LIFETIME STUDIES ON LASER DRILLED VIAS FOR APPLICATION IN EMITTER-WRAP-THROUGH-SOLAR CELLS

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ABSTRACT: Two laser sources potentially adequate for via drilling for the application in emitter or metallization wrap through cells are investigated. Both sources have the potential of very high throughput required for emitter wrap through cells. Three different drilling processes are analyzed and compared concerning the recombination activity of the resulting vias. Therefore the dependence of minority carrier lifetime on etching time in alkaline solution and via density is investigated. Further a method for determination of the surface recombination velocity originally derived for dislocations is applied to via holes. The calculated curves sufficiently describe the values derived from measurement, and values of $S = 10^6$ cm/s for the lowest etching times up to values of 100 cm/s for the highest etching times are deduced.
Keywords: EWT, laser processing, laser damage

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. While this production step constituted a bottleneck in former times, today new laser systems offer the possibility to drill such vias within adequate processing time. Appropriate laser processes induce damage in the Si - crystal, which is expected to be highly recombination active. Thus damage must be removed in a chemical postprocessing step to avoid detrimental effects on cell performance.

To evaluate laser drilling processes, accompanying chemical etching steps and passivation properties concerning the remaining recombination activity, in this work carrier lifetime has been used to investigate the electronic quality of the crystal.

Different authors describe dislocations as cylinders with radius r_0 and the recombination velocity S at the cylinder barrel [2],[3],[4]. This concept can also be applied to via holes. Van Opdorp et al [2] give an analytic expression for the lifetime dependency on the density of parallel dislocations on a square lattice in an infinite crystal. From this method the surface recombination velocity of via walls can be deduced, which is an important parameter for the performance of EWT-cells. Two different laser sources with the potential for industrial application are compared in terms of this method.

2 EXPERIMENTAL

2.1 Sample Preparation

Two laser sources with the potential of high throughput required for EWT-cells (10000 vias/s) were investigated:

A flash lamp pumped Nd:YAG system with $\lambda = 1064$ nm (KLS246 by LASAG) drilling vias with a single pulse with the pulse energy of 80-100mJ and a pulse length of 60µs-90µs. Further a diode pumped system with Yb:YAG crystal, emitting $\lambda = 1030$ nm (Disc 100Q by ROFIN [5]) and drilling vias with 7…15 pulses with pulse energy in the range of 3 mJ and a pulse length of about 1µs. Process B designates a process drilling a via with about 10…15 consecutive pulses with the latter system. Process C combines a high precision scan head with the latter system leading the beam quickly across the wafer; drilling vias in the following manner: if n designates the number of vias to be drilled, i the via number and k the pulse number, then the ith via is drilled with the pulse numbers $k=i$, $k=n+i$, $k=2n+i$ and so on. Consequently the time between two pulses at a point is significantly increased with respect to process B thus attenuation of laser radiation due to scattering or absorption of ablated material forming clouds or plume above the via hole ground can be avoided [6]. Vias were drilled into 4 Ω cm (process A) and 10 Ω cm (process B+C) FZ-material respectively.

In Figure 1 a cross section of a via after 12min of KOH etching drilled in Cz-material from the right hand side with process C is pictured. The section is rotated by 45° degrees with regard to the wafer edges. The via surface structure depends on crystal direction, which is ascribed to the anisotropy of alkaline etching.

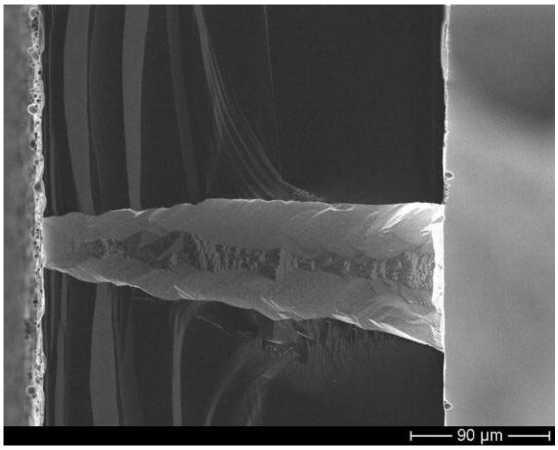

Figure 1 Cross section of a via hole in Cz-Material after 12min etching in KOH-solution. Laser irradiation incident from right side. The section is rotated by 45° to the wafer edge.

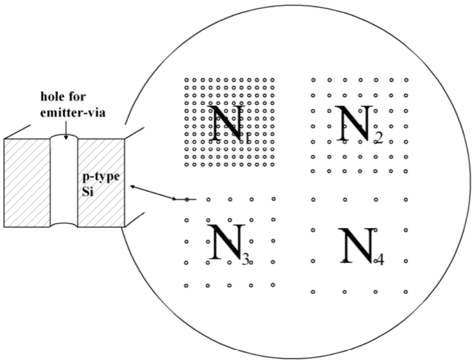

Figure 2: Sketch of sample. Via patterns of different density are drilled into FZ-Si.

Square via patterns with different pitches equal in x- and y-direction unless otherwise noted were drilled resulting in the via densities N_i (Figure 2). The wafers were alkaline etched in a 30% KOH-solution at a temperature of 80 C whereat the etching time t_{KOH} was varied. Afterwards, a SiN-layer was deposited on both wafer sides for passivation purposes. SiN_x was chosen as passivation layer to avoid dislocation propagation connected with high-temperature processes as thermal oxide [7] on the one hand and to evaluate the possibility to passivate via holes like in EWT-cell processes on the other hand.

2.2 Lifetime Measurement

For lifetime measurement two methods were used. Carrier Density Imaging [8] implicating a spatial resolution of up to 50 µm localizes areas of damage or poor passivation that do not correspond with via patterns. Quasi Steady State Photoconductance Decay measurements with WCT-100 and WCT-120 setup [9] respectively were used to measure lifetime at a defined injection density, whereat the generalized evaluation method [10] was used if not mentioned otherwise since a wide range of lifetimes was supposed to be measured. The base line conductivity was measured before each photoconductance measurement in order to account the presence of high densities of vias with large radius.

2.3 Evaluation of Lifetime Data according to Opdorp et al.

According to Opdorp the reciprocal lifetime τ_{eff}^{-1} equals the sum of the reciprocal values of bulk lifetime τ_o, the lifetime owed to the wafer surfaces τ_s and the contribution of the vias τ_{via}. Measuring lifetime of wafer areas without holes τ_{eff}^0 that includes bulk and surface contributions τ_{via} can be calculated with

$$\frac{1}{\tau_{via}} = \frac{1}{\tau_{eff}} - \frac{1}{\tau_b} - \frac{1}{\tau_S} = \frac{1}{\tau_{eff}} - \frac{1}{\tau_{eff}^0} \qquad \text{eq. 1}$$

Opdorp et al further give an analytic expression which yields a good approximation for the dislocation related lifetime τ_d which in the following will be designated as τ_{via}:

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

where N is the area related density of - in this case – vias, r_0 the via radius, D the diffusivity of electrons and S the recombination velocity on the via surface. The relation holds for $ND\tau_{via} \gtrsim 0.3$ and $r_0 < 0.2/\sqrt{N}$.

2.4 Results

2.4.1 Comparison of the laser processes

Samples produced with process A and B were measured in QSS-mode while the general evaluation method was used. Lifetime curves of process A and B were evaluated at an injection density of $\Delta n = 5 \times 10^{14}$ cm^{-3}, whereat the curves of process C were evaluated with a transient flash at $\Delta n = 1 \times 10^{14}$ cm^{-3}. The different modes and regimes were chosen for reasons of measurement quality. The references without vias were evaluated at the respective measurement modes and injection densities.

Figure 3 shows the behavior of τ_{via} (left axis, dots) and the ratio of τ_{eff}/τ_{eff}^0 (right axis, bars) with etching time in alkaline etch for a typical EWT via-density of about $N = 120$ cm^{-2} for the different laser processes.

Process A starts with relatively low values for τ_{eff}/τ_{eff}^0 of about 10 % after 300 s and recovers 30 % after 460 s etching.

In contrast to this, process B starts with a ratio of 20 % at 180 s etching time and reaches about 70 % after 300 s. Process C immediately reaches a value of 50 % after 180 s, and shows values between 60…80 % for the rest of the etching times. Similar ratios of τ_{eff}/τ_{eff}^0 have been obtained using MWPCD maps at one sun bias illumination, averaging the areas with via-holes and considering the highest lifetime value measured on the respective wafer as τ_{eff}^0. Considering the lifetime against via recombination τ_{via} gives an estimation of the relevance of recombination. For process B and process C there is no significant contribution to recombination expected after 300 s - respectively 180 s - of alkaline etching. Eideloth et al. [11] have observed analogue differences between process B and C analyzing the dependence of emitter saturation current per via with etching time. For process A τ_{via} reaches a value of about 500 µs after 460 s of etching, i.e. an effective lifetime of a wafer with passivation of 100 µs would be decreased to about 80 µs.

Both damage and geometry of vias can influence the resulting lifetime. In Figure 4 microscope images of typical vias drilled with process A and C are pictured in

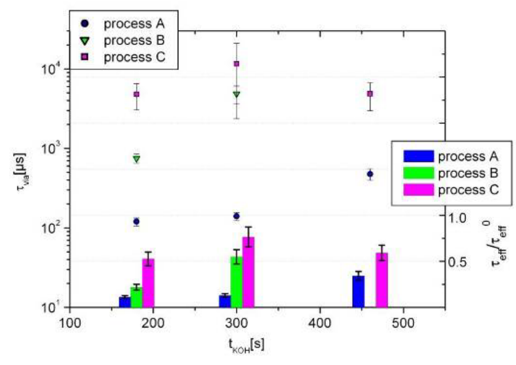

Figure 3: Comparison of different laser processes in terms of τ_{via} and the ratio τ_{eff}/τ_{eff}^0. Process B and C reach high values of τ_{via} after 300 s respectively 180 s.

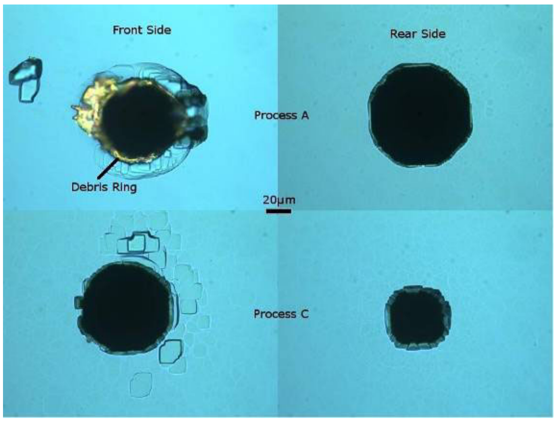

Figure 4 Microscope images of typical vias drilled with process A (first row) and with process C (second row) in front and rear side view (left column and right column).

front and rear side view. The via drilled with process A exhibits a brighter ring at the via edge visible on the front side, which is ascribed to laser debris. For etching times up to 180 s a full ring is observable, whereat after 300 s only residuals can be observed, and at 460 s no residuals are observed. If the debris consists of oxidic components, preliminary etching with HF could decrease the necessary etching time drastically. Process C did not exhibit a similar phenomenon for the etching times under investigation.

Further a different taper of the vias drilled with process A and C can be observed inFigure 4. The ratio of the radius on front and rear side process A ranges between 1.0 and 1.1 whereat the disc laser processes rather feature a value of 1.3 to 1.5. A higher value for taper can result in an enhanced SiN_x deposition on the via walls.

2.4.2 Interpretation of lifetime data according to Opdorp et al.

The injection dependence of lifetime was measured for the perforated areas of different via density. A systematic increase of lifetime with decreasing via density as pictured in Figure 5 was observed for most of the samples.

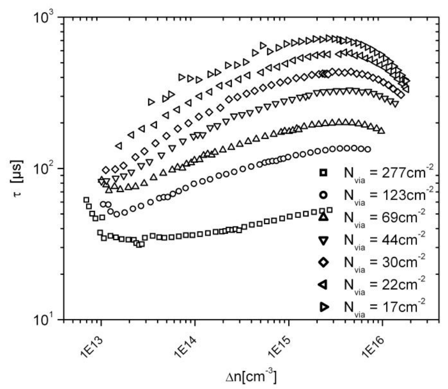

Figure 5: Example of QSSPC-measurements for different via densities N_{via}. (process A after 180 s etching time). Lifetime systematically increases with decreasing via densities. The curves were evaluated at an injection density of Δn = 5x10^{14} cm^{-3}

In the following the results of lifetime measurements are interpreted in terms of the method described above, at the injection density of Δn = 5x10^{14} cm^{-3}. In Figure 6 theory data is compared to values of τ_{via} calculated from measured values for lifetime at areas with vias τ_{eff} and lifetime on a reference wafer without vias τ_{eff}^{0} according to equation 1. Process A was used for via drilling and etching time was varied. Note that the samples for the lowest and highest etching time were produced with a higher pulse energy, thus the radius does not change systematically with etching time.

The values for τ_{via} systematically increase with decreasing via density and increasing etching time.

Further τ_{via} clearly shows a similar behavior as the curves theory data. The average radius of the samples was measured microscopically, averaging front side and back side radius. The surface recombination velocity S was used as the only free parameter. The samples with t_{KOH} = 30 s can be described sufficiently with S = 106 cm/s corresponding to a strongly damaged surface. The samples with t_{KOH} < 460 s are rather located in the regime of S = 5000 cm/s…12000 cm/s while the samples with t_{KOH} = 460 s can be described with a calculation of the surface recombination velocity of around S = 820 cm/s. Finally the curve for the highest etching time can be predicted with S = 100 cm/s. Accordingly S changes by four orders of magnitude. For the reference wafer a surface recombination velocity of S = 12 cm/s was calculated, assuming the bulk recombination to be Auger-limited. Fitting the curves with different values for the via radius, corresponding to a measurement error respectively the process variability gives an estimate for the precision of the values of S. Some examples are given in Table 1.

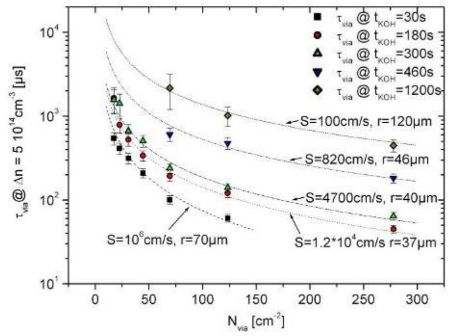

Figure 6: τ_{via} vs. N_{via} with etching time as parameter. The values increase with etching time and decrease with via density. Curves calculated from theory describe the values sufficiently.

S @ t_{KOH} [cm/s]	180s	300s	460s
r_0 – 5 µm	17200	6000	960
r_0	12000	4700	840
r_0 + 5 µm	8900	3900	750

Table 1 Values for S deduced from fits for different values of r_0.

Figure 7 shows the comparison of process A and process B for t_{KOH} = 180 s in terms of the Opdorp frame work. Accordingly the surface recombination velocities of the two laser processes differ by one order of magnitude at the etching time of 180 s. The function of $\tau_{via}(N_{via})$ can be described by a calculation with the parameters r_0 = 37 µm and S = 10^4 cm/s for process A and r_0 = 24 µm and S = 980 cm/s for process B. The values of τ_{via} for process C exceed the values of process A and B but are not evaluated due to the large error of $\tau_{via}(N_{via} = 70\text{cm}^{-2})$.

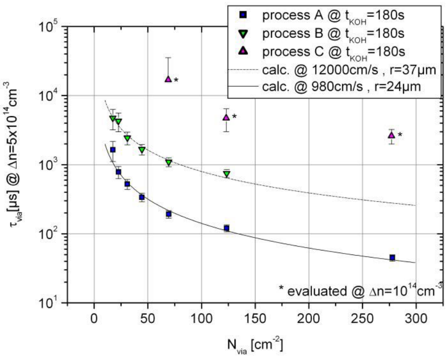

Figure 7: Comparison of process A and process B according to Opdorp et al.. After three minutes of alkaline etch the value of S_{via} process A and B differs by one order of magnitude.

3 CONCLUSION

Three different potentially high throughput laser processes are compared. Vias drilled with process A still contribute to the over all recombination activity after 460 s of alkaline etching. Laser debris residuals have been observed for etching times up to 300s. Different wet chemical etching steps will be tested. For process B and C the contribution becomes negligible for etching times greater than 300 s respectively 180 s.

The dependence of lifetime on via density and etching time is observed to be systematic for process A and partly for process B.

A method for the derivation of the surface recombination velocity of the via wall is applied to vias drilled for two different processes. The calculated curves sufficiently describe the behavior of the values derived from measurement. For process A values from S = 10^6 cm/s for the lowest etching times up to S = 100 cm/s for the highest etching times are deduced. For the etching time of 180 s the value of S for process A and process B differs by one order of magnitude: S_A (t_{KOH} = 180 s) = 10^4 cm/s and S_B(t_{KOH} = 180 s) = 980 cm/s.

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