SUMMARY: QUANTSOL 2002

TITLE: CONDITIONS FOR MINIMUM ENTROPY PRODUCTION DURING LIGHT ABSORPTION AND APPLICATION TO ADVANCED SOLAR CONVERSION CONCEPTS

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SUMMARY

By considering entropy absorption and generation rates within the distributions of the quanta involved, it is shown that there is always entropy production associated with net light absorption. Entropy generation rates are shown to be minimised by maintaining a spatially constant (but photon frequency dependent) photon spontaneous emission temperature over the absorbing volume. This principle is demonstrated by its application to advanced "third generation" solar conversion concepts. In particular, it is shown how this principle can be used to optimise the conceptual design of hot carrier cells and cells based on the impurity photovoltaic effect, where control over the spatial variation of the above temperature is feasible. The principle limits the terrestrial conversion efficiency of solar energy to useful work to a maximum value of 86.8%, for all such approaches (6000K sun, 300K earth).

The new principle is established by first demonstrating that entropy production (rate) during steady-state light absorption by an arbitrary number of elementary excitations within the absorber is proportional to the absorption rate of photons of the specific energy of interest divided by a reference temperature, multiplied by the difference between the chemical potential of the photons at the point of absorption and the net sum of the chemical potentials of the other elementary excitations generated or consumed in the absorption process, when all chemical potentials are referenced to the previous temperature.

The next stage involves the use of the time reversal symmetry of the underlying processes to show that net absorption rates are zero when the previous chemical potential difference is zero. It follows that there must be entropy production associated with steady-state light absorption.

The question then arises as to what is the optimum spatial variation of the chemical potential difference previously noted to minimise the total entropy production for a given fractional absorption of a specific photon energy. Under conditions likely to lead to maximum efficiency (specifically, non-reflective surfaces), it is shown that the entropy associated with light absorption is minimised if the net sum of the chemical potentials of the elementary excitations generated or consumed in the absorption process is constant over the absorption volume. For isotropic material where this

chemical potential is that of generated electron-hole pairs, this simplifies to constant spontaneous rates over the absorption volume (Figure 1).

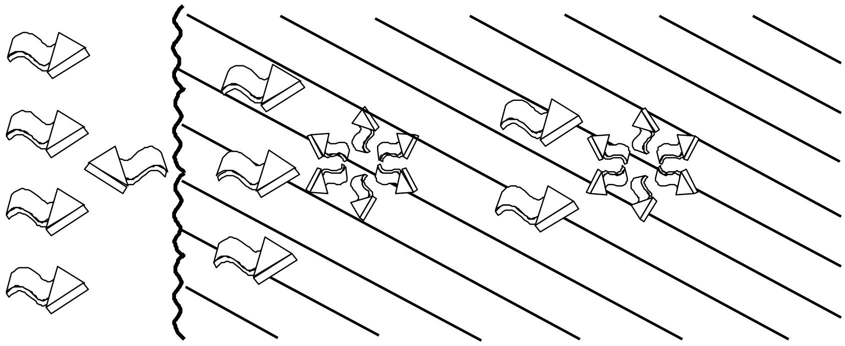

Figure 1: Conditions for minimising entropy production during absorption, i.e., constant spontaneous emission rates over the absorption volume.

In an optimally designed stack of an infinite number of tandem cells, each photon energy component in the incident light is absorbed in its own cell, where the electron-hole chemical potential ideally is controlled by the cell voltage over the absorption volume. This configuration automatically fulfils the condition for minimising entropy production during the absorption of a given fraction of this light and is therefore consistent with obtaining maximum possible energy conversion efficiency.

A hot carrier cell with different temperatures in the conduction and valence band has even more degrees of freedom, if the ability to engineer the energy-momentum relations in the bands is assumed. However, the new principle restricts the limiting efficiency to that of an infinite tandem cell and also gives the required design features, such as zero fields over the absorption volume.

Another interesting device is the impurity photovoltaic cell, where mid-gap defects are used to allow absorption of sub-bandgap light. Here, the chemical potential at each absorption site could be different for the sub-bandgap processes. However, the new principle shows that, in the case of cells of limiting performance, cells of this type must be designed to maintain constant chemical potential for these sub-bandgap processes.