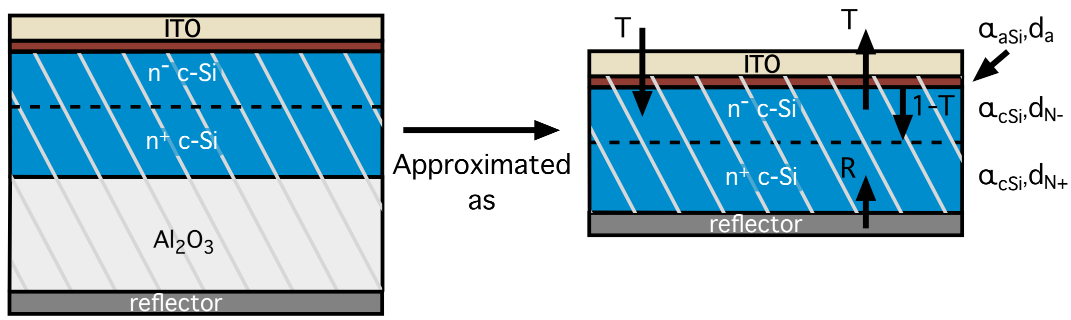
Electronic Supplementary Material (ESI) for Energy & Environmental Science

SUPPLEMENTARY INFORMATION FOR "PYRAMIDAL LIGHT TRAPPING AND HYDROGEN PASSIVATION FOR HIGH-EFFICIENCY HETEROEPITAXIAL (100) CRYSTAL SILICON SOLAR CELLS"

1. QE calculations

To calculate ideal QE for planar devices, we make the following assumptions:

- All light absorbed in the n^- c-Si layer is collected as current with 100% efficiency. Light absorbed in other layers is not collected.
- Light is transmitted into the device from the top surface with probability *T*. *T* is calculated with a simple void/dielectric/c-Si 3 layer structure, with the ITO approximated as a spectrally independent $n=2$, $k=0$ dielectric.
- We assume light is transmitted *out* of the top of the device with the same probability *T* and reflected back into the layer with probability (1-*T*)
- Light is reflected at the back surface of the device with probability R=0.95 (spectrally independent) and assume the rest of the light is absorbed in the reflector and lost.
- Because the back side of the sapphire substrate is not polished, we ignore coherence effects and simply sum the absorption from each pass through the device.



We use the following definitions for the absorption in each layer:

$N_+ = e^{-\alpha_{cSi} d_{N+}}$, $N_- = e^{-\alpha_{cSi} d_{N-}}$, and $a = e^{-\alpha_{aSi} d_a}$, where α_{cSi} and α_{aSi} are the absorption coefficients in the c-Si and a-Si:H layers, and d_{N+}, d_{N-} and d_a are the thicknesses of the n^+, n^- and a-Si:H layers respectively.

The summation can be written as:

$$QE(\lambda) = Ta(1-N_-) + Ta(1-N_-)N_+^2 N_- R + Ta(1-N_-)N_+^2 N_-^2 a^2 R(1-T) + Ta(1-N_-)N_+^4 N_-^3 a^2 R^2 (1-T) + Ta(1-N_-)N_+^4 N_-^4 a^4 R^2 (1-T)^2 + \ldots$$

By collecting the odd and even terms separately and using:

$$\sum_{n=0}^{\infty} x^n = \frac{1}{1-x} \text{ for } x<1$$

we obtain

$$QE(\lambda) = Ta(1-N_-)(1+N_-N_+^2R)\sum_{n=0}^{\infty}\left[N_-^2a^2N_+^2R(1-T)\right]^n$$
$$= \frac{Ta(1-N_-)(1+N_-N_+^2R)}{1-\left[N_-^2a^2N_+^2R(1-T)\right]}$$

We perform a similar sum to calculate the reflection, obtaining:

$$\text{reflection}(\lambda) = (1-T) + \frac{T^2a^2N_-^2N_+^2R}{1-\left[N_-^2a^2N_+^2R(1-T)\right]}$$

For the pyramidal texturing case, we make the following modifications to our calculation:

- Initial transmission into the c-Si is increased because light initially reflected off of a pyramidal surface is likely to strike a second pyramid. Thus the initial transmission is replaced as $T \rightarrow T_L = (1-R_0^2)$, where R_0 is calculated using the same air/ITO/c-Si layer stack used to calculate T in the planar case.
- As with the initial incident light, light is likely to have two chances to escape from the layer stack. However, in the Lambertian limit, transmission out of the c-Si layer is reduced by $1/n_{cSi}^2$ due to light incident at angles above the critical angle. Thus, for each incidence upon the front surface, reflection back into the layer is: $R_L = 1-(T_L / n_{cSi}^2)$
- With ideal light trapping, the oblique light path through each layer is increased, on average, by a factor of 2. For simplicity, we do not apply this path length enhancement to the a-Si:H layer because absorption in this layer is only relevant on the first pass, when the light has not been scattered to oblique angles. After the first pass, wavelengths absorbed strongly by the a-Si:H layer have already been absorbed by previous passes.

Recomputing the QE and reflection for the textured case, we obtain:

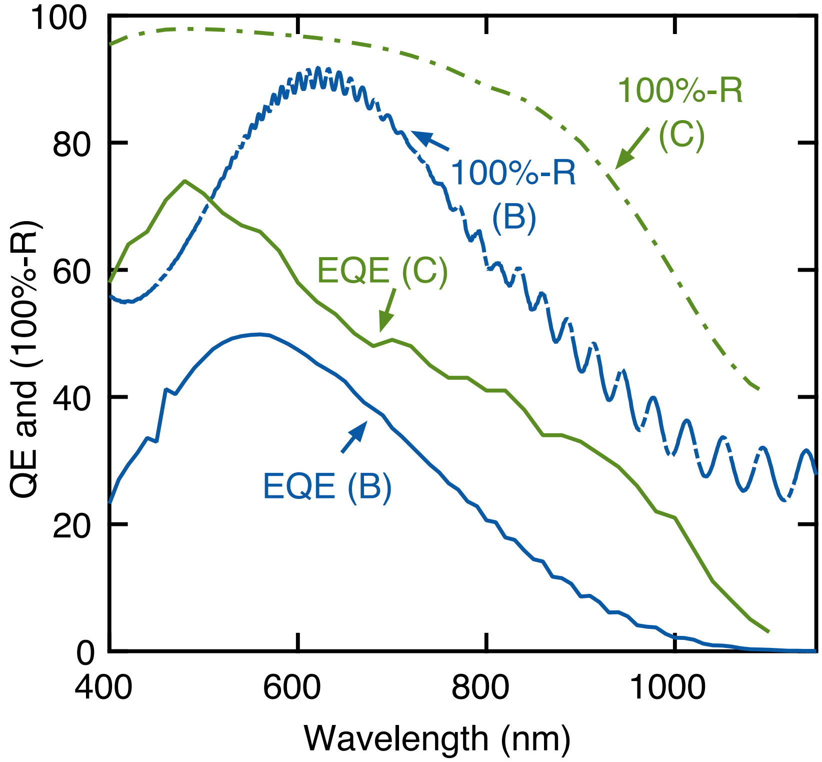
$$QE(\lambda) = \frac{T_La(1-N_-^2)(1+N_-^2N_+^4R)}{1-Ra^2N_-^4N_+^4R_0^2 / n_{cSi}^2}$$

and

$$\text{reflection}(\lambda) = R_0^2 + \frac{a^2N_-^4N_+^4RT_L^2 / n_{cSi}^2}{1-\left[N_-^4a^2N_+^4RR_L\right]}$$

2. Comparison of EQE and (100%-*R*) for Samples B and C

Below, we compare the QE and the total light absorbed (100%-*R*) by Samples B and C. The absorption includes light absorbed in both the n^- layer, the n^+ layer, the amorphous silicon layers and the back reflector.



Comparison of the EQE to (100%-*R*) spectra for Samples B and C. (100%-*R*) is calculated from the measured reflection data (Fig. 4b). Each curve is labelled with its type and Sample.