Angle restriction of photon emission for ultraefficient photo-voltaics: experimental proof of concept

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Although one approach for improving the performance of ultra-efficient solar cells is through optical concentration (principally by increasing open-circuit voltage, \( V_{OC} \)), an equally potent alternative is decreasing the cell’s recombination current – an aim that can be realized by externally recycling cell photon emission. While the theory for the potential benefit of photon recycling has recently been elucidated, experimental proof-of-concept had proven elusive - requiring a photovoltaic device possessing a high external luminescent efficiency (\( Q_e \)) combined with efficient light recycling optics. The associated prospect of approaching – and even surpassing – the nominally fundamental (Shockley-Queisser) limit for solar cell conversion efficiency [1] is tantalizing and, in principle, achievable. Here, we report experimental evidence of enhancing the performance of today’s champion single-junction commercial GaAs cells [2] by external recycling of photon emission from the cell’s front surface [3]. It is equivalent to restricting the angular range of photon emission, and can only be effective in photovoltaics with high external luminescent efficiency.

The results are discussed in terms of basic photovoltaic thermodynamics. The magnitude of the observed effect is placed in the perspective of the fundamental bounds for voltage enhancement, and the potential for future improvements is evaluated.

In particular, the magnitude of the \( V_{OC} \) enhancement is modest: \( \Delta V_{OC} = 4 \) mV at a nominal \( V_{OC} \) of 1120 mV - well below the maximal theoretical increase of 275 mV for the ideal case of perfect photon recycling (i.e., photon emission restricted to the solar angular radius) and \( Q_e = 1 \). The large difference between the maximum theoretical \( \Delta V_{OC} \) and our measured values is consistent with basic theory – explained by \( Q_e \) for our device being well below unity. However, when innovative cell design and manufacture can attain significantly higher values of \( Q_e \), the benefit of photon recycling can be considerable. Such future improvements could emerge from the conflation of substantially thinner cells with superior light-trapping architectures (e.g., 50-250 nm for GaAs [4]), to yield the necessary near-unity values for both external luminescent efficiency and net radiative recycling efficiency.

REFERENCES


Fig. 1. Schematic of the experimental configuration.