A NEW APPROACH TO THE ANALYSIS OF LIGHT COLLECTED BY TEXTURED SILICON SURFACES

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Surface texture plays a fundamental role in the development of efficient silicon solar cells as it promotes light absorption through multiple surface reflections. Purpose of this paper is to present a new approach to the investigation of light collection by textured silicon surfaces. By analysing the angular distribution of laser light backscattered from different families of texture geometry (inverted pyramids, wells, thin porous silicon layers), we have found, in fact, that for each family the total light collected is linearly correlated with the shape and intensity of the diffused light component.

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Review Abstract Preferred mode of presentation: oral

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The optimisation of surface texturisation is an important step in the development of efficient silicon solar cells. Besides improving absorption at surface due to multiple reflections, texture scatters light into the semiconductor, thereby increasing the optical path length and promoting multiple internal reflections which enhance the overall absorption process. This subject has become a key factor in the modern silicon cell technology, as the actual tendency is to reduce cell thickness down to few tens of microns. Surface texture determines light scattering into the semiconductor and backwards from the cell front surface. The analysis of light backscattered in textured silicon structures, which has never been adequately investigated, could bring new information about light collection process and new ideas about technological solutions for improving it, as light backscattered from the textured surface is a sort of image of the light propagating into the semiconductor. At this purpose, we have developed different methods and apparatus for visualizing, measuring or recording the backscattered light [1, 2].

In this paper we describe a new approach for investigating the light collection in textured semiconductors by analysis of backscattered light. Textured crystalline silicon samples are irradiated with orthogonally incident laser beams at different wavelengths in the visible, and the angular distribution of light intensity is measured. Different families of surface texture geometry are considered (see Fig. 1): inverted pyramids (IP), obtained by anisotropic etching of (100)-oriented single-Si wafers, hemispherical wells (HW), obtained by isotropic etching of single-Si or multi-Si wafers, and porous silicon layers (PS), obtained by electrochemical anodic dissolution of (100)-oriented single-Si wafers.

The apparatus used for backscattered light measurements is shown in Fig. 2. The light beam from a He-Ne laser (λ=543 or 633 nm), chopped and monitored by a reference detector, crosses the 20-cm diameter integrating sphere (IS) and strikes the sample. The IS is provided with a 6-cm diameter (D) window faced to the sample for collecting the backscattered light within solid angle Ω, and with a second detector inside for measuring it. By moving the sphere apart from the sample, or the sample apart from the sphere, the solid angle Ω changes and the corresponding linear angle θ varies from 90° at a distance x=0 to ~0° at x>>D, typically 50 cm. If $G(\theta)$ is the light collected within solid angle $\Omega(\theta)$ and $I(\theta, \phi)$ is the intensity of light backscattered towards the observing direction (θ,ϕ), where θ = zenithal angle and ϕ = azimuthal angle, then $G(\theta)$ is given by:

$$G(\theta) = \int_{\varphi=0}^{2\pi} d\varphi \int_{\alpha=0}^{\theta} d\alpha \cdot \sin\alpha \cdot I(\alpha,\phi) \qquad (1)$$

The average intensity of light backscattered at angle θ can be obtained by differentiating $G(\theta)$ and normalizing with respect to the cross section area:

$$\bar{I}(\theta) = \frac{1}{dS(\theta)/d(\theta)} \cdot \frac{d}{d\theta} G(\theta) = \frac{1}{2\pi \sin(2\theta)} \cdot \frac{d}{d\theta} G(\theta) \qquad (2)$$

To avoid differentiation of $G(\theta)$, which is generally problematic with discrete data, a simple procedure has been adopted in which the scattered light distribution is approximated to an ellipsoid of revolution with axes a (transversal) and c (longitudinal). The theoretical integrated intensities $G(x)$, expressed as function of the distance x, are reported in Fig. 3 for prolate ellipsoids. The comparison with the experimental curve of $G(x)$ allows to assign a value of aspect ratio to the experimental light distribution (see Fig. 3).

Purpose of the present work is to show the correlation found between the properties of the diffused component of backscattered light (angular distribution and intensity) and light collection, as derived from total reflectance measurements on the textured silicon samples at the same illumination conditions (orthogonal incidence). At this purpose, total reflectance R_{tot} and diffused reflectance R_{diff} were measured for all the textured samples by using well established methods [3].

If the light collection LC, defined as LC = 1-R_{tot}, is plotted as function of the variable $\xi = r \cdot R_{diff}$ for all the families of textured samples (see Figs. 4 and 5), it appears evident that the data of the same texture family arrange themselves in a linear plot. As expected, light collection is higher for most densely textured samples, but the dependence of light collection on the backdiffused light properties is strongly dependent on the geometry of texturisation features and wavelength. Investigations about the parameters that influence the correlation are still open, both for samples textured by a regular array of features (IP and HW) (see Fig. 4) and for randomly textured ones (PS) (see Fig. 5).

Further light backscattering measurements will be carried out by polarized light at other wavelengths. The above research is expected to improve the knowledge of interaction between light and textured semiconductor surfaces, which play a relevant role in the modern photovoltaic technology.

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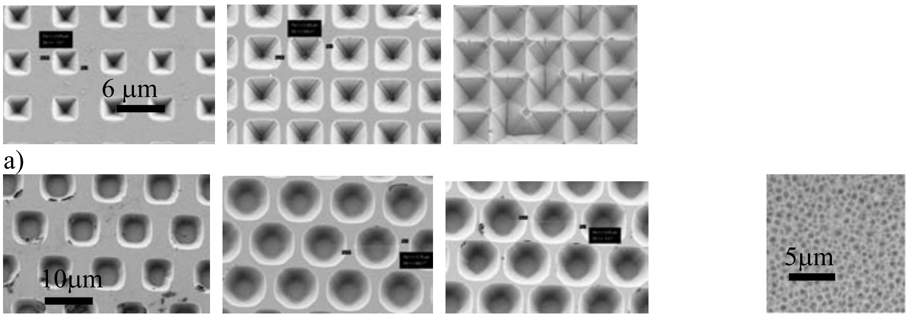

a)

b)

c)

Figure 1. SEM pictures of textured (100)-oriented single-Si wafers: a) inverted pyramids (IP); b) hemispherical wells (HW); c) porous silicon layer (PS). The families of pyramids or wells were obtained by adopting different etching process times. The family of PS layers was obtained by adopting different HF concentration.

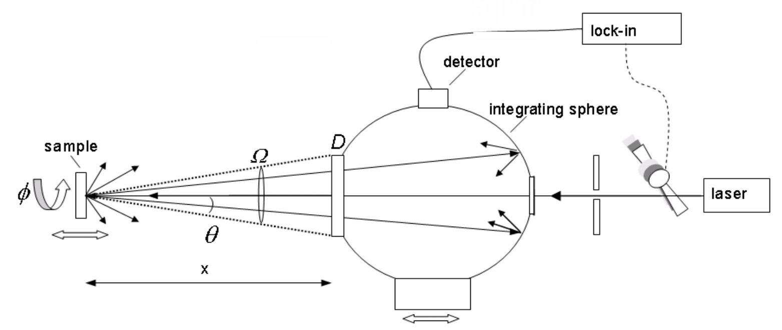

Figure 2. Apparatus for measurement of backscattered light angular distribution.

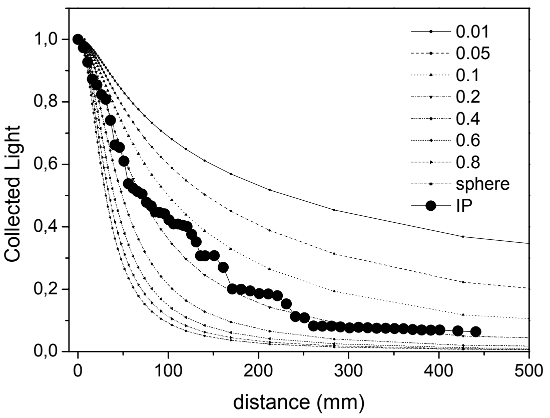

Figure 3. Normalized integrated intensity, G(x), of prolate ellipsoids, as function of the sample-sphere distance. The experimental curve of one IP sample is also shown, and it was assigned an aspect ratio r = 0.18.

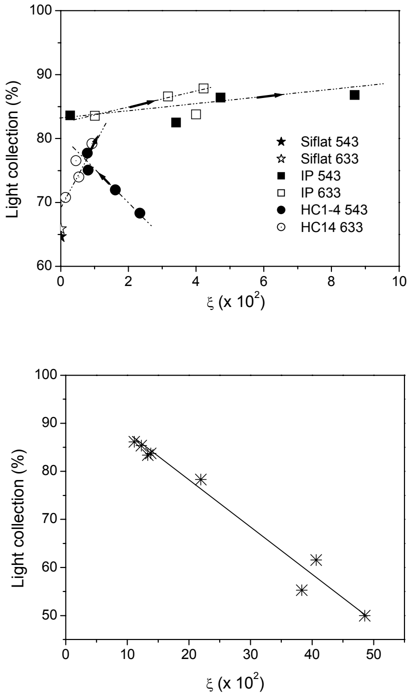

Figure 4. Light collection as function of $\xi = r \cdot R_{diff}$ for a) HW and IP texture families and b) porous silicon samples (PS).