QUANTITATIVE CLASSIFICATION OF SAW MARKS OF SILICON WAFERS

A. Lawerenz[1], S. Dauwe[1,2] and F.-W. Schulze[3]
[1]CiS Institut für Mikrosensorik gGmbH, SolarZentrum Erfurt, Konrad-Zuse-Str. 14, 99099 Erfurt, Germany
e-mail: alawerenz@cismst.de
[3]PV Silicon Forschungs und Produktions AG, Wilhelm-Wolff-Str. 25, 99099 Erfurt, Germany

ABSTRACT: In this work, we measured surface profiles of silicon wafers and analysed these profiles quantitatively in order to classify those saw marks which are regarded as important features of the wafer surface. These features include steps, grooves and waviness. We present new definitions for these saw marks. Steps and grooves are detected by scanning a given surface profile by means of a virtual tip. The waviness of a wafer is determined by subtracting two differently averaged profiles. These definitions are successfully applied to complicated real surface profiles and can easily be implemented into computer algorithms.
Keywords: silicon, wafer monitoring, surface profiles

1 INTRODUCTION

The vast majority of today's solar silicon wafers are sawn by multi-wire saws. The sawing process induces a series of different flaws to the wafer, among them steps, grooves and waviness. These surface related profile properties play an important role for both wafer and solar cell manufacturers. Firstly, these properties are important for the wafer manufacturers as a quality control tool and characterise the sawing process. Secondly, solar cell manufacturers depend on a wafer surface quality that ensures a reliable processing of solar cells. Especially for the screen printing of front and backside contacts, smooth wafer surfaces are mandatory. Thirdly, saw marks can impair the optical appearance of the wafers.

Until now, surface profiles of wafers are not generally measured in the production lines of wafer and cell manufacturers. It is more common to perform a visual inspection using wafer templates. Therefore, there is little experience of how to evaluate these surface profiles. In order to get this experience and to be able to handle the data of measured surface profiles these profiles must be classified by certain key parameters. Such parameters are related to steps, grooves and waviness. However, up to now there are no generally accepted definitions for these saw marks.

Starting point of the present paper are height profiles measured on real as-sawn wafers. As key features of these profiles steps, grooves and waviness are identified. We present new definitions which allow an easy quantification of the wafer profile and its key features.

2 EXPERIMENTAL

We measured the surface profiles of wafers which were sawn by multi-wire saws. The surface was scanned perpendicularly to the saw marks with a laser probe (NanoFocus µScan). A high height resolution (100 nm) was obtained using confocal focussing. The lateral resolution was 2 µm.

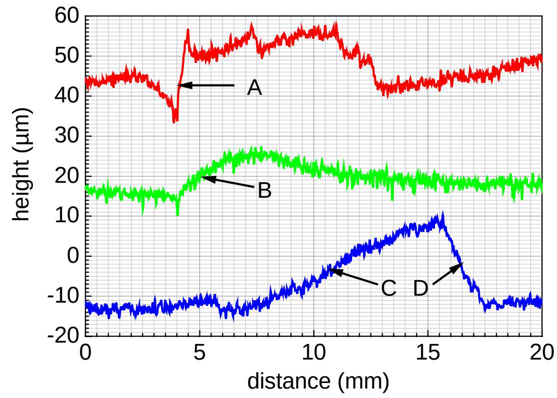

Figure 1: Surface profiles of silicon wafers: examples of steps

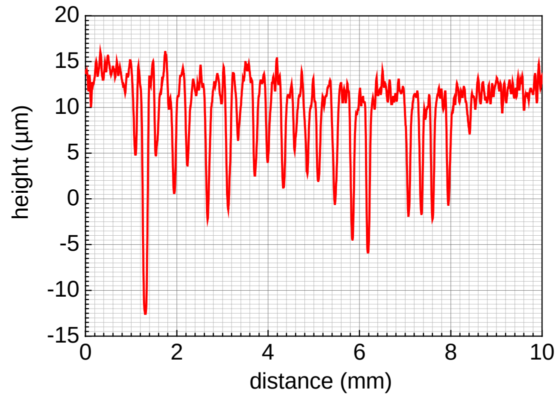

Figure 2: Surface profile of a silicon wafer: examples of grooves

3 CHARACTERISATION OF WAFER PROFILES

An ideal step is a structure in a surface profile with two flat sections which are separated by a section with a steep slope. But real profiles are often characterised by steps which deviate considerably from this ideal case (see Fig. 1). The steep sections of the shown steps have the following slopes: 0.04 (step A), 0.004 (step B), 0.004

[2] now with SCHOTT Solar GmbH, Alzenau, Germany

(step C) and 0.025 (step D), where the slope is defined as usual as Δy / Δx; Δy: height difference, Δx: difference in x-coordinate (distance). Slopes of the step profile which are smaller than 0.01 are not considered here as relevant to the solar cell process.

An ideal groove is a longish indentation in an otherwise flat wafer surface. Similar to the case of steps, real grooves can differ from the ideal ones. This is shown in Fig. 2, where many grooves are lying closely side by side so that a flat surrounding of each groove does not exist. The grooves we investigated are near the upper surface typically 100 to 200 µm broad. Their depths vary typically between 10 and 50 µm. For the slope of the profile at the steepest edge of a groove, we measured values between 0.012 and 0.5.

4 DEFINITIONS

4.1 Definitions of grooves and steps

The common feature of steps and grooves is that at some point in the profile the absolute value of the slope at this point of the profile exceeds a certain value. It is the surrounding of this point which determines whether this point belongs to a step or to a groove.

Therefore we suggest an algorithm for tracking down steps and grooves. This algorithm scans the measured profile and locates all points of the profile whose absolute value of the slope is exceeding a value f which has to be predetermined. This can be visualised by a two-dimensional virtual tip which scans the already measured wafer surface (see Fig. 3 and 4). This virtual tip has a triangular shape with its vertex directing downwards. Both slopes of the side edges of the tip are identical (except for their sign) and their absolute value is identical to f. The tip can be regarded as being indefinitely large so that the upper corners of the triangle can never touch the given surface profile. Whenever the slope of the surface profile exceeds the slope of the scanning tip's edge, the tip touches the profile at two points (T_1 and T_2 in Fig. 3 and 4). A third point (M) is the minimum of the surface profile between T_1 and T_2. Further definitions are h_o: height difference between T_1 and T_2; h_u: height difference between M and the lower one of points T_1 and T_2.

By relating h_o and h_u, the structure found by the scanning form can be identified as a step or a groove. We define a step character s by the equation

$$s := h_o / (h_o + h_u).$$

A profile structure is defined as a step if $0.5 \leq s \leq 1$ and as a groove if $0 \leq s < 0.5$.

The heights h_o and h_u also quantify the step depth and the groove depth. The step depth is defined as $h_o + h_u$. The groove depth is defined in the same manner ($h_o + h_u$), although another definition (½ $h_o + h_u$) can also be reasonable.

For the virtual scanning tip, there is only one parameter to be ascertained. That is the slope of the edge f. It must not exceed the slope of the saw marks that have to be detected. However, if the slope is too small, some saw marks could be summed up by the virtual scanning tip. A reasonable value is 0.01, because the slope of the interesting saw marks is larger than this value as shown in section 3.

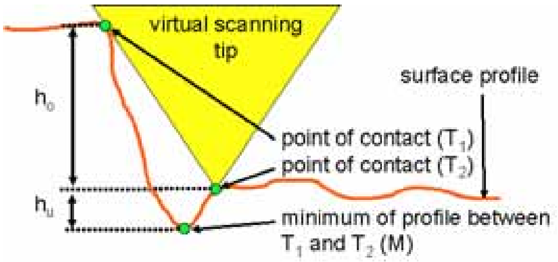

Figure 3: A virtual scanning tip is touching the profile at two points. $h_o > h_u$, hence this profile structure is identified as a step.

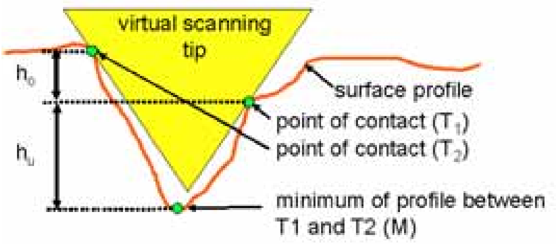

Figure 4: A structure in a surface profile that is detected by the imaginary scanning tip. $h_o < h_u$, hence this profile structure is identified as a groove.

4.2 Definition of waviness

The waviness reflects the deviation of the profile from a flat wafer surface on a medium scale. The word waviness usually implies a periodic behaviour. Our measurements show that there are wafers whose profiles are not periodic, but nevertheless would be called wavy by many users (see Fig. 5). Hence we suggest a definition for waviness that relaxes the periodicity requirement.

Instead of applying a fourier transformation, we use a simpler procedure by subtracting a coarsely averaged profile (which reflects the long-periodic behaviour of the wafer such as the wafer bow) from a finely averaged one (which reflects the short-periodic behaviour such as the roughness and grooves). Thereby, we obtain a profile which yields the required medium scale behaviour (Fig. 6). Determining the maximum deviation from the base line (y = 0) gives a measure of the waviness. The averaging is carried out by using a trapezium (with two parallel sides) as a weighting function. The base length T (see Fig. 7 a) is 0.3 mm for the finely averaged profile, and 12 mm for the coarsely averaged profile, respectively. The averaging can also be described by filtering the measured profile with a transfer function A which is the Fourier transform of the weighting function,

$$A = \frac{4}{3}\left[\frac{\sin(2\pi fT)}{2\pi fT}\right]^2 - \frac{1}{3}\left[\frac{\sin(\pi fT)}{\pi fT}\right]^2$$

(f: spatial frequency). At the cut-off value the amplitude of the transfer function falls to 50 % of its maximum value (at $f = 0$). This cut-off value is reached at 0.66/mm mm for the finely averaged profile, and at 0.016/mm for the coarsely averaged profile, respectively. This corresponds to a cut-off wavelength of 1.5 mm and 60 mm, respectively.

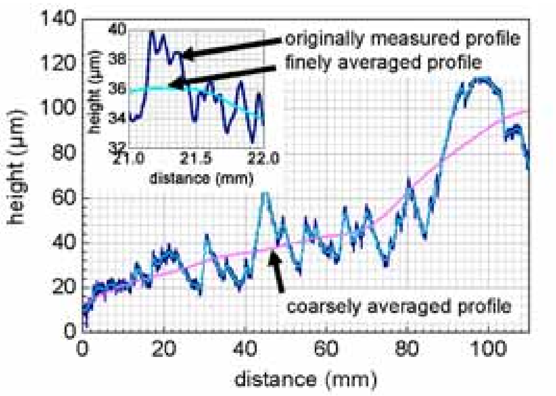

Figure 5: Surface profile of a wavy wafer. The inlet shows a detail to illustrate the difference between the originally measured profile and the finely averaged profile

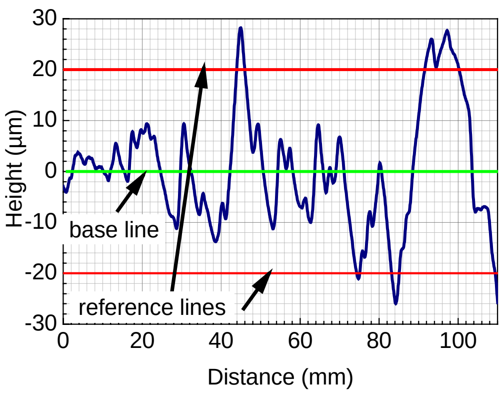

Figure 6: Differential profile of the wafer of Fig. 5 yielding the waviness

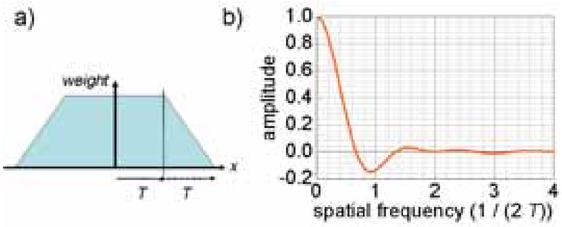

Figure 7: (a) weighting function used for the averaging of the profiles, (b) transfer function for the averaging

This approach is similar to the determination of the waviness described in an European norm [1].

By counting the profile points, which exceed two given reference lines (with a certain distance to the base line), another measure for the waviness can be found. If all profile segments lie between the reference lines a waviness is measured that can be tolerated.

5 EXAMPLES

In Fig. 8 two examples of complete height profiles are given. The surface properties of these profiles we obtain by applying our new definitions and implementing the associated algorithm into a computer programme are included in Table I. Only steps and grooves whose depths are larger than 10 µm are considered.

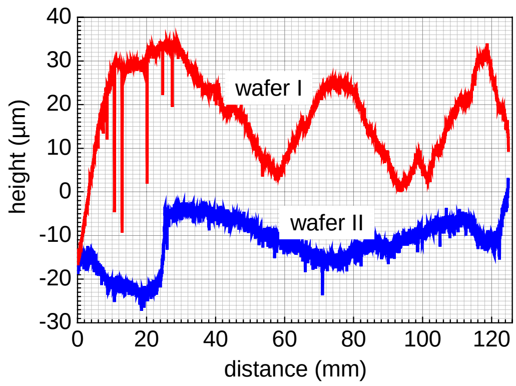

Figure 8: Measured profiles of two silicon wafers, one of which is characterised by several grooves (wafer I) and one of which is characterised by a step (wafer II)

Table I: Surface properties of the two wafers shown in fig. 8 (slope of the virtual scanning tip *f*: 0.01, *s*: step character)

position (mm)	*s*	depth (µm)
wafer I		
8.55	0.09	12
10.65	0.00	34
12.89	0.01	38
20.15	0.04	31
24.65	0.11	12
27.47	0.04	15
wafer II		
24.01	0.86	18

6 DISCUSSION

Steps and grooves are usually identified by comparing the height differences of the profile within a base length whose extent is not commonly established. This procedure has the disadvantage that complicated surface structures (as shown in Fig. 1 and 2) cannot easily be classified as steps or grooves. Also the extent of grooves and particularly steps (in the x-direction) can exceed the chosen base length.

These disadvantages can be overcome by our newly introduced definitions of steps and grooves, because our definitions only rely on the concept of the slope. Every profile structure with a slope exceeding a well chosen value is recognised and can be assigned to a step or a groove by assessing its step character. Another advantage of our definition is that it can easily be described by the virtual scanning tip: whenever it touches the surface profile at two points there is a surface structure which can be identified as a step or a groove.

Alternative shapes of the virtual scanning tip are also possible but the implementation of the associated algorithm in a computer programme is more complicated.

Another feature of the surface profile is the waviness which we determine by subtracting two differently averaged profiles. For the averaging we used a trapezium as a weighting function. We chose this function, because it is easier to implement into a computerised algorithm than the also possible Gauss function. Our approach is more descriptive than the more complicated fourier analysis procedure but yields similar results.

7 CONCLUSION

Using our new definitions of steps, grooves and waviness, we are able to describe and quantify even complicated surface profiles by a small number of key parameters such as the number of steps and grooves (exceeding a given depth) and the waviness. These definitions are descriptive and overcome the restrictions of commonly used definitions. Algorithms can easily be implemented in automated profile analysis tools.

8 REFERENCES

[1] EN ISO 4287 Geometrical Product Specifications (GPS) - Surface texture: Profile method - Terms, definitions and surface texture parameters