

Surface Texturization and Interface Passivation of Mono- and Polycrystalline Silicon Substrates: Evaluation of the wet chemical Treatments by UV-NIR-Reflectance

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Motivation

Economically attractive silicon solar cells need appropriate substrate preparation and passivation methods to optimize the light trapping properties and to reduce recombination losses on textured interfaces.

The texturization of Si substrates, however, leads to a strong increase in crystallographic surface irregularities, resulting in a high density of rechargeable states $D_{it}(E)$ and in high recombination losses on structured interfaces. To reduce the density of these states, it is necessary to remove the damaged surface layer and to decrease the micro-roughness of textured surfaces on the nanometer scale.

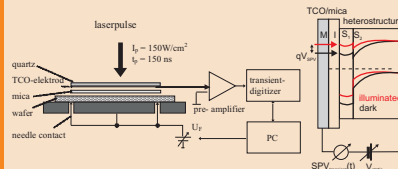
Wet chemical treatment is still state-of-the-art to texturize Si surfaces. Classical processes comprise the application of strong acid and alkaline etchants.

Wet-chemical cleaning and passivation methods developed for flat surfaces are not so effective for textured substrates. We investigated sequences of wet-chemical smoothing and oxide removal to prepare atomically smooth, contaminant-free silicon interfaces with excellent electronic properties on these surfaces.

The relations between structural imperfections at atomically flat and textured Si, light trapping behavior and interface state densities were investigated by scanning electron microscopy (SEM), surface photovoltage (SPV) and total hemispherical UV-NIR-reflectance measurements.

Industrial production processes demand an in-line metrology to characterize the surface quality of structured solar wafers. UV-NIR-reflectance measurement opens a way for a fast and robust in-line characterization of etched wafer surfaces.

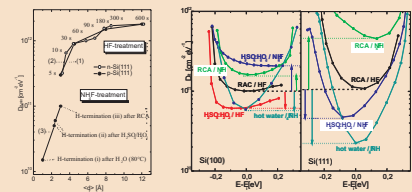
Surface photovoltage method (SPV)



Determination of :

- surface Fermi-level position $E_{FNS} = E - E_i$
- energetic distribution of interface states $D_{it}(E)$
- minimal value of interface state density $D_{it, min}$
- time decay of the photovoltage

Nano-roughness ↔ density of states

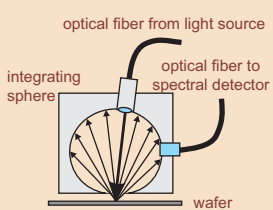


- $D_{it}(E)$ on H-terminated Si(100) and Si(111) after removing oxide layers in HF1% or NH4F as a function of the preparation-induced micro-roughness $< d >$

Minimization of D_{it} :

- Decrease of initial interface roughness by non-aggressive oxidation
- Oxide removal by HF or NH4F solution considering the Si orientation

Reflectance Measurement



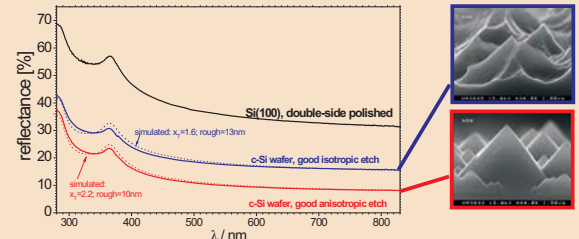
Measurement setup with integrating sphere allows fast characterization of spectral reflectance of textured and rough wafers.

- measurement time: 50 ms
- optical measurement without mechanical contact
- measurement method is fully capable for in-line measurement in production processes

Texture: reflected light is directed to the surface again.

Nano-roughness: effective refractive index is decreased for rough boundaries. Rough boundaries act as anti-reflection layer.

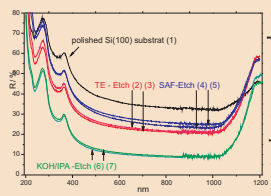
Interpretation of reflectance spectra



The influence of texture and nano-roughness can be separated and described by two quantities:

- texture parameter x_T , specific for the average number of reflections which a light beam experiences at incidence
- effective thickness of the roughness

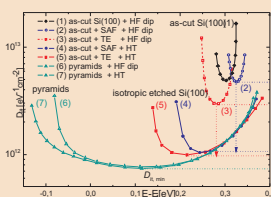
Reflectance after wet-chemical etching



Optical reflection spectra

- Acid etchant SAF^{1,2}:
- combination of saw-damage removal and texturisation
- fast process at ambient temperature
- KOH / IPA:
- Si*111 (pyramids by anisotropic etching)
- high light absorption

Interface state density on textured surfaces



SPV: $D_{it}(E)$

- High density of interface states on as cut and textured surfaces
- Decrease of interface state density by wet-chemical smoothing procedures

¹ W. J. Sievert, K.-U. Zimmermann, J. S. Starzynski, Wafer Thinning Products, European Semiconductor, 27(2005) 17.
² W. J. Sievert, K.-U. Zimmermann, B. Hartmann, C. Klimm, K. Jacob, H. Angermann, Solid State Phenomena 145-146 (2009) 223.

Conclusion

Light absorption of Si is influenced by texture and nano-roughness on the surface of the wafer.

Texture and nano-roughness can be characterized by measuring the integral spectral reflectance.

Spectral reflectance measurement is suitable for in-line monitoring in production lines.

It was demonstrated, that contactless SPV measurements provide detailed information about the influence of wet-chemical processes on the preparation-induced electronic surface properties.

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