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Investigation of Emitter Homogeneity on Laser Doped Emitters

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Abstract

The selective emitter formation by laser doping is a well known process to increase the efficiency of silicon solar cells [1], [2].
For the characterization of laser doped emitters, SIMS (Secondary Ion Mass Spectroscopy) and ECV (Electrochemical Capacitance Voltage Measurement) techniques are used to analyze the emitter profile [3].
It is very difficult to get acceptable result by SIMS on a textured surface, so only ECV can be used. It has been shown, that a charge carrier depth profile can be measured on a homogeneous emitter only by ECV.
The use of laser doping results in a non-homogeneous emitter. We have shown that the emitter depth is not just a function of the pulse power, but in addition of the surface structure of the wafer. The texture seems responsible for a strong variability in the doping profile.
It has been shown, that the ECV measurement is not applicable to characterize the emitter depth on laser doped areas, because of the microscopic inhomogeneities in the emitter on the macroscopic measurement area. The real emitter profiles are to complex to be characterized by SIMS or ECV. We have shown that the variation in the emitter profile is resulting from the texture in the laser-doped regions.

Keywords: Laser doping, selective emitter, doping profile

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1. Introduction

SIMS is a standard measurement method to get carrier depth profiles. It is difficult to get a stable sputter rate on heavy structured surfaces. For that reason it is only possible to get significant results on planar surfaces. For industrial inline spray diffusion, the wetting process of the wafer depends on the surface energy. Emitter formation on different surfaces varies [5]. Results from textured and planar surfaces are not comparable. Therefore SIMS on textured surfaces is not applicable.

Using ECV it is possible to measure on textured surfaces. The surface will be etched, and the capacitance is measured. By the alternation of etching and measuring, a charge carrier depth profile will be obtained. The accuracy of this method depends on how accurately the size of the area with the electrolyte in contact is known [6]. Another advantage is that ECV measures only the active phosphorus concentration. Based on the depth profile, the sheet resistance can be calculated.

$$R_S = \left(\int_0^d \sigma(n,z)\,dz \right)^{-1} \tag{1}$$

To investigate a homogenous standard emitter, this method can be used, because there are no strong lateral differences in the depth (Fig. 2a). When the emitter in the survey area is highly inhomogeneous, however, then this method is not suitable to describe the depth profile (Fig.3b; 4b).

Nomenclature

d	junction depth
σ	resistance of the layer
n	density of free charge carriers
z	depth

2. Experiments

2.1. Investigation of the homogeneity of standard in-line emitters

On industrial standard mono crystalline wafers (resistivity: 1.5-3 Ohm*cm) with an acidic texture, a 85 Ohm/sq and a 115 Ohm/sq emitter with standard production equipment was created. After removing the PSG (Phosphorus Silicate Glass), the carrier depth profile was measured with ECV (3 measurements on the 85 Ohm/sq and one on the 115 Ohm/sq wafer) and the sheet resistance was measured with a capacitive method. Beside the ECV measurement, we cracked the wafer and decorate the emitter with an etching mixture, so that only the n-doped area is etched which is detectable with the SEM (scanning electron microscopy). After measuring the emitter depth with the SEM, both results were compared.

On standard multi crystalline wafers (resistivity: 1-1.5 Ohm*cm) a 115 Ohm/sq emitter with the same standard production equipment was created. The homogeneity of the emitter has been also investigated by emitter decoration. However, no ECV profiles were measured.

2.2. Investigation of the homogeneity of laser-doped emitters

In a second step, we created a 115 Ohm/sq emitter on mono crystalline silicon (standard acidic texture) and did not remove the PSG layer. With the help of a q-switched, frequency doubled solid state laser (532 nm), areas on the wafer with a lower sheet resistance were produced by the irradiation of the PSG with the laser (patented IPE-procedure [7]; Institute for Physical Electronics of the University Stuttgart; Fig.1a, b). The emitter depth on these different doped regions was measured with ECV and the sheet resistance was calculated. The sheet resistance was also determined by a capacitive method. All of these test areas were decorated to make the emitter visible. The results have been compared.

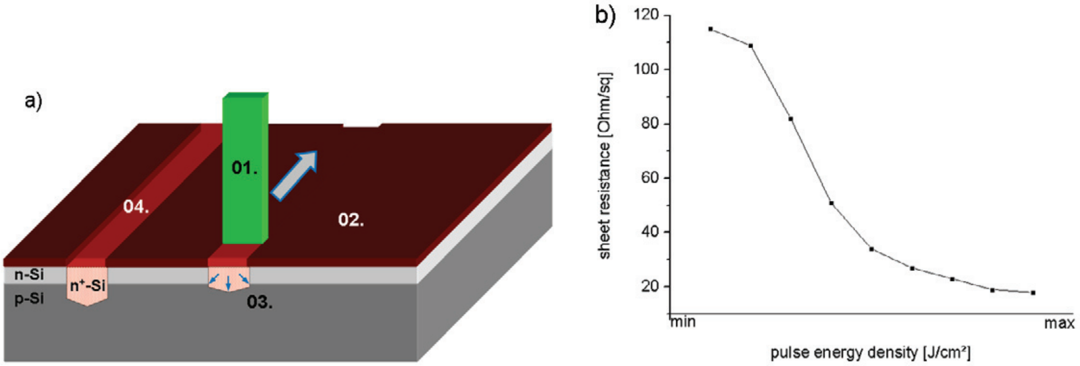

Fig. 1 (a) Schematic of the laser-assisted doping process with phosphorus silicate glass as source (01 Pulsed laser beam, elliptical beam profile; 02 PSG-layer; 03 Diffusion of phosphorus in the Silicon melt; 04 highly doped contact region) (b) Sheet resistance vs. pulse energy density (stable repetition rate and scan velocity; min = 3 J/cm², max = 4.8 J/cm²) [8]

3. Results and Discussion

3.1. Homogeneity of standard in-line emitters

In Fig 2a, a decorated 115 Ohm/sq emitter is shown. The generated spray diffusion emitter is very homogenous.

Comparing SEM measurement (Fig.2a) with the ECV profile (Fig.2b), a difference in thickness has been found. These measurement variations are comparable to all measurement areas on the wafer. ECV shows approximately, how deep the emitter could be (Tab.1). This method can therefore be used for homogeneous emitters.

Table I. Comparison between the measured emitter depth with ECV and the measurement with SEM (mono crystalline silicon) for an 85 Ohm/sq emitter (CM = capacitive measurement)

Mean of sheet resistance (Ohm/sq), **CM**	85
Mean of sheet resistance (Ohm/sq), **ECV**	91
ECV emitter depth (4E16 1/cm³; range, mean) [nm]	165-200 (181)
SEM emitter depth (range, mean) [nm]	95-183 (145)

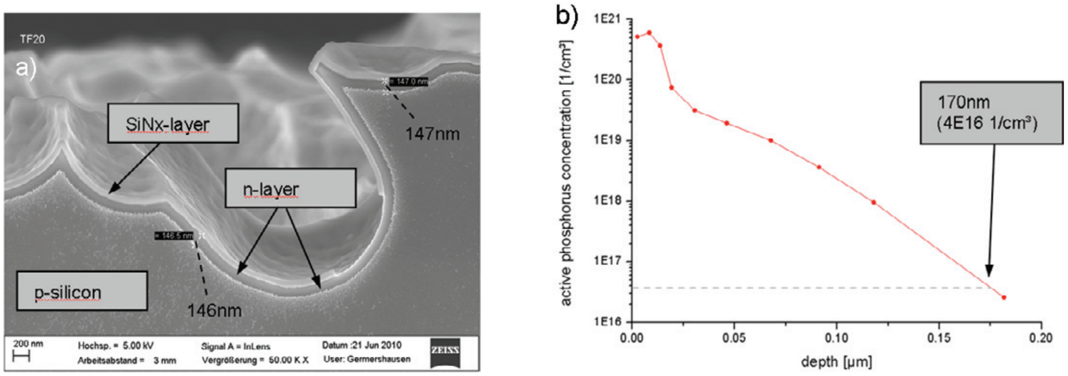

Fig. 2 (a) Homogenous emitter 115 Ohm/sq (decorated) on mono crystalline silicon, created by inline diffusion; (b) Emitter depth profile (ECV measurement, 115 Ohm/sq)

Multi crystalline material has a lot of lattice defects in the crystal [9]. This can lead to inhomogeneities in the emitter (Fig. 3b). ECV measurements are, due to the large measured area, only partly suitable to characterize such an emitter. Microscopic differences in the emitter thickness could not be observed by using this method (compare Fig. 3a and 3b).

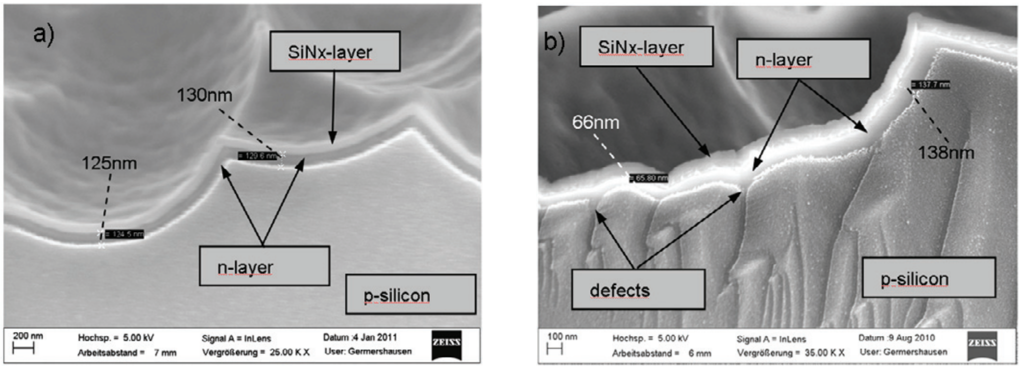

Fig. 3 (a) Relatively homogenous emitter 115 Ohm/sq (decorated) on multi crystalline silicon, created by inline diffusion, (b) inhomogeneous emitter 115 Ohm/sq of multi crystalline silicon, caused by crystal defects

3.2. Homogeneity of laser-doped emitters

The target of selective emitter processing should be a sheet resistance below 50 Ohm/sq to get an acceptable contact resistance. To obtain these values, the silicon surface has to be melted for a specific time by irradiation with a specific energy density (Fig. 1b).

The investigations show that the emitter is inhomogeneous in the laser-doped region (Fig. 4a-d, 5a). This is caused by the different coupling conditions for the laser radiation and the differences in the heat conduction. Both are influenced by the texture structures. Also the influence of heat conduction is a dominant factor.

By increasing laser power the homogeneity of the emitter is reduced (Fig. 4a-c) [8]. Overheating and thus a longer melt time could lead to the formation of a deeper emitter on exposed structures.

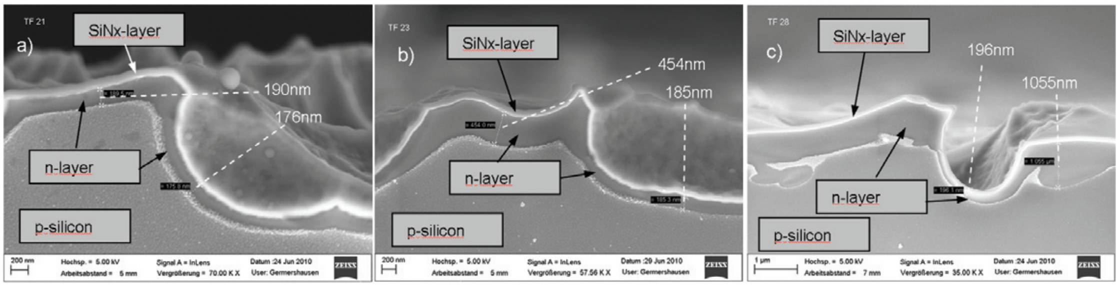

Fig. 4 (a) Laser doped 82 Ohm/sq (3.4 J/cm²) emitter (relatively homogenous); (b) 34 Ohm/sq (3.8 J/cm²) emitter (not homogenous); (c) 17 Ohm/sq (4.2 J/cm²) emitter (strong inhomogeneous) on mono crystalline silicon [8]

By using ECV measurement, the measured values are the arithmetic mean values of the whole macroscopic measurement area (Tab. II). This area includes shallow and deep emitter structures (Fig. 5a). Microscopic differences in the emitter thickness could not be observed by using this method.

Table II. Comparison between the measured (capacitive) and the calculated (ECV) sheet resistance as well as measured emitter depth with ECV and the measurement with the SEM; all measured wafers have the same texture structures (comparable surface roughness)

Sheet resistance (Ohm/sq) **ECV**	55	36	28	24
Mean of sheet resistance (Ohm/sq), **CM**	63	38	33	25
ECV emitter depth (4E16 1/cm³) [nm]	195	210	290	380
SEM emitter depth (range) [nm]	110-420	125-490	106-750	125-1700

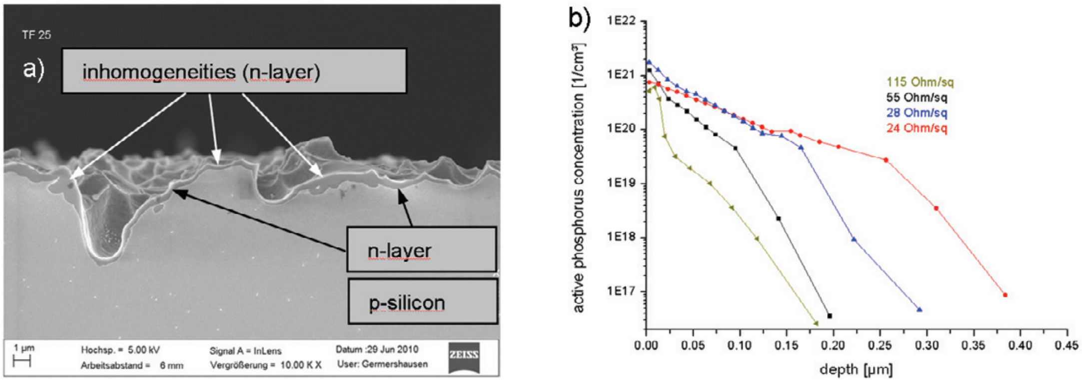

Fig. 5 (a) Inhomogeneous laser doped 24 ohm/sq (4 J/cm²) emitter on mono crystalline silicon; (b) ECV profiles of different heavily doped areas

Sheet resistances are achieved, which are normally used in selective emitter concepts, just with a strong variation of the emitter thickness (on acid texture). The calculated emitter sheet resistances by integration of the ECV profiles are correct (compare sheet resistance values from ECV with CM measurements), but the description of the emitter with this measurement is inaccurate (Tab. II, Fig. 5b).

4. Conclusions

ECV measurements are applicable to measure a carrier depth profile on textured surfaces with an acceptable accuracy. The emitter depths measured with SEM and ECV are comparable in this respect. ECV measurement gives meaningful results on a homogeneous emitter.

Laser doped emitters are inhomogeneous. On these emitters, ECV is an instrument to get the mean sheet resistance values for a specific area. The calculated values for sheet resistance correlate with the capacitive measurement. The real emitter profile depends strongly of the laser power. There is a direct relation between the pulse energy density and the homogeneity of the doped region. This behavior needs further investigation. In the laser doped areas, the use of ECV for measuring the depth is questionable, because of the strong differences in the emitter thickness.

Acknowledgements

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