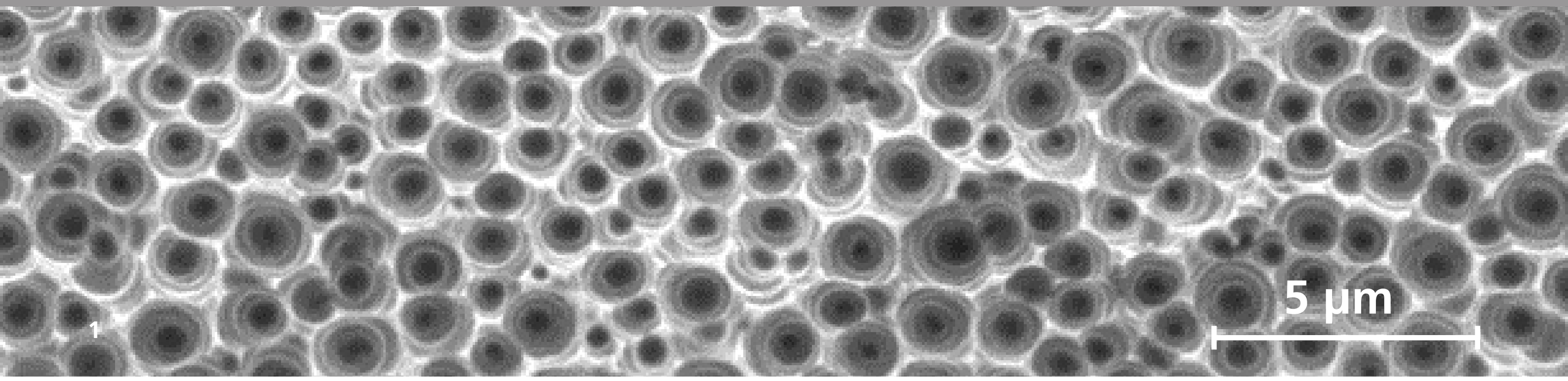
FRAUNHOFER CENTER FOR SILICON PHOTOVOLTAICS CSP



1 *Top view of moth-eye structures for crystalline silicon solar cells. (SEM-image).*

MOTH-EYE EFFECT FOR CRYSTALLINE SILICON SOLAR CELLS

A nanostructure for crystalline silicon is imitating the surface morphology of moth eyes and is decreasing optical losses in solar cells.

The Moth-Eye Principle

Scientists at Fraunhofer Center for Silicon Photovoltaics CSP and the University of Applied Sciences Anhalt have developed a nanostructuring for silicon solar cells which is imitating the optical characteristics of moth eyes. In nature, this structure protects the moth from predators. Goal of the technological development is an implementation in current industrial processes. Due to this technology, low reflectivity values can be achieved leading to an improved efficiency of the solar cells.

The physical fundamental of moth-eye structure is a surface morphology with widths of 400 nm and smaller (see Fig. 1). The width of the texture is in the order of the visible light, making the texture works as a so-called effective medium. This effective medium causes a gradual transition of the refractive index between air and silicon. The incident light is almost entirely absorbed.

The 'Black-Silicon-Method'

The moth-eye structures are formed by a maskless anisotropic plasma etching with SF_6 and O_2, which is called 'The Black-Silicon-Method'. This technology is based on two opposite effects. On the one side, the silicon gets etched isotropically by F-atoms. On the other side, the F-atoms and O-atoms form with the silicon surface a SiOF self-masking layer, which prevents an F-atom etching of the sidewalls. Incoming ions from the plasma discharge open locally the SiOF layer, which results in a maskless anisotropic etching.

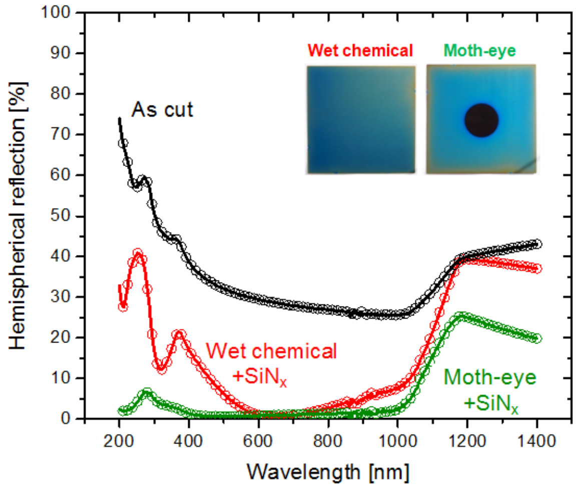
Fraunhofer Center for Silicon Photovoltaics CSP

Otto-Eissfeldt-Strasse 12
06120 Halle (Saale) | Germany

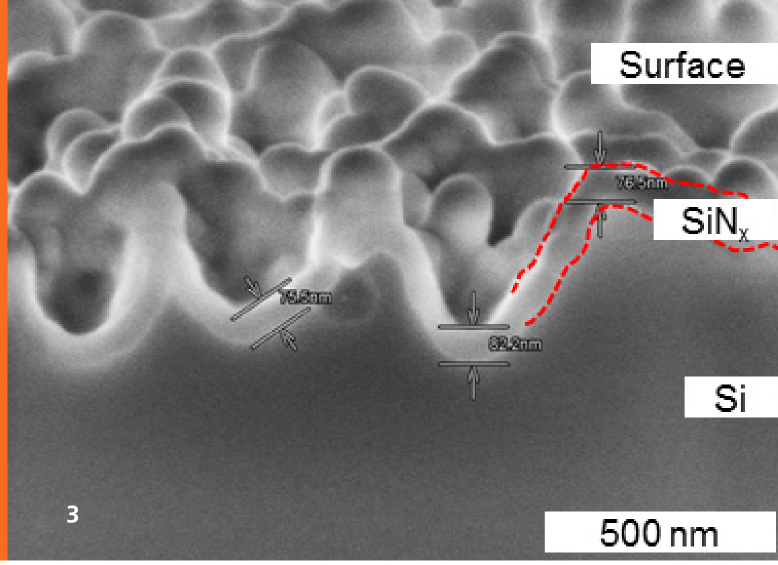
Contact

Dr. Dominik Lausch
Telephone +49 345 5589 5114
dominik.lausch@csp.fraunhofer.de

www.csp.fraunhofer.de



2



3

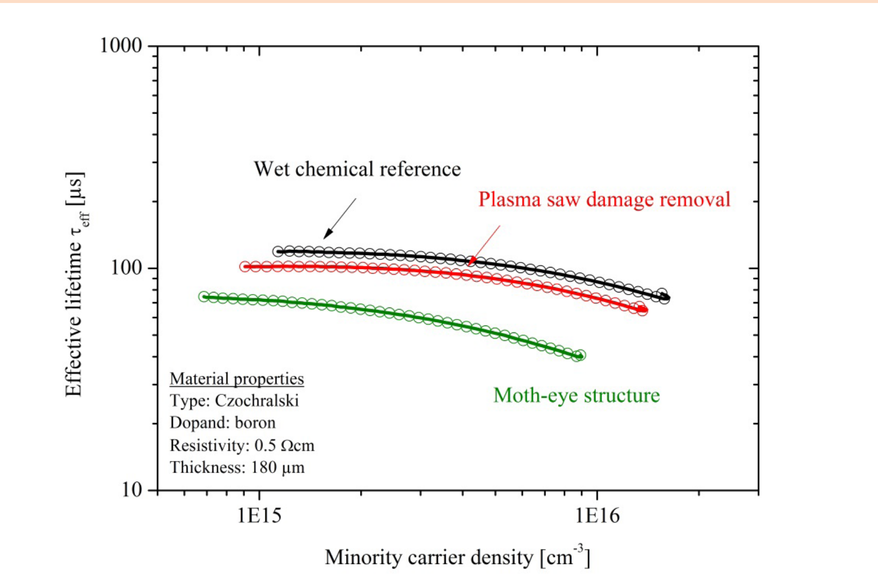
This technology is also suitable for both, mono-crystalline and multi-crystalline silicon. Moreover, the plasma etching process is independent of the surface characteristics of the wafer. As a result, the technology is particularly suitable for texturing of diamond wire sawn wafers and wafers from kerf-less technologies.

Optical Properties

The formation of an effective refraction index between air and silicon results in excellent optical properties under normal and oblique angles of incidence. Fig. 2 shows a comparison of the hemispherical reflection of moth-eye structures and industrial state of the art wet chemical textures. The moth-eye structure shows in the visible range of the incident light a total hemispherical reflection below 1 %. Over the entire shown spectrum (200-1400 nm), the moth-eye structure shows 10 % Abs. less reflection than wet chemical reference textures. This significant decrease is the reason why the wafer appears black for the observer.

Surface Passivation

The standard 'Black-Silicon-Method' forms surface structures with a typical aspect ratio above 5. Therefore, a sufficient SiN_x PECVD surface passivation is not possible, caused by the enlarged effective surface area. The Fraunhofer Center for Silicon Photovoltaics CSP has developed adapted plasma processing, which results in a surface texture with an aspect ratio of approx. 1. This allows a homogenous SiN_x deposition with state of the art plasma tools (see Fig. 3). This image shows a conformal deposited 70 nm thick SiN_x layer on top of the moth-eye structure. Fig. 4 compares the achieved effective minority carrier lifetimes of a wet chemical reference, plasma saw damage removal and an moth-eye structure after PECVD SiN_x passivation. The plasma saw damage removal result is close to the reference and shows a sufficient etch back of surface near damages by the wafer separation. Both samples achieve approx. 100 µs effective minority carrier lifetime at 10^{15} cm^{-3} minority carrier density (MCD). The moth-eye texture shows approx. 70 µs effective minority carrier lifetime at 10^{15} cm^{-3} MCD, which is caused by the enhanced effective surface area and a non-optimized PECVD SiN_x passivation for textures in the nm-scale. The SiN_x surface passivation of textures in the nm-scale will be optimized at the Fraunhofer Center for Silicon Photovoltaics CSP in upcoming studies.



4 QSSPC results of a wet chemical reference, plasma saw damage removal and moth-eye texture after PECVD SiNx passivation.

2 Comparison of the hemispherical reflection of moth-eye structures and industrial standard wet chemical textures after PECVD SiNx deposition.

3 Cross-section of a PECVD deposited SiN_x layer on top of moth-eye structures (SEM-image).