Hot-carrier solar cells: a question of thermodynamics ?

Tom Markvart,
Solar Energy Laboratory,
University of Southampton,
Southampton SO17 1BJ, UK.

Like Fermat's last theorem, a rigorous theoretical foundation for hot-carrier solar cells presents a challenge to the highest calibre of minds[1,2]. Unlike the 17th century conjecture, however, no generally accepted solution has been found to-date. This talk will attempt to solve a less illustrious simplified problem which, nevertheless, may cast some light on the achievable efficiencies and general features of the electrical output from these high efficiency third-generation devices.

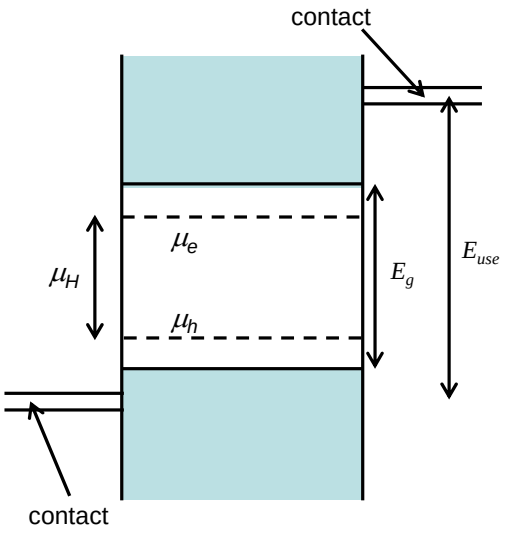

Fig. 1 The concept of hot carrier solar cell based on selective contacts[1]

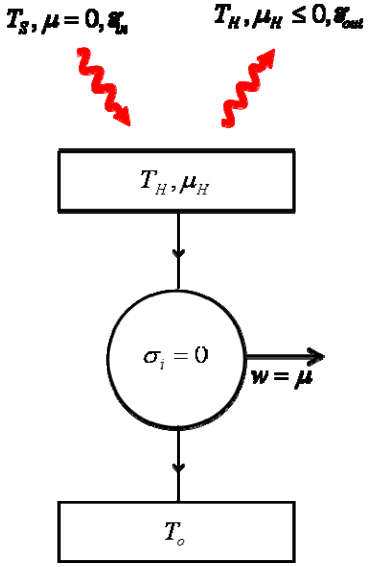

Fig. 2 A "thermodynamic" model of the hot carrier solar cell.

The traditional Ross and Nozik model of hot-carrier solar cells rests on the notion of selective energy contacts (Fig. 1). This paper will consider a slightly different approach where the energy capture by a hot absorber and the conversion into useful work are described in thermodynamic terms. This description avoids some of the difficulties of the Ross and Nozik model[3] as the energy extracted for conversion is naturally equal to the mean (internal) energy of the electron-hole pairs. Furthermore, unavoidable losses are restricted *a priori* to the fundamental entropy generation associated with the kinetics of operation (current extraction), and the (possible) étendue expansion loss under one-sun illumination.[4]

By restricting analysis to “constant volume” processes (inherent to ideal efficiency models such as the Shockley - Queisser detailed balance limit[5]) we obtain a relatively simple formalism that can be used to produce useful efficiency estimates achievable by such devices. We shall also argue that the output from the conversion process should more rigorously be described in terms of exergy or availability of the photon gas, invoking the Landsberg efficiency.[6,7]

References

[1] R.T. Ross and A.J. Nozik, Efficiency of hot-carrier solar energy converters, J. Appl. Phys. **53**, 3813 (1982)..

[2] M.A. Green, Third Generation Photovoltaics: Advanced Solar Energy Conversion, Springer, Berlin, 2003

[3] P. Würfel, A.S. Brown, T.E. Humphrey and M.A. Green, Particle conservation in the hot-carrier solar cell, Prog. Photovolt. Res. Appl. **13**, 277 (2005)

[4] T. Markvart, Thermodynamics of losses in photovoltaic conversion, Appl. Phys. Lett., **91**, 064102 (2007)

[5] W. Shockley and H.J. Queisser, Detailed balance limit of efficiency of p-n junction solar cells, J. Appl. Phys., **32**, 510–519 (1961).

[6] See, for example, P.T. Landsberg and J.R. Mallinson, Thermodynamic constraints, effective temperatures and solar cells, Colloque International sur l'Electricitè Solaire, CNES, Toulouse, 1976, p. 16.

[7] T. Markvart and G.H. Bauer, What is the useful energy of a photon ? Appl. Phys. Lett., **101**, 193901 (2012)