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Fast large area reflectivity scans of wafers and solar cells with high spatial resolution

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Abstract

A solar cell local characterization (CELLO) set-up is modified to measure reflectivity maps of any objects in a non-destructive way. Four different laser wavelengths (BLUE 403 nm, RED 630 nm, IR 830 nm and SIR 934 nm) are applicable. This paper will present the measurement principle, the reflectivity calibration to samples previously analyzed with an integrating sphere, and demonstrate the reflectivity analysis of wafers and solar cells. Compared to other measurement techniques like integrating spheres, this approach has two advantages: First, being fast on large areas (15.6 cm x 15.6 cm sample size; 1 million pixels, measurement time 10 min to 1 hour depending on the accepted noise-level) and second, resolving details in zoom scans with high local resolution (10 µm-spot size). This may allow optimizing processes, where reflectivity is a key parameter like texturization, SiN-PECVD-Antireflective coating or wafer cutting and cleaning processes. Furthermore, independently measured reflectivity maps may be helpful for CELLO photo-impedance analysis in the future.

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Keywords: CELLO; reflectivity; wafer; solar cells; bathlifetime; texturization

1. Introduction

Reflectivity is one key parameter in the characterization of solar cells. It is well-known that texturing, antireflection coating deposition of SiN, and grain orientation of multi-crystalline material have a major impact on the reflectance. Reflectivity losses are direct losses of the photocurrent of a certain wavelength. The front reflectivity R is linked with the external quantum efficiency EQE and the internal quantum efficiency IQE via the equation $IQE(\lambda)=EQE(\lambda)/(1-R(\lambda))$[1]. Standard reflectivity measurement techniques like IQE, or global reflectance measurements, or integrating spheres give just integral values averaged over an area of at least some square-

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millimeters. Additionally, there are some commercially LBIC-systems which measure the local reflectivity, too. However in this paper, we will present an adapted CELLO set-up for much faster reflectivity measurements. Another advantage of this approach is that the measurement is contactless and by this not restricted to solar cells. Any object can be simply used. This paper presents the modified CELLO set-up, explains the calibration procedure and finally, gives some first examples of the technique. Furthermore, independent measured reflectivity data will also be very helpful in the future to improve the CELLO photo-impedance analysis.

Nomenclature

BLUE	laser with 403 nm wavelength
CELLO	solar CELl LOcal characterization
IR	laser with 830 nm wavelength
RED	laser with 630 nm wavelength
SIR	laser with 934 nm wavelength

2. Measurement principle

Fig. 1 presents the modified CELLO set-up [2] for reflectance measurements. Objects, here a sample wafer, are placed on the Au coated Cu chuck. A laser beam is scanned across the sample. The reflected light is collected via a vertically arranged solar cell mini-module that is contacted via a four probe arrangement. This is the first big difference compared to the set-up for standard CELLO measurements. The laser beam is intensity modulated with a perturbation frequency *f* of around 6 kHz. The collected signal is analyzed via a lock-in routine resulting in an amplitude map of the sample. For reflectance measurements the sample holder room is covered with diffusively light reflecting material, imitating the function of an integrating sphere and increasing the signal yield of the reflected laser light, which is the second big modification of the standard CELLO set-up. A typical map has a size of 1000 x 1000 pixels, with 200 µm being the length of one pixel. The smallest possible pixel length is 50 µm. The measurement time for this typical map is 10 minutes to one hour, depending on how many periods of the lock-in measurement are used to average.

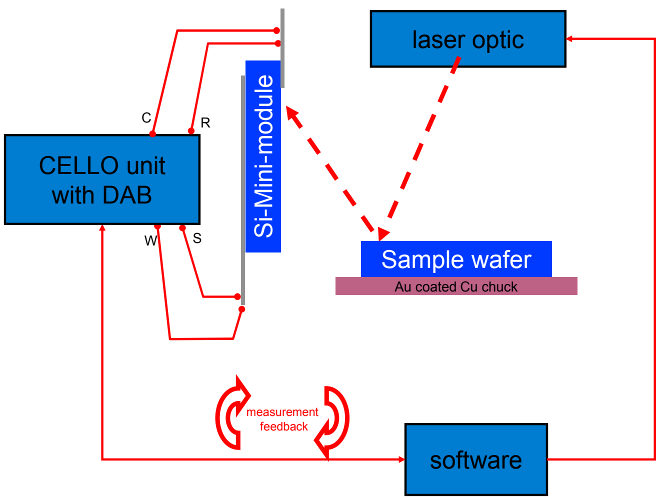

Fig. 1. Schematic of a modified CELLO set-up for reflectivity measurements. The reflected laser beam is collected via a vertical placed solar cell mini-module that is connected via a 4 probe set-up (C: counter electrode; R: reference electrode; W: working electrode; S: sense electrode) to the CELLO unit with the data acquisition board (DAB).

3. Calibration

For calibration, a solar cell is used, that has been previously characterized via an integrating sphere [1], cf. “reference solar cell” in Fig. 2. The global integral reflectance values in % at the four different wavelengths are used to calibrate the CELLO amplitude maps, cf. Table 1. The solar cell as calibration reference has some drawbacks: it is quite big and brittle. Thus, for easier handling in further measurements, a surface structured Al-block is used as a reference sample for calibration, instead of the reference cell, that can be simply placed next to the chuck. Thus the calibrated reflectivity values of the Al-block are used as reference for calibrating the reflectivity maps, cf. Table 1.

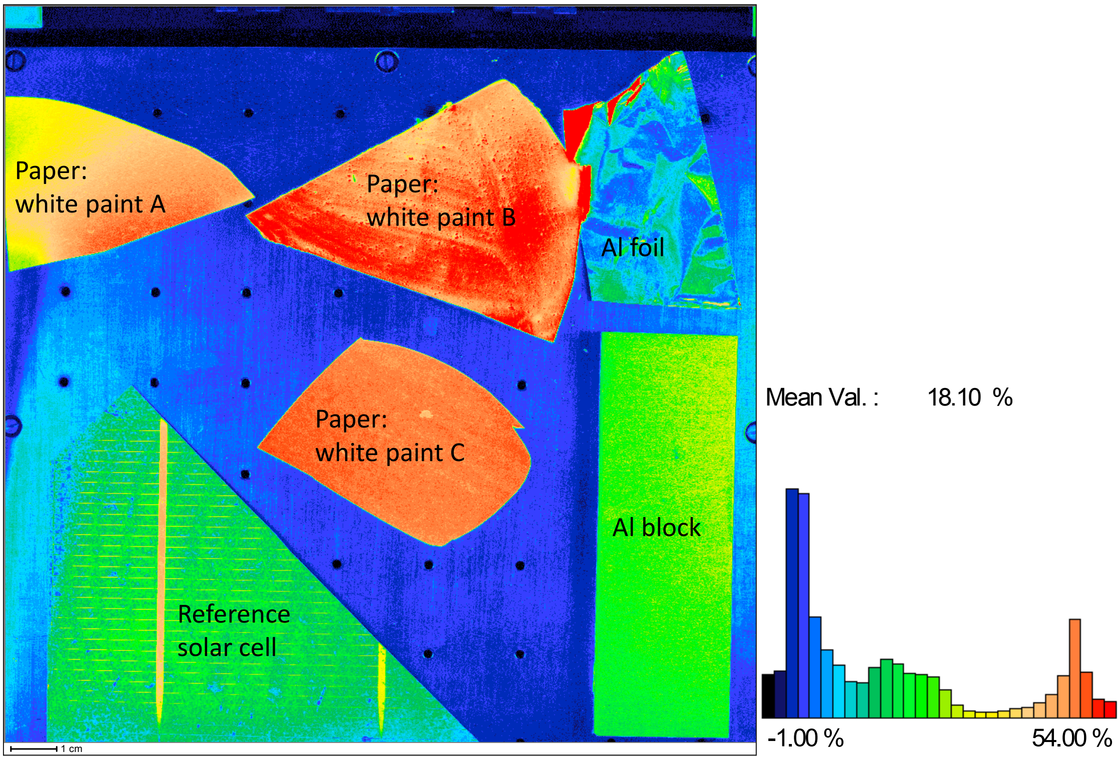

Fig. 2. BLUE laser (403 nm) reflectivity map after calibration of various objects.

Table 1. For calibration routine the maps are multiplied with the scaling factor. Reflectivity values of the Al block and the paints are given as examples.

LASER	*Amplitude Reference solar cell* (µA)	*Reflectivity Reference solar cell* [2] (%)	*Scaling factor map* (%/µA)	*Reflectivity Al block* (%)	*Reflectivity Paint A* (%)	*Reflectivity Paint B* (%)	*Reflectivity Paint C* (%)
Blue	39.65	20	0.5044	26.84	73.71	66.67	60.24
RED	6.41	1.25	0.1950	23.79	64.71	60.21	52.67
IR	14.12	3.33	0.2358	20.61	62.13	58.48	53.08
SIR	14.57	5.41	0.3713	19.44	74.31	69.76	63.77

4. Examples of reflectivity scans

4.1. Object and paint selection of the sample room

Fig. 2 and Table 1 present a calibrated reflectivity scan of various objects, including the reference solar cell, the reference Al-block, a piece of Al-foil and several pieces of paper painted with white paint of different compositions. Here, white latex paint is used mixed with various compositions of BaS, the standard paint for integrating spheres. Paint A shows the highest reflectance and is selected for the room walls as diffused light reflector. The slight inhomogeneity has only a negligible effect on the global diffusively reflected light. The optimal white paint increased the signal of the back reflected light and thus increases the measurement accuracy and reduces noise.

4.2. Alkaline textured solar cell

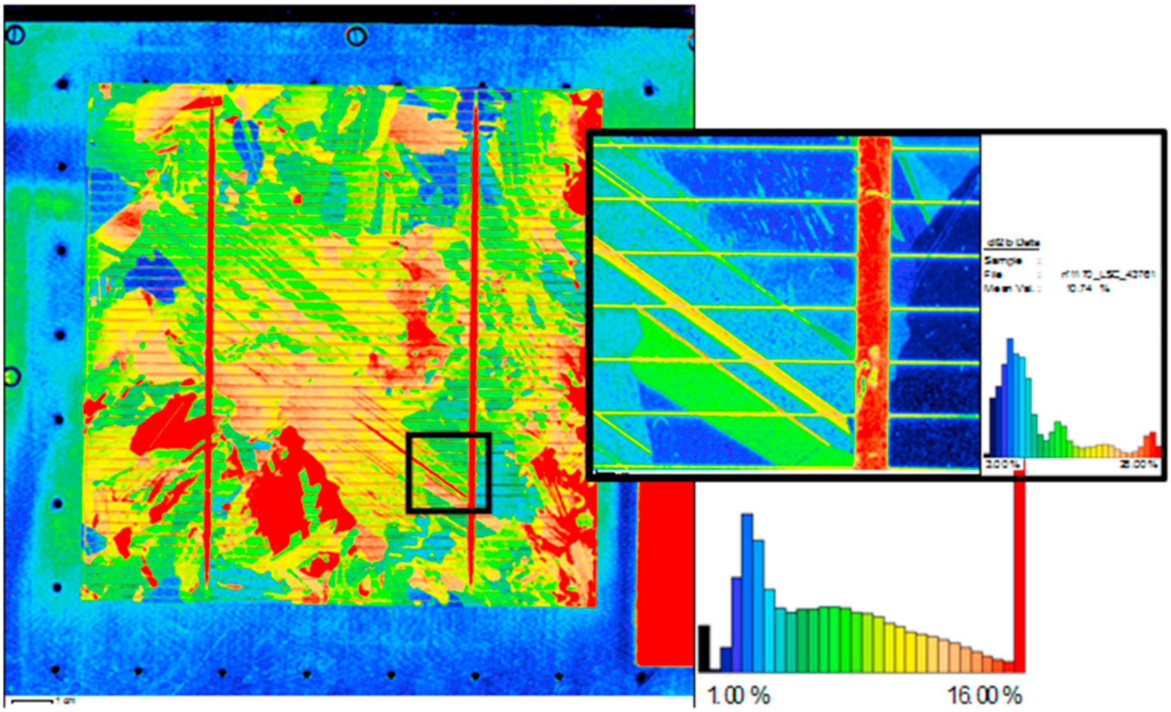

Fig. 3. Blue laser (401 nm) reflectivity map of an alkaline textured solar cell. Zoom picture (black frame) reveals details due to isotropically etched grains.

Fig. 3 presents the blue reflectance map of an alkaline textured solar cell. The zoom map reveals details of the isotropically etched grains, resulting in reflectivity differences. This information can be very useful in the future to optimize the texturization processes. In general, such reflectance maps of solar cells give precious additional information for the interpretation of standard CELLO measurements: The CELLO photocurrent maps are typically partially affected by reflectivity inhomogeneity. In the analysis of CELLO photo-impedance measurements via a sophisticated fit model, also the spectral reflectivity maps can be calculated. However, with the new reflectivity measurement approach presented in this paper we have access to these maps, independently measured. Using this independently measured reflectivity maps as input parameter for the impedance analysis might result in more convincing photo-impedance results. We will publish a direct comparison of the two differently measured reflectivity maps and their impact to the CELLO photo-impedance analysis in the future elsewhere.

4.3. Black silicon surface texturization

Black Silicon samples were produced by a maskless ICP etching process with SF_6 and O_2 at 5 ° C [3]. For this, a plasma etch chamber from Oxford Instruments (Plasmalab System 100 ICP 65) was used with 13.56 MHz frequency and 600 Watt ICP power. The plasma etching time was varied between 0 minutes (reference) and 10 minutes. An overview CELLO reflectivity scan with the Blue laser is presented in Fig. 4. Within this magnification, a strongly reduced reflectivity across the complete area can be observed. Fig. 5 presents reflectivity zoom maps of various wavelengths. The maps reveal various inhomogeneities and spots having higher reflectivity. These spots can be attributed to atmospheric particles (dirt) since the samples were present in air for a few days or even particles from the aluminum chamber wall, which gets etched by the fluorine radicals as well. Scratches due to the manual handling are also very likely. Global reflectivity measurements were performed using the UV/VIS/NIR spectrometer Lambda 1050 from Perkin Elmer, cf. Fig. 6. Table 2 summarizes the results. In general, there is a good correlation between the integral reflectance values and the plasma textured regions with the CELLO reflectivity measurements. However, the good positions of the CELLO high resolution reflectivity maps are a few percentage points better than the integral reflectivity values, cf. Table 2. One possible explanation for this might be, that the “bad” spots shift the mean value of the integral maps. Thus the CELLO maps high resolution maps helps to better reveal the full potential of the black Si material. Further, it is obvious that lateral inhomogeneity’s of the plasma texturing process can be revealed excellently by using the CELLO reflectivity technique.

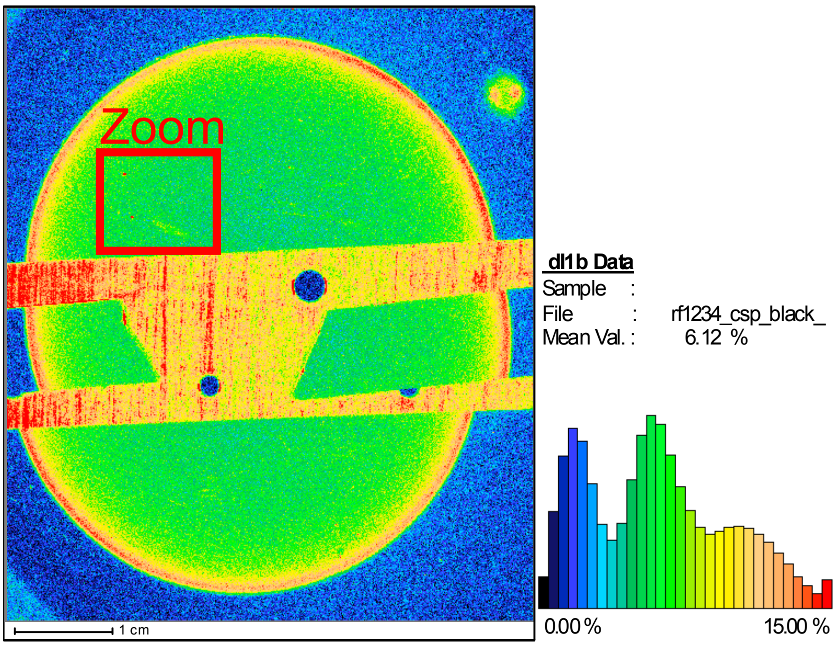

Fig. 4. BLUE laser (403 nm) reflectivity map of a black Si sample. The sample is cleaved. The red area in the center is the measured reflection of the Cu chuck.

Table 2. Comparison of global reflection measurements and CELLO-reflectivity measurements.

LASER	*Wavelength (nm)*	*Black Si sample GRM* integral value *reflectivity* (%)	*CELLO Bad spot reflectivity* (%)	*CELLO normal spot reflectivity* (%)
Blue	401	7.92	15	5.3
RED	650	3.95	32	1.9
IR	830	3.23	15	1.2
SIR	934	2.95	10	1.0

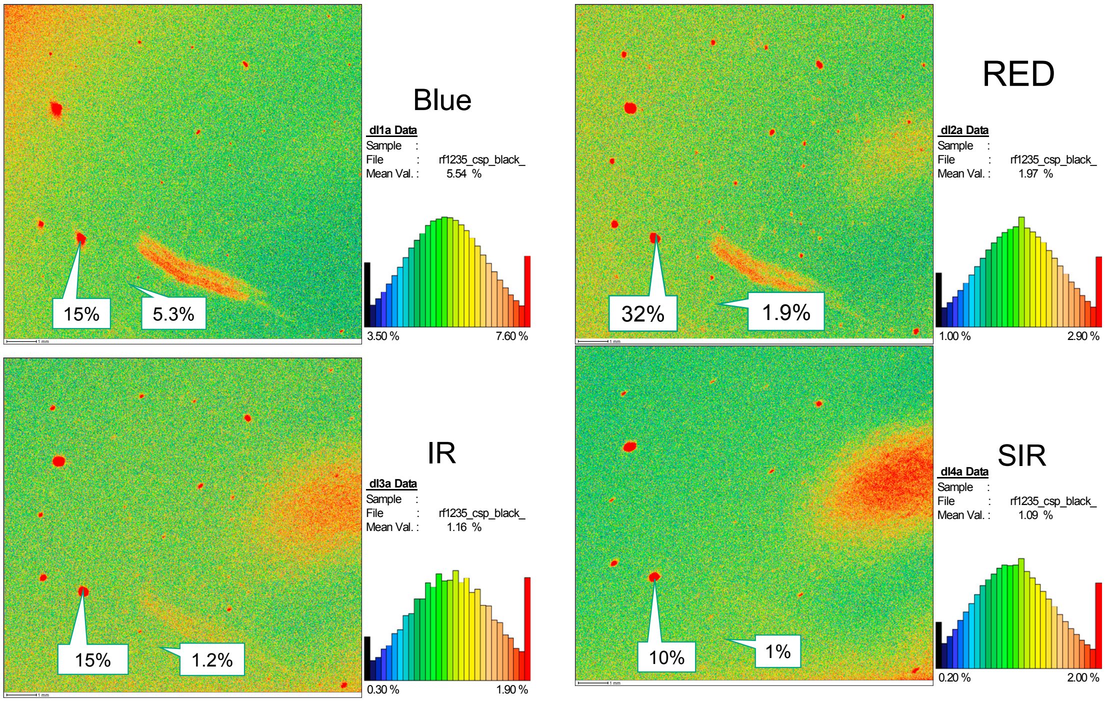

Fig. 5. Zoom map of Fig. 4 of the black Si sample with various wavelengths.

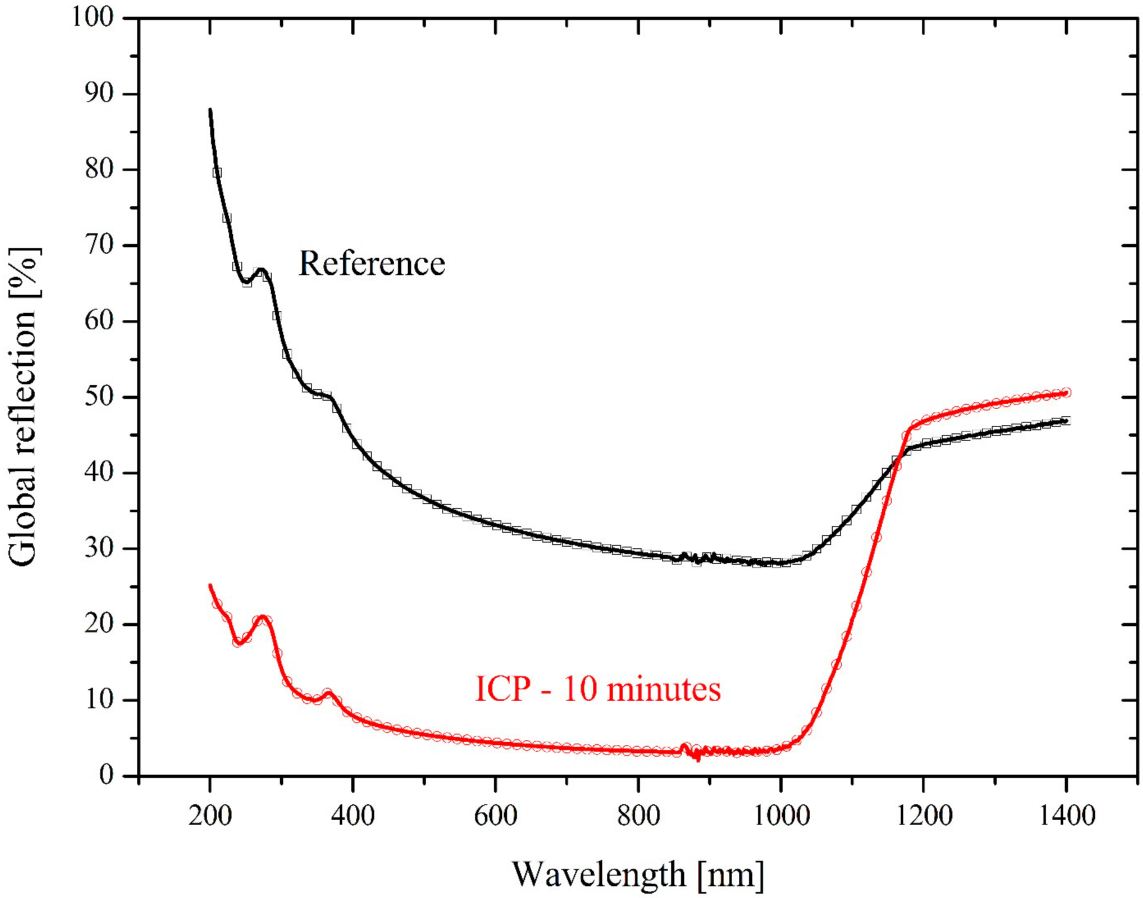

Fig. 6. Global reflection measurement (GRM) of the black Si wafer (red line). Reference (black line): as cut wafer with no texture and no antireflection coating.

4.4. Silicon wafer sawn by diamond wire

Fig. 7 presents the IR reflectivity map of a diamond wire sawn silicon wafer. Visible are thin horizontal lines in slicing direction, which are also visible with naked eye. However the vertical stripes, not visible with naked eye, are unexpected. Their cause is unknown. They are visible on both wafer sides. These patterns might have a negative effect on the efficiency of the final processed solar cell, since similar patterns have been previously be observed on defected solar cells. In the future, systematic CELLO reflectivity measurements of wafers in comparison with CELLO efficiency analysis measurements might clarify this issue.

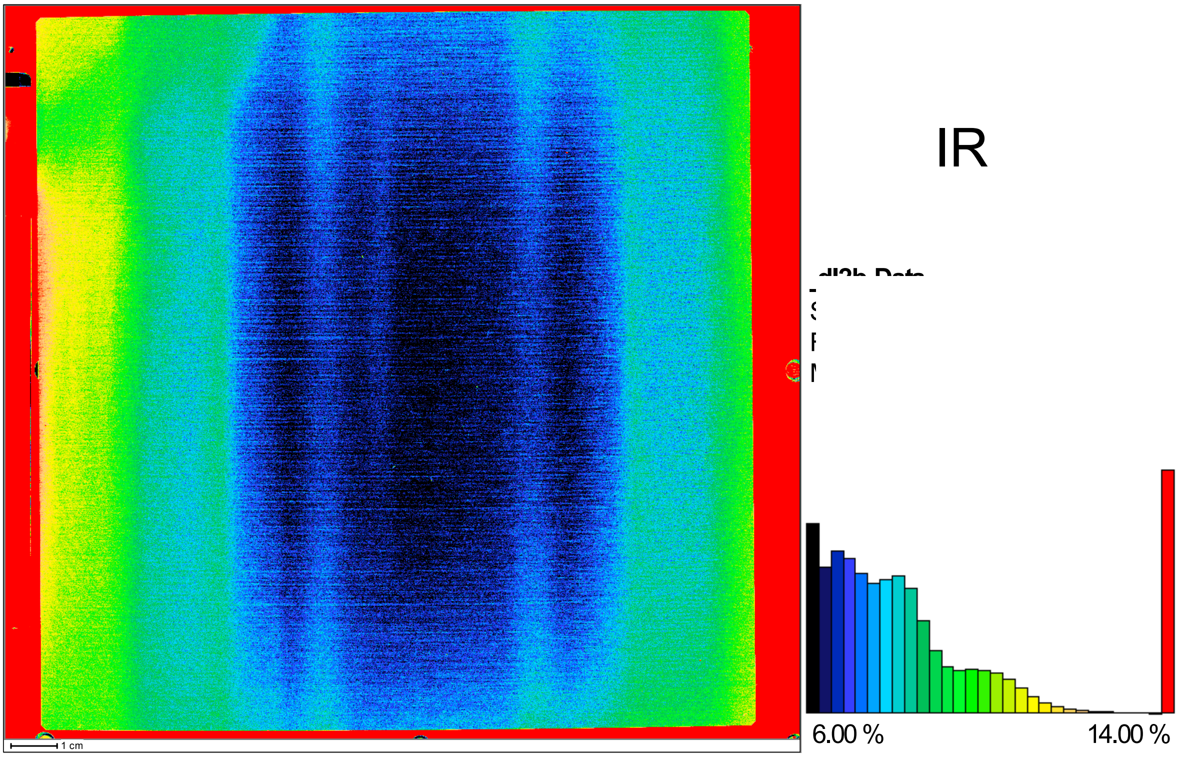

Fig. 7. IR laser (830 nm) reflectivity map of a diamond sawn silicon wafer.

5. Importance and future deployment

Spatially resolved reflectance maps of solar wafers and cells are very helpful for the optimization of various processes that influence the reflectivity, like surface texturization and antireflection coatings. The method may be very interesting for the optimization of bath life times of the texturization process. A correlation of texturization bath life times with reflectance maps may help to find the optimal time to replace the bath, thus reduce processing and disposal costs.

Additionally, reflectance maps might become an interesting independent measurement parameter map as input for the CELLO photoimpedance analysis that is capable of measuring local diffusion lengths, bulk lifetime, and back surface recombination velocity [2, 4].

6. References

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