PAPER PRESENTATION

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Black silicon solar cells with interdigitated back-contacts achieve 22.1% efficiency

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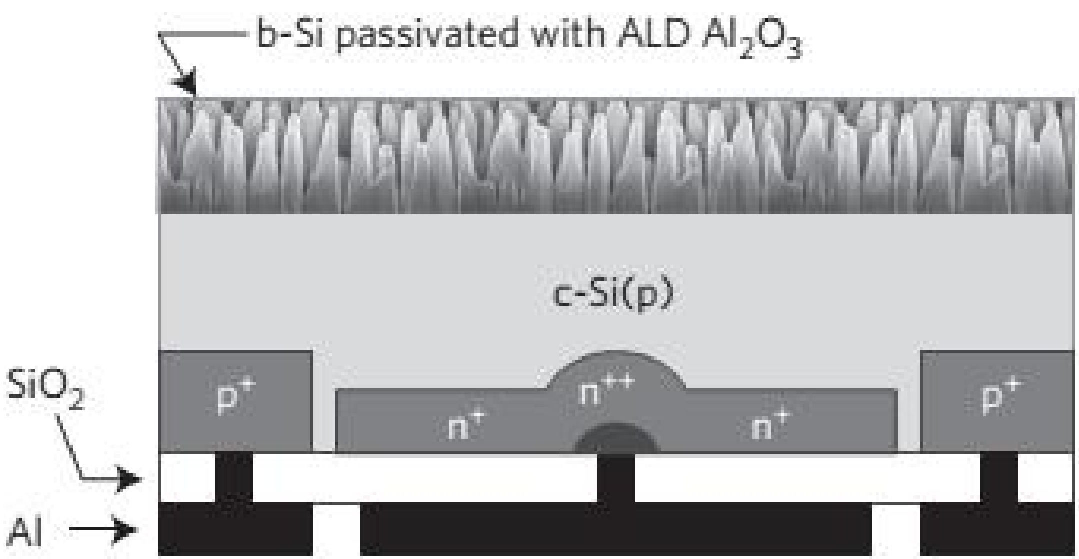


Introduction

- **Black silicon** is a semiconductor material, a surface modification of silicon with very low reflectivity and correspondingly high absorption of visible (and infrared) light. Because of its high absorption capacity it absorbs light of wide range of wavelength and appears black to eye.

- Because of its many superior properties, b-Si has potential for a range of applications, such as self-cleaning surfaces, microelectromechanical systems, ion mobility spectrometers, drug analysis, photodetectors and antibacterial surfaces.

- Surface modification of black silicon such as nanocones are very useful for solar cell application because of its excellent light management properties.

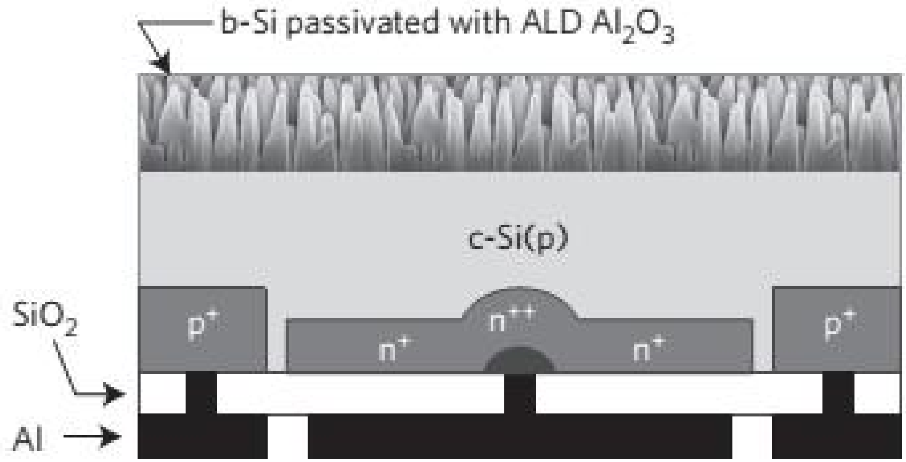
- The main challenges that have hindered the use of b-Si in photovoltaics are related to increased surface recombination due to the larger surface area of the nanostructures, and the situation is even more challenging in a conventional front-contacted solar cell structure due to Auger recombination at these highly doped nanostructures.

In this Paper

- They have prepared black silicon by etching which is a promising approach to eliminate front surface reflection in photovoltaic devices without the need of the conventional antireflection coating.
- They have used here that alumina film can solve the problem of surface recombination by acting as a surface passivating layer.
- They have used interdigitated back contact cell where carrier transport is very sensitive to front surface passivation resulting in increase the efficiency to grater than 22%.
- They have shown here how the black silicon results in 3% increase in the daily energy when compared with a reference cell.

Sample fabrication

- They have used single crystalline silicon wafer and it was etched using a cryogenic inductively coupled plasma reactive ion etching process at 153K using SF_6 and O_2 as etching gases.This results in symmetrical etching.
- The reference cell is produced by anisotropic etching using a mixture of tetramethyl ammonium hydroxide(TMAH), isopropanol, deionized water at 80^{o}C for one hour.
- Al_2O_3deposition on the b-Si cells was carried out using TMA and H_2O as the precursors, and the passivation was activated with 30 min anneal at 400 °C in N_2.



- ALD of Al_2O_3 of thickness 20 nm and 90 nm was done on b-Si etched and random textured cell for surface passivation.

- Boron and phosphorous diffusions, using solid dopant sources to form p+ (base contacts), n+(low doped emitter) and n++(high doped emitter) regions, respectively, were patterned using standard photolithography.

- A back-reflector scheme was created consisting of a thermal SiO_2/Al stack.

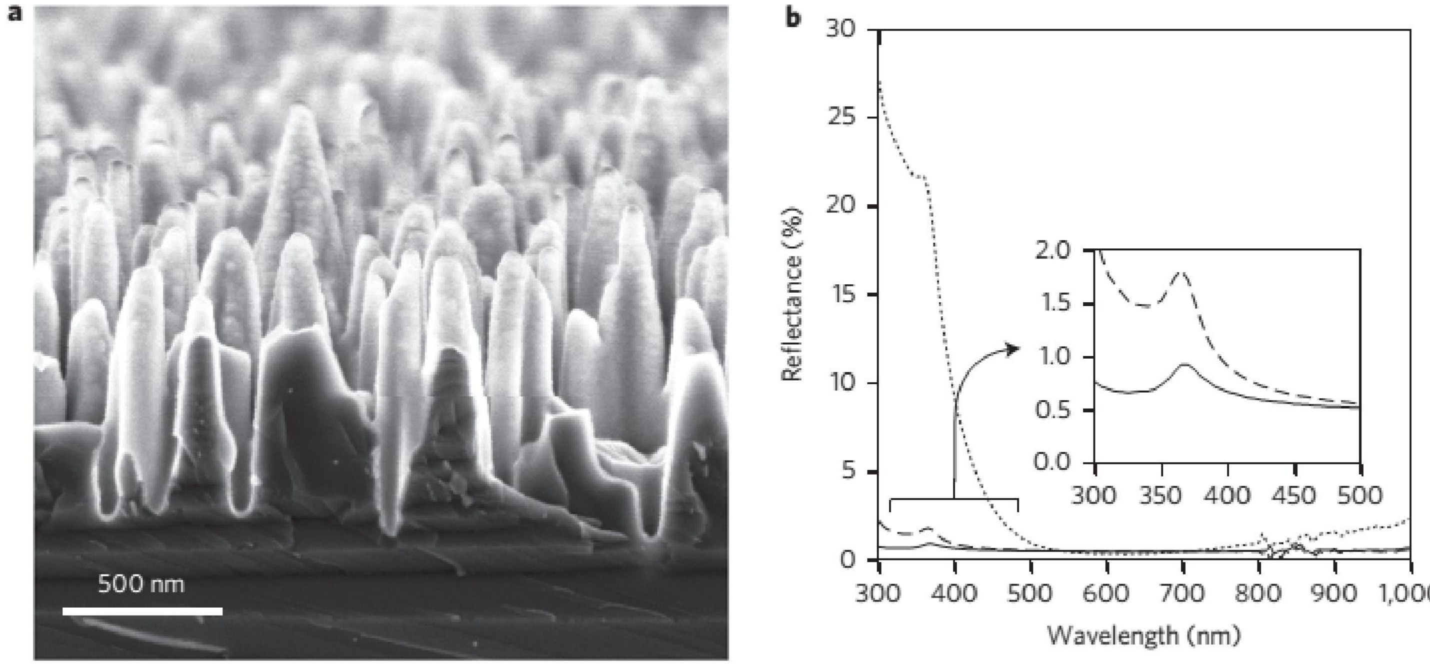


Figure 1 |Structure and reflectance of b-Si. (a) Scanning electron microscopy (SEM) image (cross-sectional view) of a b-Si surface. Typical height of a silicon pillar,~800 nm; diameter at the bottom of the pillar,~200 nm. The 20 nm Al_2O_3layer can be seen as a brighter layer on top of the pillars. (b) Measured reflectance spectra in the 300–1,000 nm wavelength range. The dashed line represents the reflectance of a bare b-Si sample and the black solid line shows the reflectance of b-Si with 20 nm of Al_2O_3.The reflectance of random pyramids coated with 90-nm-thick Al_2O_3film (dotted line) is shown as a reference.

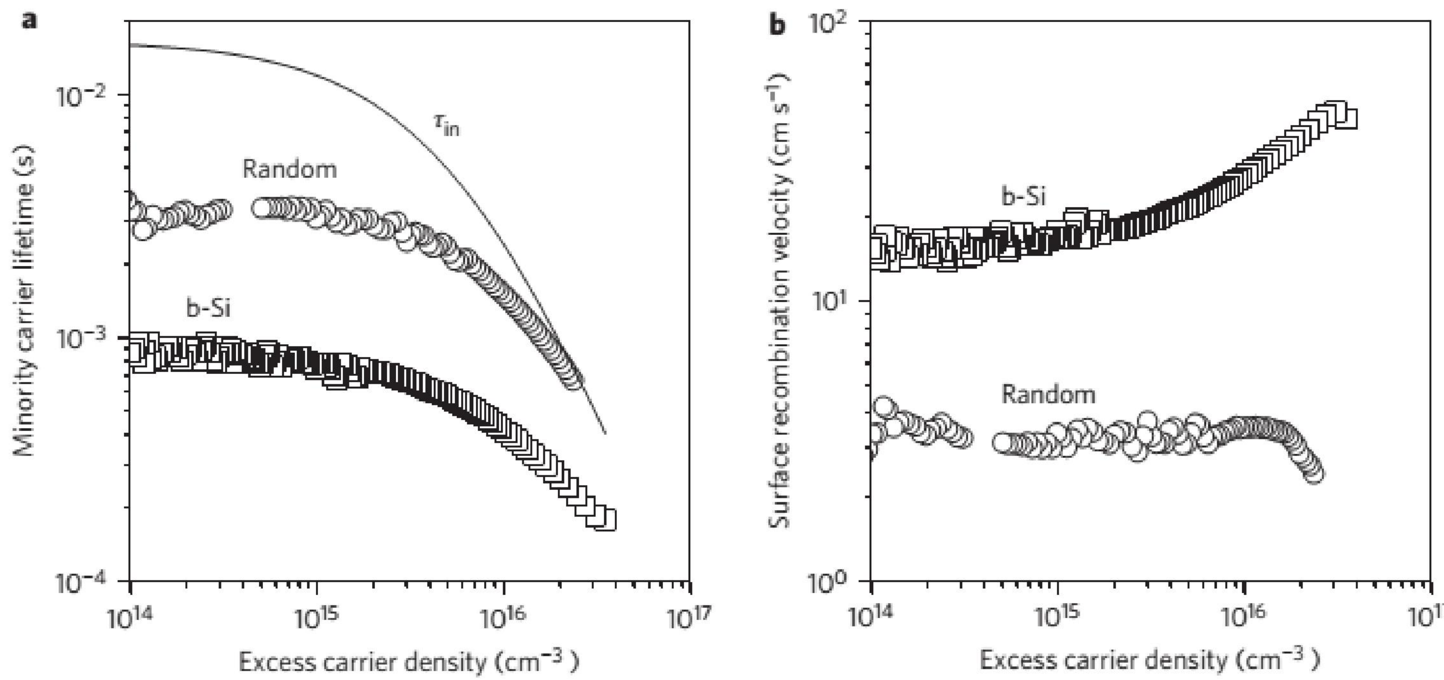


Figure 2 |Lifetimes and corresponding surface recombination velocities. (a)Minority carrier lifetimes and (b) corresponding surface recombination velocities as a function of minority carrier density. The solid line in (a) represents the intrinsic lifetime.

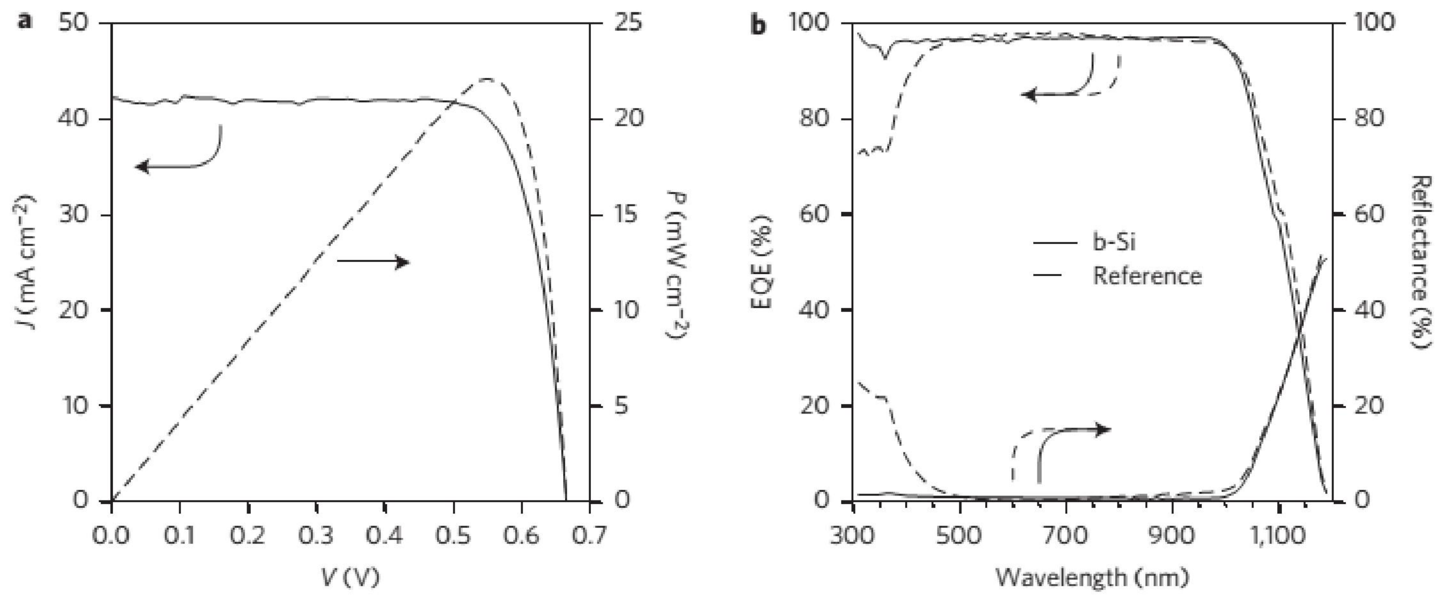


Figure 4 |EQE and J–V and P–V characteristics for the selected b-Si solar cell. (a) J–V(solid line) and P–V(dashed line) characteristics of the b-Si cell with 80% emitter coverage. (b) EQE and reflectance measurements for the best b-Si cell (solid lines) and the corresponding randomly texturized cell (dashed lines).

Table 1 | Photovoltaic results for the b-Si solar cell with emitter coverage of 80%.

Cell	J_{sc} (mA cm^{-2})	V_{oc} (mV)	FF (%)	η (%)
b-Si	42.2	665	78.7	22.1
Reference*	42.0	667	78.6	22.0

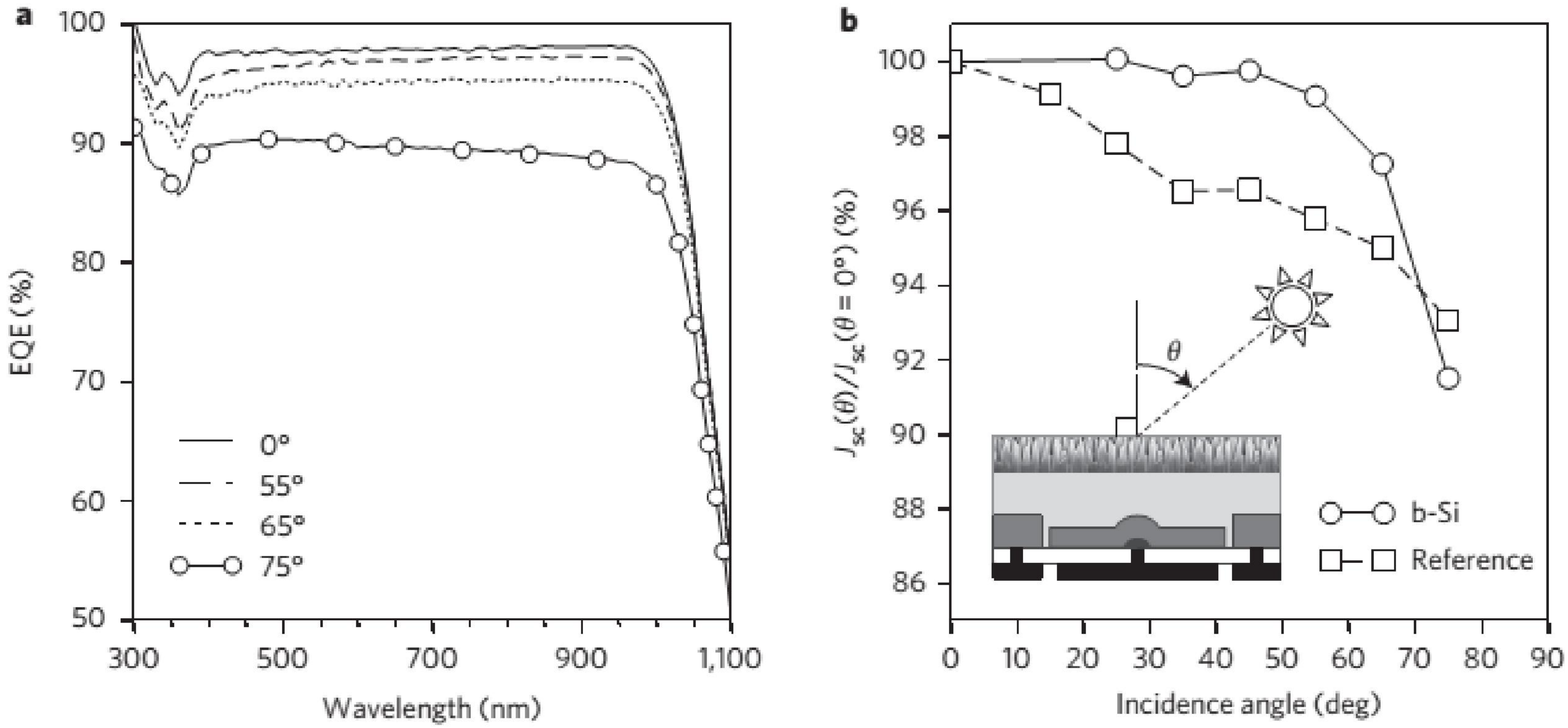
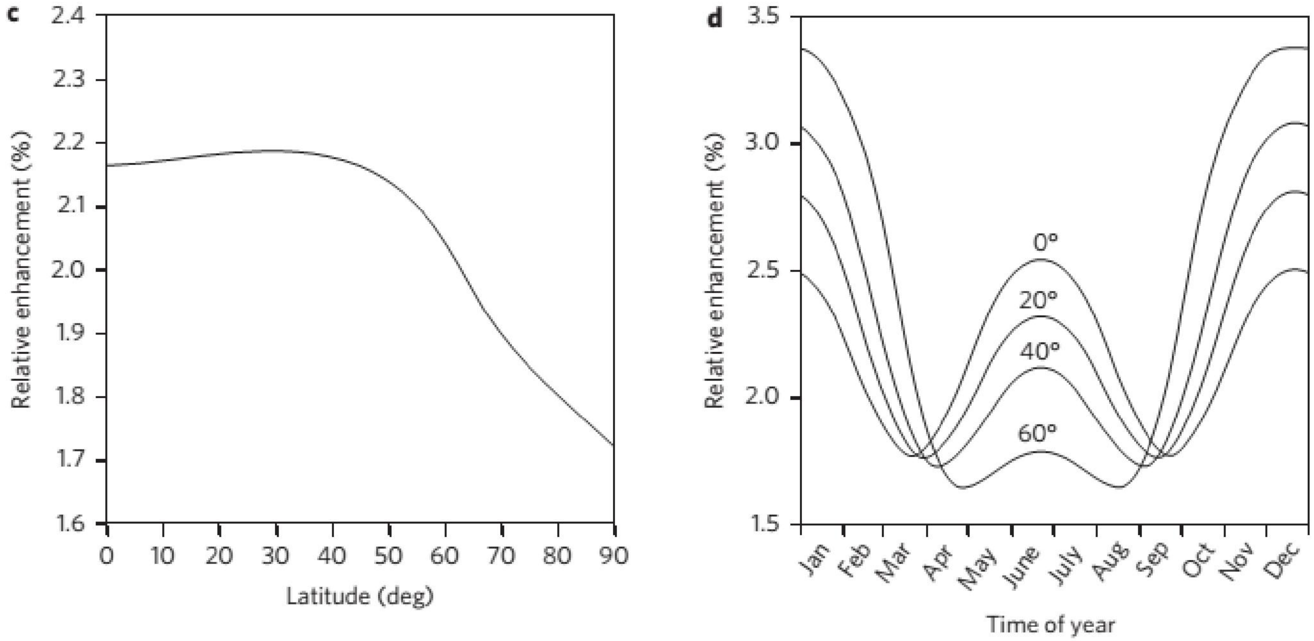


Figure 5 |Angle-dependent EQE and daily/yearly energy production enhancement. (a) EQE of the b-Si cell for different angles of incidence. (b) Relative photocurrent, with respect to photocurrent at normal incidence, for different light incidence angles for both the b-Si (circles) and reference (squares) solar cells.



(c) Relative increase in total delivered energy throughout the year for the b-Si cell compared with the reference cell as a function of latitude (d) Daily relative increase, throughout the year, in the energy generated by the b-Si cell compared with the reference cell for different locations (60° latitude corresponds to Helsinki, 40° to Barcelona).

What further can be done

- Even higher efficiencies could be expected by optimizing the emitter coverage.
- Other improvements could be implemented in current IBC structures to increase fill factor (FF) and V_{oc} values. For instance, a thicker aluminium layer in fingers and busbars would reduce ohmic losses, thereby achieving higher FF values.
- Moreover, an optimized phosphorous doping profile in the low and high doped emitter regions might further decrease the emitter saturation current density, J_{oe}, increasing V_{oc} accordingly.

Summary

- They have successfully developed a high-efficiency, b-Si IBC solar cell, with greater than 22% efficiency with a surface area of 9.0 cm^2.
- Here, they have used cryogenic deep reactive ion etching (DRIE) as it has multiple advantages: it is fast and inexpensive, there is no dependence on crystalline orientation, and there is no requirement for mask layers.
- Etching makes the surface rough (zigzag) which itself acts as anti reflection agent. There is no additional anti reflection agent used. This makes it cost effective.
- They have achieved optimal surface reflectance without affecting surface recombination, due to the outstanding surface passivation achieved with conformal ALD Al_2O_3.

- IBC structure proves that surface recombination, which has been hindering the use of b-Si in photovoltaics, is no longer a limiting factor.

Future Perspective

- We can try for electrosprayed solar cell.