DOI: 10.24996/ijs.2021.62.11(SI).7

ISSN: 0067-2904

Optimizing the Radius of Curvature of Black Silicon Peaks for Solar Cell Using Matlab Simulations

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Received: 10/1/2021 Accepted: 6/6/2021

Abstract

As part of our research on efficiency improvement of PERC (Passivated Emitter Rear Solar Cell), achieving very low reflectivity values of solar cell surface is a must. One of the most advance technologies to do so is the use of advanced texturing for the front surface of the cells. This texture, also known as Black Silicon, consists of peaks and valleys of nano metric dimensions and capable of dramatically reducing the reflectance of the front surface. A reflectance around 5% was reached ,using simulation, when using a Black-Silicon texturing with height of 50nm with peak rounding of 5nm. Even though this texturing may affect other parameters such as series resistance or surface recombination, as a starting point, simulation was used to find the optimum peak rounding, where the radius of curvature of the peak is maximum, while keeping reflectance as low as possible.

Keywords: Black Silicon, Solar Cell, Reflectivity

تحسين نصف قطر انحناء قمم السيليكون الأسود للخلايا الشمسية باستخدام محاكاة ماتلاب

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الخلاصة

كجزء من بحثنا حول تحسين كفاءة PERC (الخلية الشمسية الخلفية ذات الباعث الخامل) ، فإن تحقيق قيم انعكاسية منخفضة جدًا لسطح الخلايا الشمسية أمر لا بد منه. واحدة من أكثر التقنيات تقدمًا للقيام بذلك هي استخدام نسيج متقدم للسطح الأمامي للخلايا. يتكون هذا النسيج ، المعروف أيضًا باسم Black Silicon ، من قمم ووديان ذات أبعاد نانوية وقادرة على تقليل انعكاس السطح الأمامي بشكل كبير. تم الوصول إلى انعكاس حوالي 5٪ باستخدام المحاكاة عند استخدام نسيج Black-Silicon بارتفاع 50 نانومتر مع ذروة تقريب تبلغ 5 نانومتر. على الرغم من أن هذا التركيب قد يؤثر على معلمات أخرى مثل مقاومة السلسلة أو إعادة التركيب السطحي ، كنقطة انطلاق ، فإننا نستخدم المحاكاة للعثور على تقريب الذروة الأمثل ، حيث يكون نصف قطر انحناء الذروة هو الحد الأقصى ، مع الحفاظ على الانعكاس منخفضًا قدر الإمكان.

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Introduction

The photovoltaic industry is currently a mature industry whose main producers offer solar panels to the market that increase in power every year, and at a proportionally lower cost. Most of these panels use Silicon solar cells, which are progressively migrating towards PERC (Passivated Emitter Rear Solar Cell) technology, since optimum cost / efficiency ratios are currently achieved with such technology [1]. For even better improved efficiency, PERC have been combined with Black-Silicon (B-Si) which is an extremely promising material for photovoltaic applications due to its low light reflection losses [2,3].

Black Silicon (b-Si), as the name suggests absorbs the majority of photons incident on the surface and therefore appears black to the naked eye.It consists of a nano-textured surface. A common solution to minimize the reflection is an antireflection coating (ARC) applied on the front surface of a solar cell to suppress sunlight reflection [4, 5]. However, simple ARC based on quarter-wave-length layers perform well in a limited spectral range and for a certain angle of light incidence only. Black Silicon possesses near-zero reflection over a broad range of incident angles with features smaller than the wavelength of light, which eliminates the need for conventional vacuum deposited ARC.

When the size of surface features equals or exceeds the wavelength of the incident light, these nano or microstructures provides beneficial light trapping that increases the effective path length in the silicon [5, 6].

The unusual photoelectric characteristics, combined with the semiconducting properties of silicon makes b-Si interesting for solar cells applications as antireflection layers [7,8]. In particular, these nanostructures as an antireflection layer increase the surface area of the solar cells, and increase the amount of sunlight that is captured rather than reflected back from the cells. When the surface structures are much larger than the wavelength of light, the phenomenon can be explained intuitively by geometric optics based on multiple reflections, while in the case of b-Si , nano-structured surfaces provide a gradual variation of the refractive index that minimizes reflections (Figure 1) [9, 3].

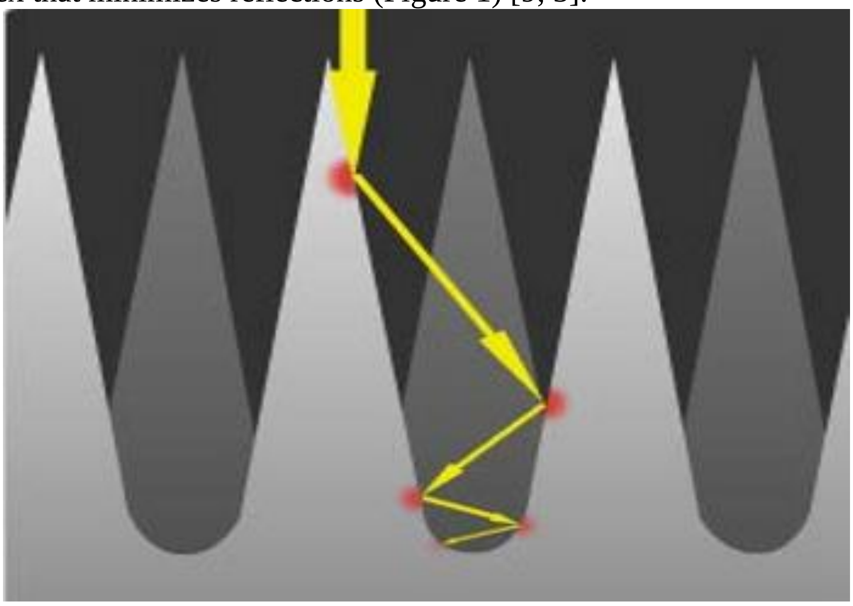

Figure 1-Schematic diagram depicting of b-Si [8].

Methodology

In this work , optimum peak rounding will be explored, where the radius of curvature of the peak is maximum, while keeping reflectance as low as possible using Matlab simulations with Rigorous Couple Wave Analysis (RCWA) method, starting from previous smoothing experiments performed at the laboratory and improving it. In these experiments a sample first have been etched using RIE (Reactive Ion Etching), and then a smoothing process have been made using a chemical etchant (mixture of HF and HNO3) for different etching times. The resulting surface consists of a succession of peaks and valleys defined by a characteristic distance and height which corresponds to smoothing times of 0, 30, 60, 90 and 120 second, a 400 nm, 250, 160, 100 and 50 for the amplitude and 150 nm period (Period of peak repetition do not change when doing the smoothing).

Using RIE produces sharp peaks that results in high recombination rates that lowers the efficiency [10]. Rounding the peaks is then an expected good way of avoiding this problem [11]. Simulations of the smoothing experiments will be performed while modifying the texture profiles in the program in order to include the rounding of the peaks and measure the reflectivity for different amplitudes and radii of curvature.

The work consisted of simulation of different texture profiles. Each profile consisted of different radius of curvature for the peak, 8 different sets of radius have been used, starting with 5nm and ending at 40nm with step of 5. Each set consisted of four amplitudes (250 nm, 160, 100 and 50) corresponding to different smoothing times of 30 second, 60, 90 and 120, respectively as shown in Figure 2 b-e. Where Figure 2a shows the surface texture with peak amplitude of 400nm directly after RIE but before chemical etching (smoothing time is 0). Figure 2 is an example when radius of curvature of the peak is 5nm for different smoothing times with their corresponding amplitudes. The same process is repeated for seven more different radii of curvature (10 nm, 15, 20, 25, 30, 35 and 40) to see how the radius of curvature as well as the amplitude after smoothing affects the reflectivity of the solar cell.

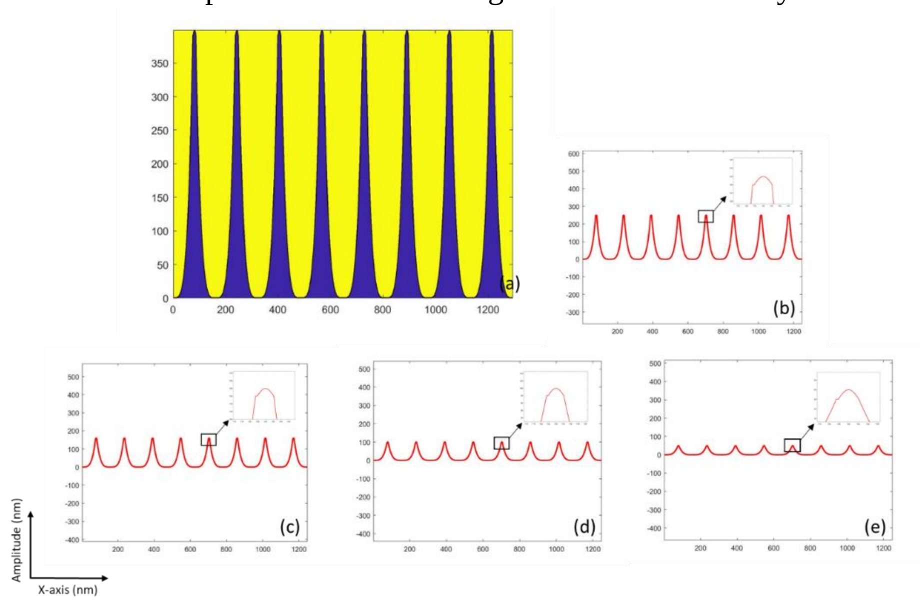

Figure 2-Surface texture with 5nm radius of curvature for the peak, (a) Texture after RIE (before smoothing) with amplitude of 400nm, (b) Texture at smoothing time of 30 second with amplitude of 250nm, (c) Texture at smoothing time of 60 second with amplitude of 160nm, (d) Texture at smoothing time of 90 second with amplitude of 100nm, (e) Texture at smoothing time of 120 second with amplitude of 50nm.

Results

After building the texture for all of the eight different radii of curvature (each radius with four sets of amplitudes representing different smoothing times), the reflectivity of the surface was measured (using Matlab simulation) using wavelength of 760-780 nm because it is a good representation of the average reflectance value.

Figure 3a shows the surface reflectivity for the different eight radii of curvature after a smoothing time of 30 second (amplitude 250nm). Where Figure 3b and 3c is just a reference or example of the surface texture profiles, only lower and upper radii of curvature (5nm and 40m) was placed as a texture reference.

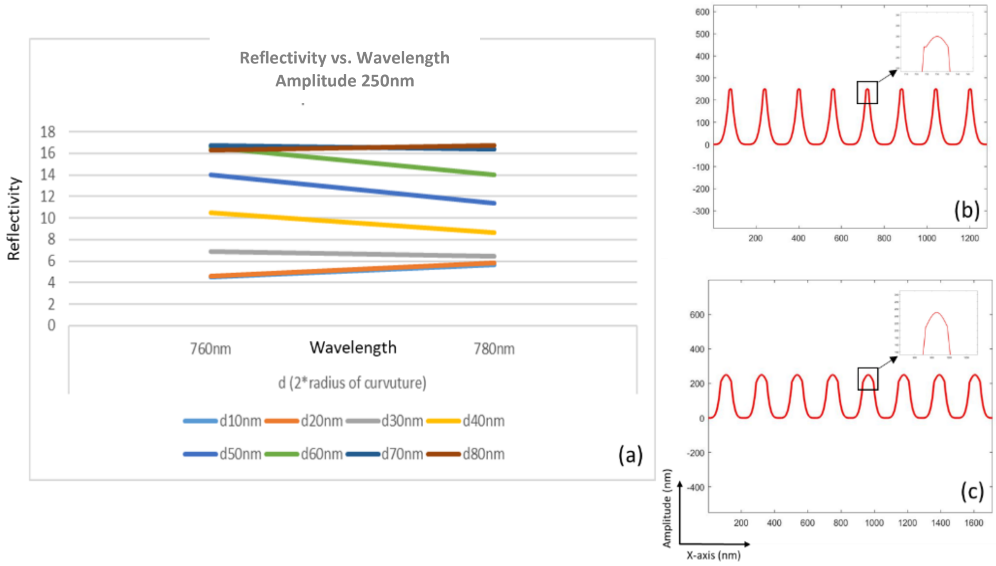

Figure 3-(a)The surface reflectivity for the different eight radii of curvature after smoothing time of 30 second (amplitude 250nm), (b) Texture profile of 5nm radius of curvature, (c) Texture profile of 40nm radius of curvature.

It can be from Figure 3a that the reflectivity is much lower at small radius of curvature of the peak. The lowest reflectivity value was at diameter of 10nm and 20nm with reflectance between 4-6 %. The same was repeated in Figure 4,5 and 6 but for smoothing time of 60 second, 90 and 120 (amplitudes of 160nm, 100 and 50), respectively.

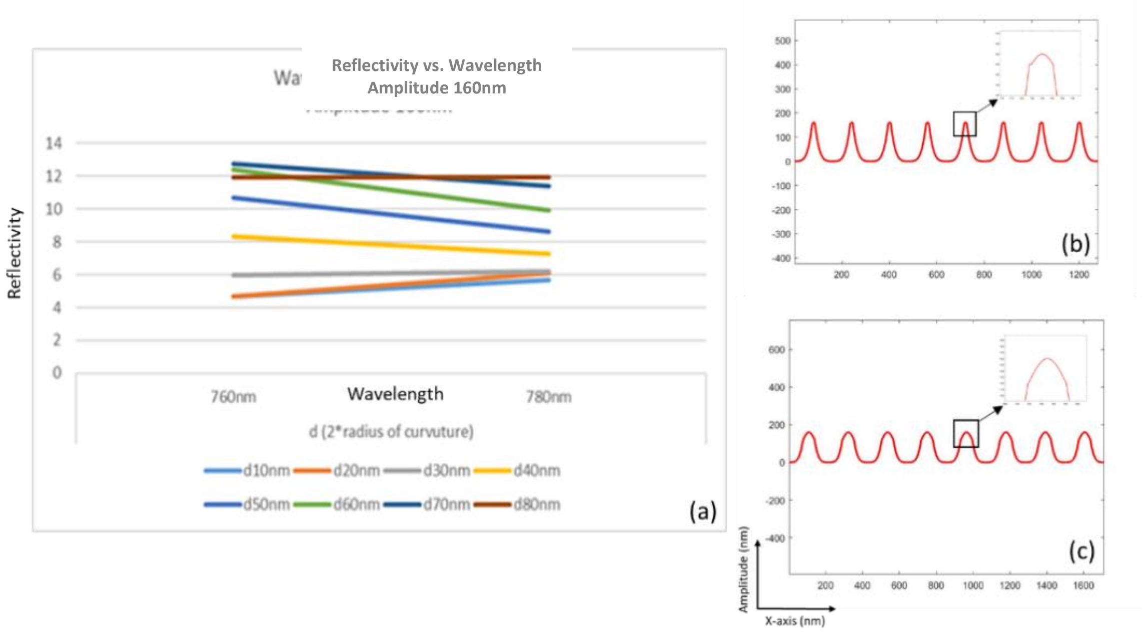

Figure 4-(a)The surface reflectivity for the different eight radii of curvature after smoothing time of 60 second (amplitude 160nm), (b) Texture profile of 5nm radius of curvature, (c) Texture profile of 40nm radius of curvature.

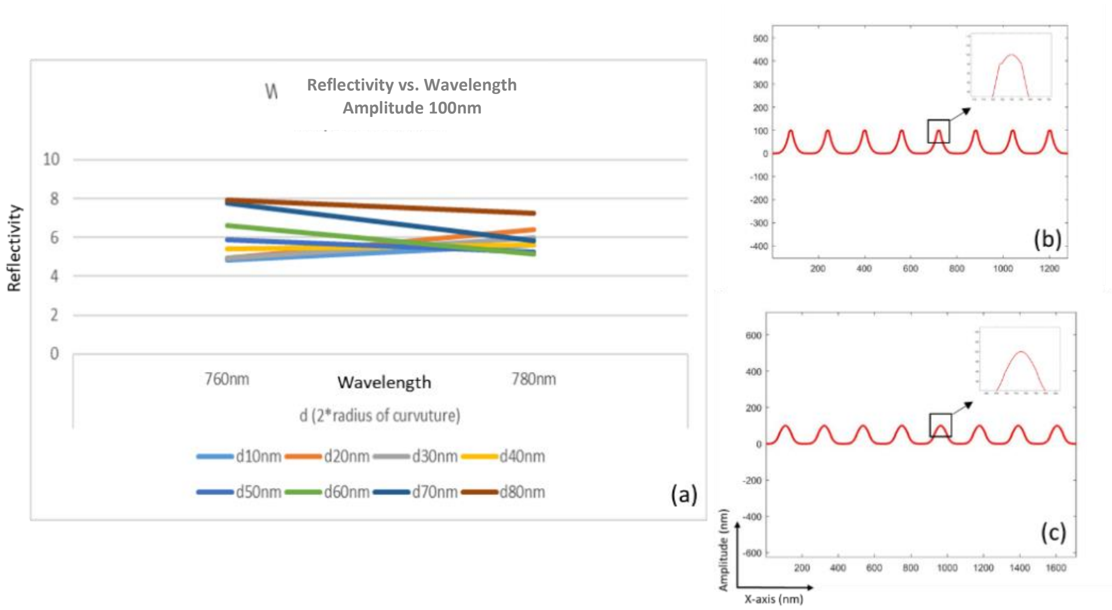

Figure 5-(a)The surface reflectivity for the different eight radii of curvature after smoothing time of 90 second (amplitude 100nm), (b) Texture profile of 5nm radius of curvature, (c) Texture profile of 40nm radius of curvature.

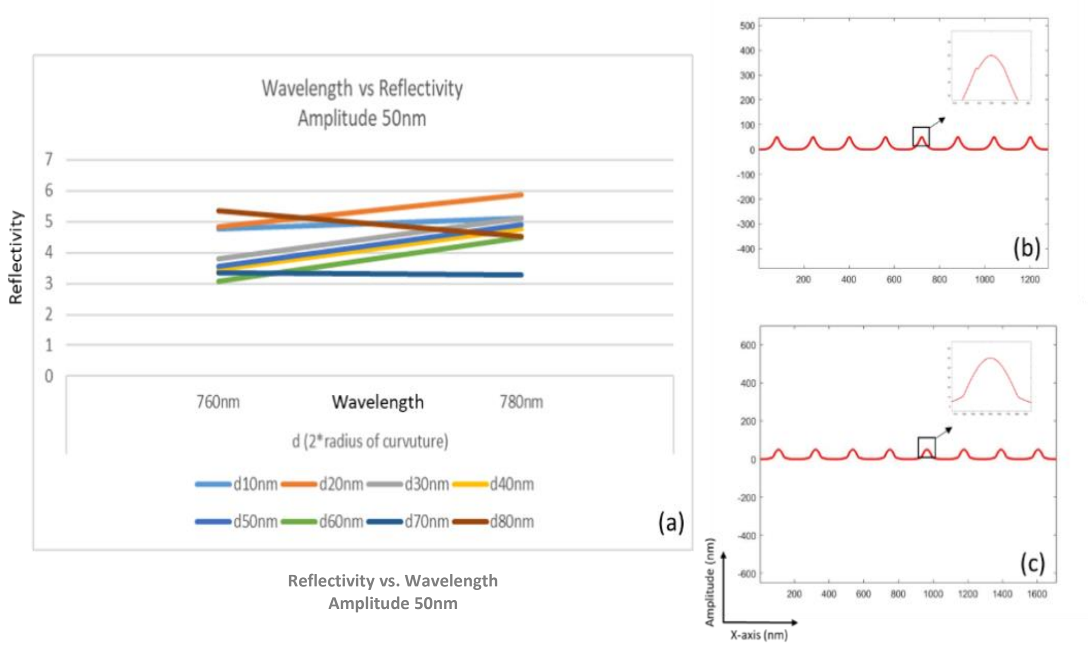

Figure 6-(a)The surface reflectivity for the different eight radii of curvature after smoothing time of 120 second (amplitude 50nm), (b) Texture profile of 5nm radius of curvature, (c) Texture profile of 40nm radius of curvature.

From Figures 3-6, it can be noticed that reflectance variability is much higher at higher amplitudes, with overall reflectance lower at lower amplitudes. In order to find the optimum radius, the results of reflectance and radius as “reflectance vs radius” were plotted for each one of the amplitudes (as shown in Figure 7).

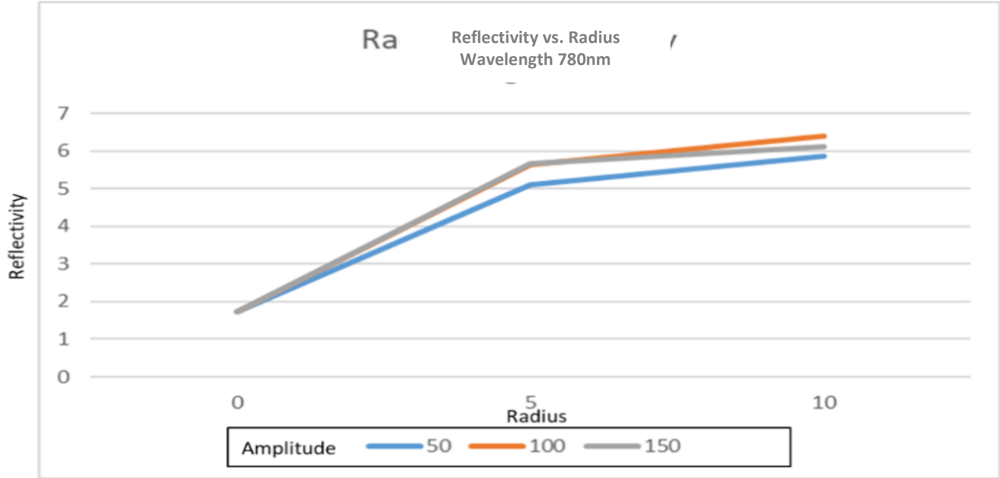

Figure 7- reflectance vs radius of curvature for each peak amplitude.

Conclusion

It can be concluded from Figure 7 that 5 nm radius of rounding is a safe starting point, which shows lower reflectance for each one of the amplitudes. This working point will be used for modeling of the emitter diffusion and smoothing process using Silvaco's Athena software (Version 2.10.26.R). This will be a background for the experimental part, where high efficiency PERC cells will be manufactured, in order to verify the influence of advanced texturing on the properties of the cell.

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