Thermally modified photoluminescence matched to GaAs and Si with 40% optical conversion efficiency and 4-fold reduction in heat load

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Despite the potential of concentrated photovoltaics (CPV) to harness sunlight with extreme efficiencies, it has not yet been implemented as a cost-effective solution. Together with the added cost of tracking and the loss of diffused sunlight, the need to cool the CPV and the high cost of multi-junction solar cells prevented the penetration of this technology. Thermally modified photoluminescence (PL), is a process where the line-shape spectrum of photoluminescence is defined by the temperature and chemical potential of the absorber [1]. An incoming energetic radiation is absorbed by a PL material and raises the temperature through thermalization, leading to a blue-shift of the emitted PL, which is coupled to a high bandgap solar cell benefiting from enhanced voltage [2]. Thus far, poor external quantum efficiency (QE) at high temperatures and poor solar absorption were the limiting factors in harnessing the full potential of PL for solar energy systems [3]. Here, we tailor the PL absorber to absorb concentrated solar radiation, and its high-temperature emission spectrum matches a combination of GaAs and Si solar cells. We experimentally demonstrate PL absorber that absorbs the solar radiation up to 1μm and emits at external QE of 90% while operating under concentrated 200 suns at temperatures as high as 500C. The PL emission is characterized by a double-hump line-shape that matches GaAs and Si solar cells at a projected efficiency of 40%. In addition, the modified spectrum holds a 4-fold reduction in heat load when absorbed by the PV compared to a direct solar absorption. This demonstration opens the door for high-efficiency CPV without the need of costly multi-junction and cooling system.

The core of this design is the photo-luminescent (PL) absorber-emitter material placed between the concentrated sunlight and the photo-voltaic cells (Fig. 1a). We choose a transparent matrix (YAG single crystal for this study) doped with different combinations of transition metals and rare-earth (RE) elements; specifically Chromium, Cerium, Neodymium, and Ytterbium. Together these materials show full absorption of the solar spectrum up to 1μm, and measured PL QE of over 90%. We tested the samples under real solar concentration system and found that the QE is preserved even for elevated temperatures as high as 500C, which is the maximal temperature we were able to reach without thermally insulating the PL absorber. The power spectrums for the operating temperature of 400C are depicted in Fig. 1b. Assuming ideal solar cells, the power out-put efficiency of a pair of ideal GaAs & Si PV cells, as a function of absorber temperature, is presented in Figure 1c. We note that the efficiency up to 400^{o}C is preserved at 40%, negating the need to actively cool the PL material. Interestingly enough, the temperature response Cr,Ce,Nd:YAG presents a constant emission rate of photons with wavelength shorter than 850nm due to the combined reduction in Cr 700nm emission line (caused by increase of energy transfer rate to the Nd acceptor) with enhancement of the Nd 830nm emission line, caused by the thermally enhanced photo-luminescence[3].

The shown spectrums indicated on the considerable reduction of heat load on the PV cells. Most of the impinging light on the PV cells are much closer to their band-edge; mitigating the thermalization of energetic photons in the photo-chemical reaction. Evidently, the expected heat load can reach less than 40% of the direct illumination heat load. Taking into account additional heat load of sub-band-gap radiation, which doesn't reach the PV, the overall heat load is less than 28% of the direct illumination.

Even though, the demonstrated optical efficiency is significantly lower than the thermodynamic limit for GaAs and Si solar cells (of about 48%), the reduced heat load removes the need to actively cool the PV. A preliminary cost breakdown of such a device suggests a record low LCOE, which may enable its full commercialization. The next challenge in the realization of such a concept is optimizing the photon management, which couples the PL emission into the solar cells and recycles un-absorbed photons.

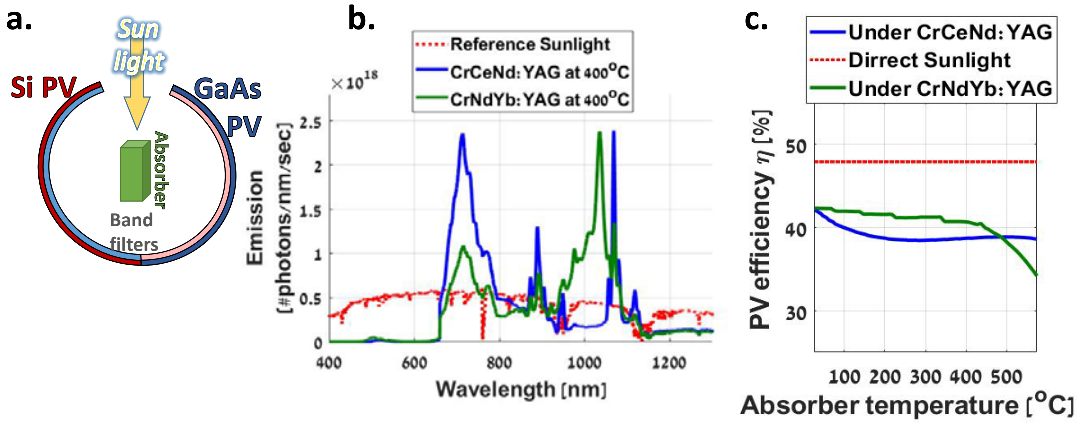

Figure 1: PL absorber absorbs the solar radiation and emits towards GaAs and Si solar cells (a) The heated PL spectrum (b) and the projected efficiency (C).

References:

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