Insights into Plasma Nanotexturing of Silicon Surfaces Using Tailored Voltage Waveforms Excitation

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Abstract:

The nanotexturing of the surface of a crystalline silicon (c-Si) wafer for improved photovoltaic performance can be achieved through the use of an SF_6/O_2 reactive ion etching (RIE) capacitively coupled plasma (CCP). The resulting surfaces typically consist of nano-sized structures resembling cones (sizes ranging from 30 nm to 1 µm). The process occurs through competing mechanisms involving Si etching by fluorine radicals, formation of in-situ micro-masking species, and physical etching by ions, all these mechanisms being strongly influenced by plasma conditions.[1]

As has been done for previous processes and chemistries,[2-3] we attempt to decouple the influence of various plasma properties through the use of Tailored Voltage Waveforms (TVWs), and thus obtain insights into the mechanisms involved in the dry nanotexturing of silicon. TVW excitation consists of adding harmonic frequencies with controlled amplitudes and phase-shifts to the RF (13.56 MHz) driving voltage. In this study, the phase-shift of the harmonic frequencies of the TVW excitation is varied at constant discharge power in an SF_6/O_2 mixture, therefore modifying the mean IBE on the powered substrate holder. The impact of varying the TVW shape is observed through both the plasma properties and the morphological and optical properties of the processed surface. The effectiveness of the nanotexturing is then quantified by the surface effective reflectance (R_{eff} – i.e. the average reflectance weighted by the solar irradiance spectrum).

Thanks to studies of the dynamic evolution of nanostructured surfaces, it has been observed that the size of the nanostructures increases with process time. In the meantime, the reflectance of the surface is strongly decreased in the whole range of wavelengths of the solar spectrum, and R_{eff} values below 4 % are obtained when the nanostructures reach a lateral size superior to 200 nm. It is here shown that the nanostructures evolution is faster when the mean IBE on the substrate is increased, so that the effective reflectance of the processed surface can also be controlled by the IBE. This opens the potential to obtain very low reflectance silicon surfaces at practical process duration. However, for the integration of these plasma textured surfaces in high-efficiency solar cells, the excellent optical properties will have to be balanced by the electrical properties. It is indeed expected that defects induced by ion bombardment in the silicon will make it more challenging to obtain good surface passivation.[4-5]

References:

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