{KOH} = 480 s.

4 ACKNOWLEDGEMENTS

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5 REFERENCES

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