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Simulation and Measurement of Angle Resolved Reflectance from Black Si Surfaces

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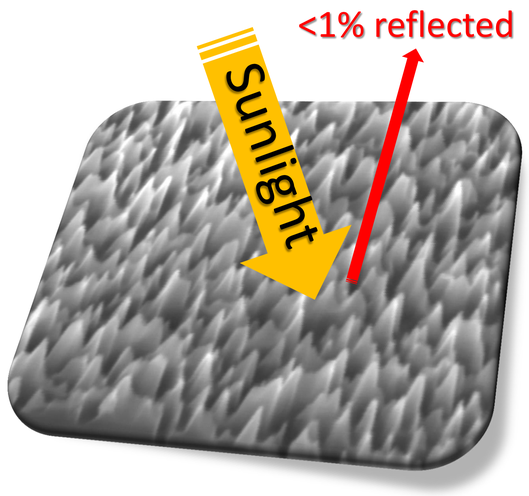
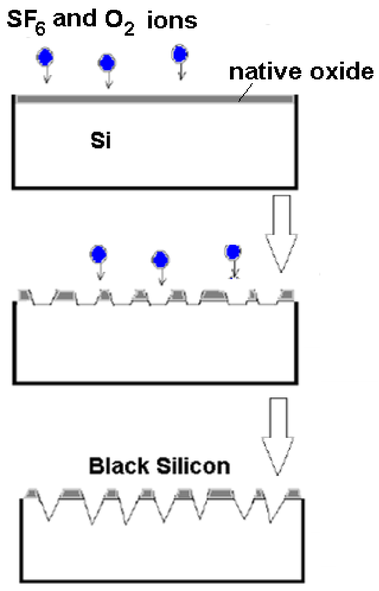
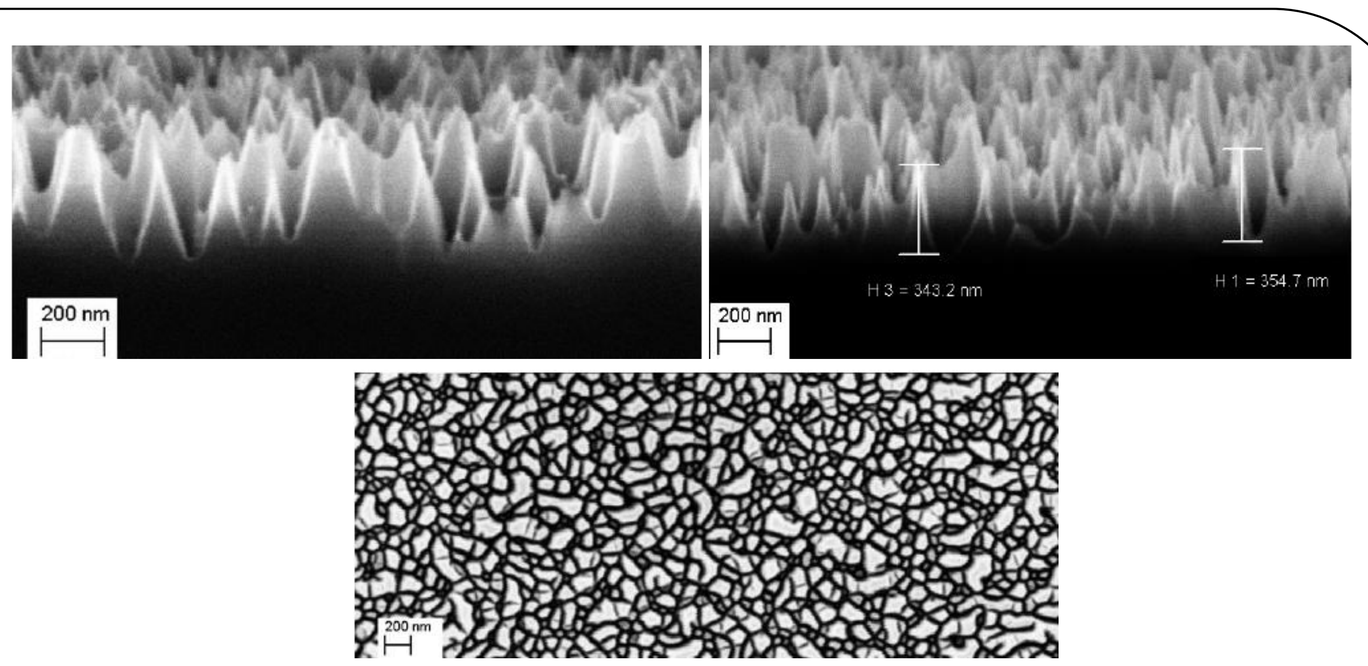
Concept



Black Silicon nanostructures suppress AM1.5G weighted, average reflectance from solar cell surfaces to less than 1%.

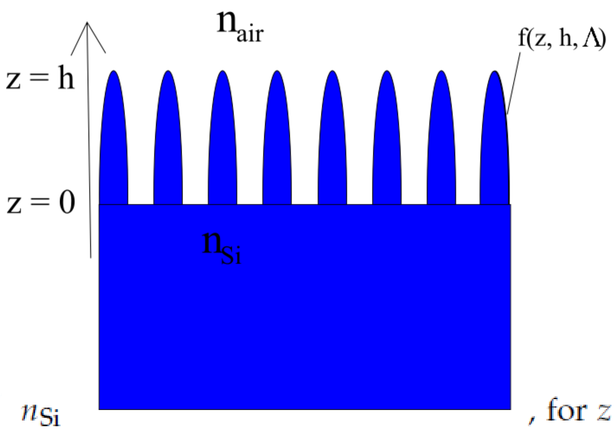


Nanostructures are fabricated by means of maskless reactive ion etching (RIE) using SF_6 and O_2 plasma.



SEM-images at 45° (top) and 0° (bottom) of RIE-textured Si surfaces with 300 nm nanostructure height. The nanostructures represent approximately linear (top, left) and non-linear (top, right) graded refractive index profiles.

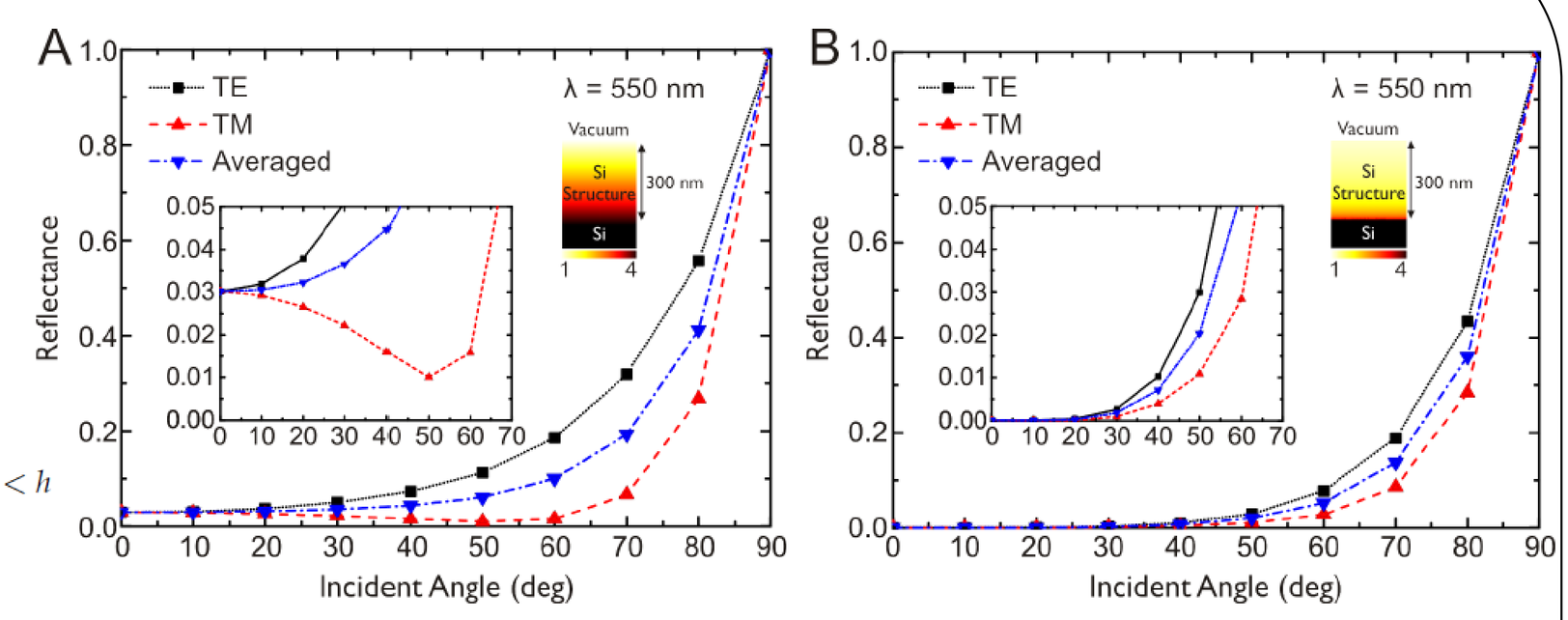
Simulation Method



$$n(z) = \begin{cases} n_{\mathrm{Si}} & , \text{for } z \le 0 \\ n_{\mathrm{air}} & , \text{for } z \ge h \\ n_{\mathrm{air}} f(z,h,\Lambda) + n_{\mathrm{Si}}\left[1 - f(z,h,\Lambda)\right] & , \text{for } 0 < z < h \end{cases}$$

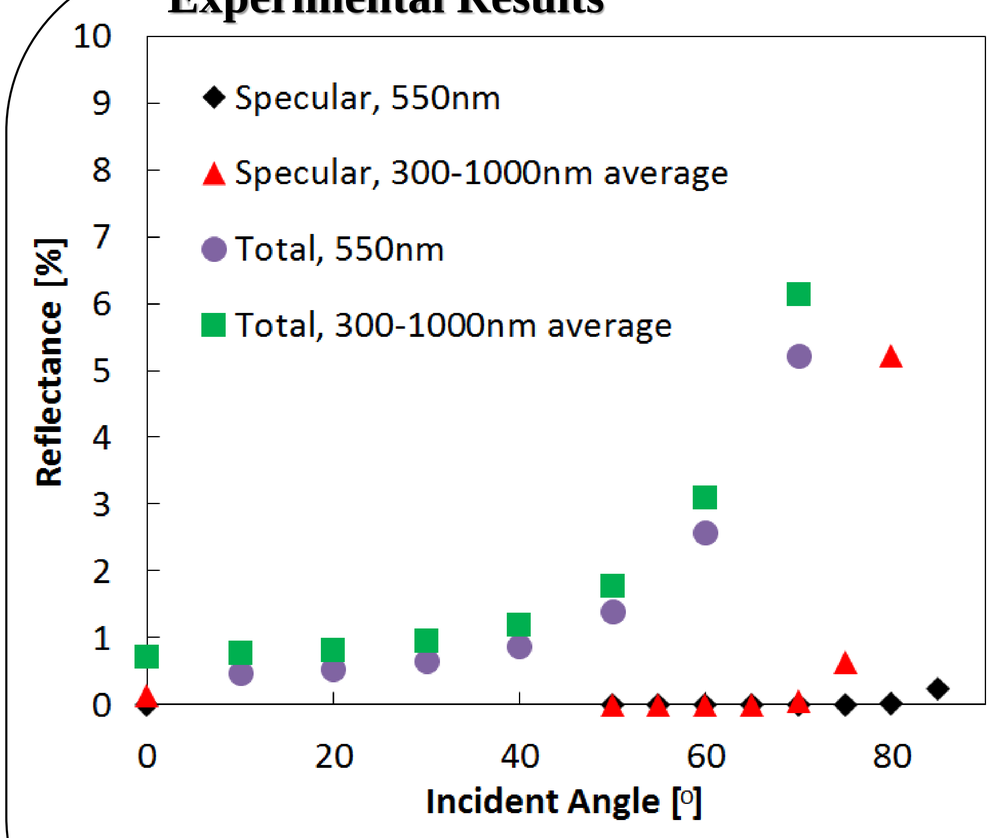
The nanostructure topology is modelled as a graded refractive index. Λ is a nonlinearity parameter. The index shape function was defined as f (z, h,L) = ln (1 + z/L)/ln (1 + h/L) in case of a non-linear index profile and f (z, h,L) = z/h in case of a linear index profile; here the parameters L = 10 nm and h = 300 nm were used.

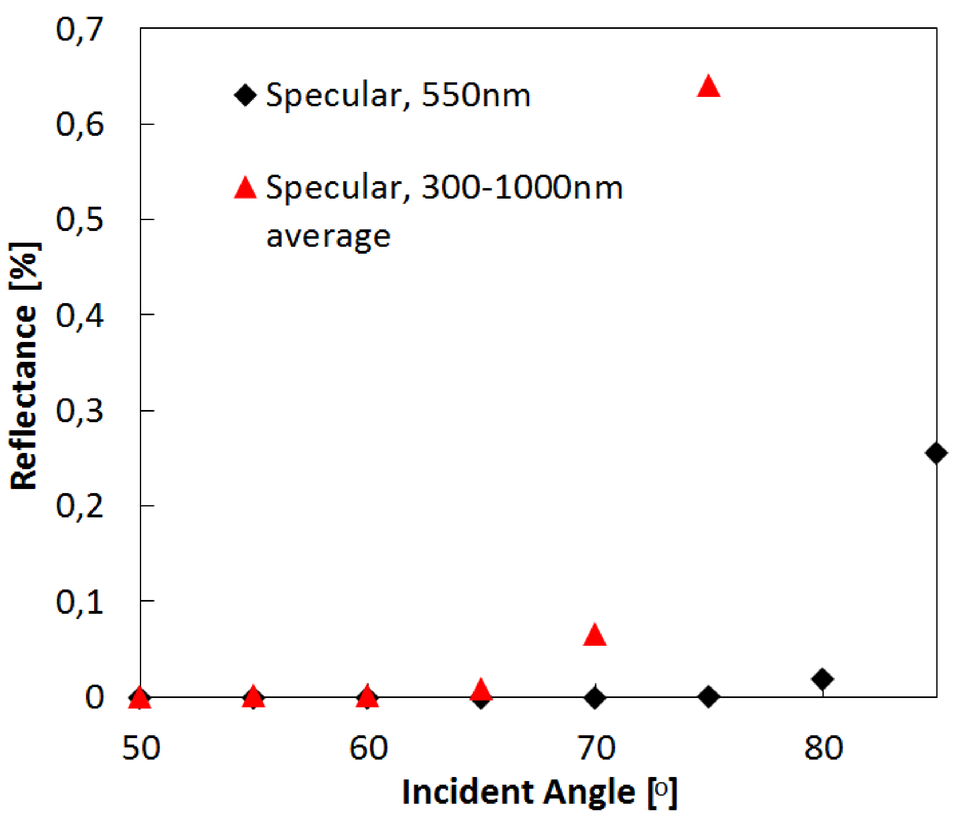
Simulation Result



Simulated reflectance as function of incident angle at a wavelength of 550 nm for surfaces with nanostructures of 300 nm in height in case of (a) linearly graded refractive index and (b) non-linearly graded refractive index.
The insets in (a) and (b) show the simulated reflectance at incident angles of 0-70°.
The non-linear profile yields the lowest reflectance; below 1% for angles up to 45°.

Experimental Results





Experimental specular and total reflectance as a function of incident angle. The average reflectance in the wavelength range 300-1000 nm and the value at a wavelength of 550 nm are shown (left). The specular reflectance at incident angles from 50-85° is shown to the right.

Conclusion

Angle-resolved reflectance from nanostructured Si surfaces realized by maskless RIE texturing has been simulated and measured. In both simulation and experiment the specular reflectance is below 10% at incident angles below 65 and below 1% at incident angles below 45 in the case of non-linear graded refractive index. From the simulation results the non-linear graded refractive index yields lower reflectance than the linearly graded refractive index.