

PURE EXPERIMENTAL DETERMINATION OF SURFACE RECOMBINATION PROPERTIES WITH HIGH RELIABILITY

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ABSTRACT

A major task in developing new surface passivation layers for solar cells is their electrical characterization. A key value is the surface recombination velocity S . It can be extracted from the measured effective carrier lifetime τ_{eff} in two ways: (1) with τ_{eff} measured at one wafer and theoretical assumptions made for the bulk lifetime which leads to a major uncertainty in the S -determination. Or (2) with τ_{eff} from a set of wafers with identically processed surfaces and different thicknesses W . Plotting τ_{eff} in an $1/\tau_{eff}$ vs. $1/W$ -diagram, the slope of a linear fit to the data equals $2S$. The infeed grinder used in our study to prepare wafers with different thicknesses is an excellent tool to produce identical, planar surfaces with low damage depth and high reproducibility. Final damage-etching gives a perfect initial point for surface texture and passivation steps. By means of this technique S is determined for oxide-passivation surfaces on different doping concentrations.

1. INTRODUCTION

A key value of surface characteristics is the surface recombination velocity S . It represents the time electrons and holes recombine at the surface. A low S -value represents a good electrically surface passivation. The fundamental problem is that S is not directly accessible but has to be extracted from the measured effective carrier lifetime τ_{eff} . This extraction can be achieved by two different approaches:

- The half theoretical way uses the τ_{eff} data from one single wafer and theoretical assumptions for the bulk lifetime τ_b [1]. Depending on the validity of the used bulk lifetime model the extracted S -value can be quite inaccurate.
- To avoid this uncertainty resulting from the theoretical assumptions for τ_b , a pure experimental way can be used. This pure experimental method uses a set of wafers with exactly identically processed surfaces but different thicknesses W . Only the experimental data of τ_{eff} and the wafer thickness is needed, without any assumptions for the bulk lifetime τ_b . Plotting a $1/\tau_{eff}$ vs. $1/W$ -diagram, the slope of a linear fit to the data equals $2S$. This paper will focus on this method.

2. Theory

τ_{eff} is an accessible value and can be easily measured by many techniques. The surface lifetime τ_s and out of that S have to be extracted.

The basic correlation between τ_{eff} and τ_s is:

$$\frac{1}{\tau_{eff}} = \frac{1}{\tau_b} + \frac{1}{\tau_s} \quad (1)$$

The correlation between τ_s and S is not that simple and was investigated in several papers theoretically (e.g. [2]):

$$\frac{1}{\tau_s} = \alpha_0^2 D \quad (2)$$

with α_0 as the smallest eigenvalue α_n of the equation:

$$\tan(\alpha_n W) = \frac{S_1 + S_2}{\alpha_n D - \frac{S_1 S_2}{\alpha_0 D}} \quad (3)$$

If the two following assumptions are made:

$$I) S_1 = S_2 = S$$

$$II) S < \frac{D}{4W} \quad (4)$$

the relationship between τ_s and S can be written in an easy approximation with less than 4% error [2,3]:

$$\frac{1}{\tau_s} \approx \frac{2S}{W} \quad (5)$$

The assumptions can easily be accomplished. The first constriction is met by preparing both surfaces exactly the same. This is achieved with high reproducibility by using an industrial infeed-grinder (see section 3.1). Since the goal of this method is to investigate “normal” up to “excellent” passivation layers the second constriction is not limiting also. For example: diffusion constant $D_n = 27 \text{ cm}^2/\text{s}$ ($= 1 \text{ } \Omega \text{ cm}$, p-doped), $W = 250 \text{ } \mu\text{m}$ results an $S < 270 \text{ cm/s}$ ($= \tau_s > 46 \text{ } \mu\text{s}$). This is a value “normal” passivation layers accomplish easily.

Therefore the following equation can be used:

$$\frac{1}{\tau_{eff}} = \frac{1}{\tau_b} + \frac{2S}{W} \quad (6)$$

In an $1/\tau_{eff} - 1/W$ plot, $2S$ will be represented by the slope of a linear fit to the data points (see Fig.5). This can be performed for different excess carrier densities Δn in order to obtain $S(\Delta n)$. The measurement is explained in section 3.3.

3. EXPERIMENTAL

This pure experimental method is not new. For example Yablonovitch et al. [4] used this plot to determine S . The fundamental requirement for reliable data are absolutely equal surfaces of all the wafers of the thickness-variation and a broad range of thicknesses. Till now this was often the limiting factor of most papers that used this method.

3.1 Wafer Preparation

To obtain perfect equal surfaces we used a pure mechanical abrasive industrial infeed-grinder DFG850 of DISCO Corp. .

From the technical point of view the grinding is done in the following way: A micro porous chuck holds the wafer from bottom by vacuum. From the upper side a rotating wheel (1000 – 6000 RPM) with grinding teeth on the outer diameter is lowered to the wafer (Fig.1). The grinding teeth do the actual grinding. They grind the wafer from its edge to its center. (The fact that the grinding goes only to the center of the wafer and does not continue to its other edge is a question of the tilt between the rotation axis of the wheel and the rotation axis of the chuck/wafer. To gain a wafer with parallel surfaces a non planar chuck is needed.)

The chuck/wafer rotates itself (40 - 200 RPM) and ensures that the whole wafer surface is ground homogeneously. By lowering the wheel with its teeth at low speed (0.1 up to 5 $\mu\text{m/s}$) the wafer is ground to the requested thickness. DI-Water is used to transport the abrasive material away and to cool the system.

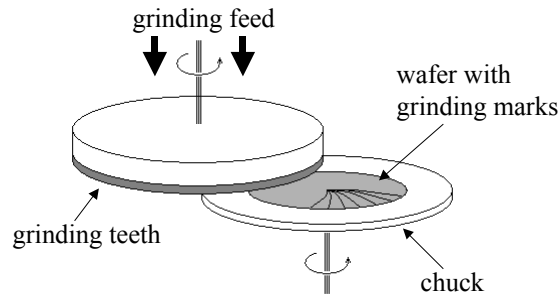


Fig. 1 Schematic principle of the pure mechanical infeed grinding.

This mechanism is a perfect tool to obtain planar, parallel surfaces (total thickness variation TTV over the wafer $\leq 1\mu\text{m}$) and same quality surfaces. This is achieved regardless to the cut-off amount, the final thickness and the initial surface topography.

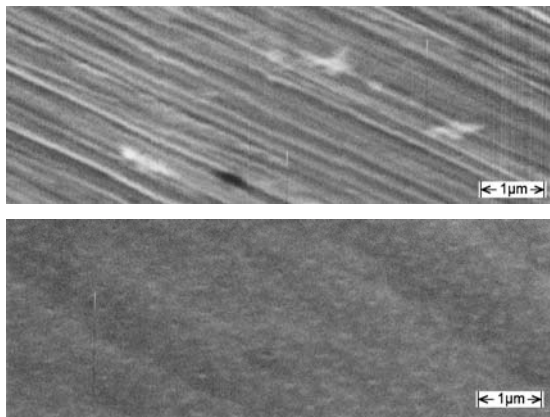


Fig. 2 top: After grinding the damage depth is $<1\mu\text{m}$. SEM image of the surface. **bottom:** The surface is free of damage after a damage etch of 1 min KOH. SEM image of the surface.

The crystal damage caused by the grinding process is $\leq 1\mu\text{m}$ (mono crystalline Si). This damage is mainly due to subsurface cracks which are highly electrical active (Fig.2 top). A damage removal step is necessary. Already a 1 min etch in a common anisotropic 40% KOH at 80 °C will remove this damage layer (Fig.2 bottom).

For the determination of S a higher etch removal of 6–8 μm was used. It turned out that a higher etch removal reduces the medial roughness and therefore the area of the surface even when an anisotropic KOH etch is used.

Fig. 3 shows an optical surface profile scan of a shiny etched wafer how it is usually shipped (top). At the bottom the same scan is shown at a ground and 6 μm KOH etched wafer. If a isotropic etch or an polishing method is used, the area of the surface could be further minimized.

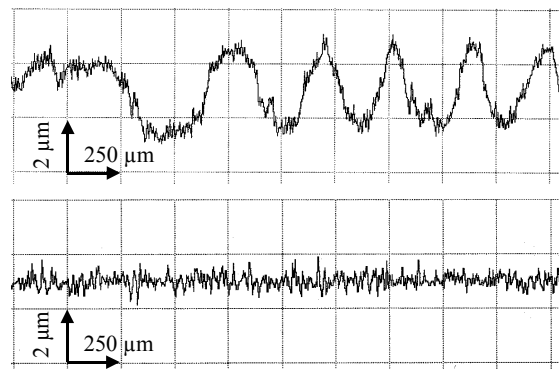


Fig. 3 top: Optical surface profile scan of a lapped, chemical polished wafer “out of the box”. **bottom:** Optical surface profile scan of an ground and 6 μm KOH etched wafer.

3.2 Silicon-Oxide-Surface

A standard RCA clean was used as a cleaning step for the passivation layer. A thermal anti-reflection oxide which is mainly used on high-efficiency solar cells was chosen to demonstrate this experimental method. The wafers have a measured oxide thickness of 100. Finally a 60 min 450 °C sintering was performed.

3.3 Measurement

We used a quasi-steady-state measurement system WCT-100 fabricated by Sinton Consulting [5]. With this system it is possible to measure Δn and τ_{eff} at the same time in a broad injection range. The generalized data analysis for quasi-steady-state and quasi-transient carrier lifetime measurement [6] was used. Several measurements with different filter sets were performed to increase the Δn range.

For each wafer thickness such a plot has to be produced. In Fig. 4 the $\tau_{\text{eff}}(\Delta n)$ for 9 different wafer thicknesses are shown.

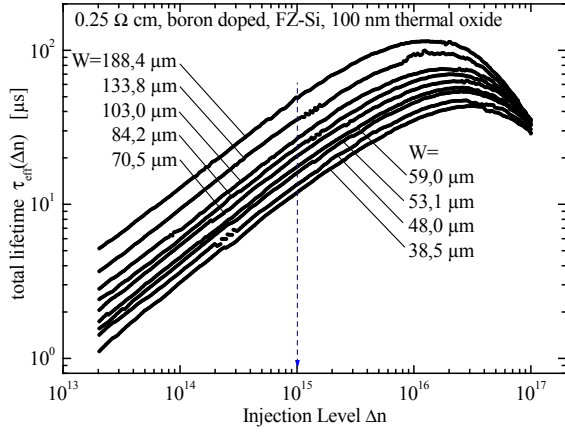


Fig. 4 $\tau_{eff}(\Delta n)$ plot for different wafer thicknesses W measured using quasi-steady-state photoconductance.

As an example the injection-level $\Delta n = 1 \times 10^{15}$ is selected to demonstrate the determination for S and τ_b (Fig. 5). Based on Eq.6 the slope of a linear fit in a $1/\tau_{eff} - 1/W$ plot represents $2S$ and the interception with the $1/\tau_{eff}$ axis represents $1/\tau_b$.

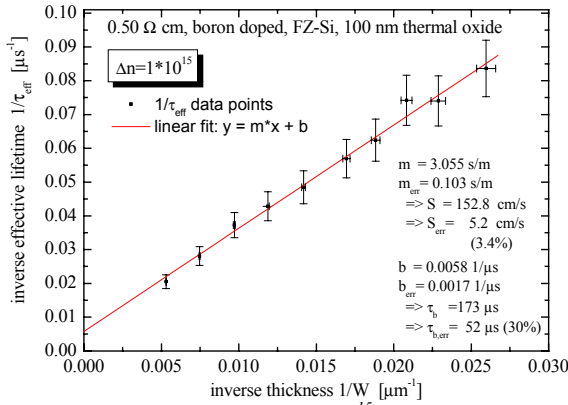


Fig. 6 $1/\tau_{eff} - 1/W$ plot for $\Delta n = 1 \times 10^{15}$. The slope m equals $2S$ and the y-axis interception b equals $1/\tau_b$ at this specified Δn .

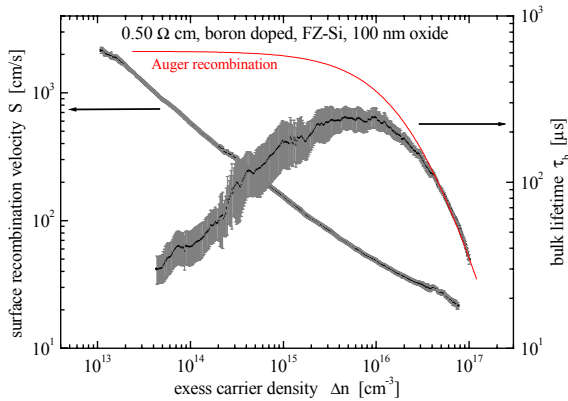


Fig. 7 $\tau_b - \Delta n$, $S - \Delta n$ and our Auger recombination model plot for 0,5 Ω cm, boron doped FZ-Si with 105 nm thermal oxide

This determination of S and τ_b is performed for all injection levels as shown in Fig. 6.

As it will be discussed in section 4 the S values have a much lower error than τ_b . For comparing the quality of surface passivation layers on different bulk-dopings, two $S(\Delta n)$ plots for 0.25 and 0.50 Ω cm doping levels are plotted in Fig. 7. The dependence of the passivation quality on doping and injection level can clearly be seen.

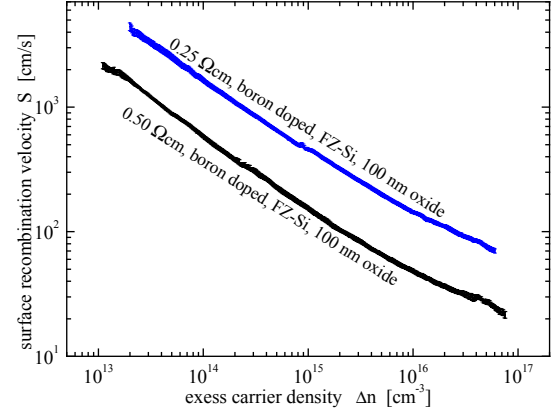


Fig. 8 $S - \Delta n$ plot for a boron-doped 0.25 Ωcm and 0.50Ωcm FZ-wafers with ≈ 100 nm thermal oxide.

4. DISCUSSION

As can be seen in Fig.5, the linearity of the data points is excellent. All errors are mainly determined by the statistical error of the linear fit in Fig. 5. The error concerning τ_{eff} is set to 10%, the maximal error of the generalized analysis [6].

As one can see the S -values can be determined at a much higher accuracy than the τ_b values (Fig.6). The error of the slope in Fig.5 and therefore directly S_{err} is mainly dominated by the accuracy of the measured effective lifetime τ_{eff} . The S value in Fig. 5-7 have all errors of less than 6%.

The value and the error of τ_b is dominated by the quality of the extrapolation $W \rightarrow \infty$ (interception with $1/\tau_{eff}$ axis) if determined in this geometrical way. The error can only be minimized if the range of W is increased and τ_{eff} is measured as precise as possible.

Nevertheless, especially the τ_b values at high injection levels can be described by our Auger model [7].

We will use the unambiguous determination of τ_b presented in this paper for a discussion of different Auger recombination models.

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