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The Impurity Photovoltaic Effect in GaAs Solar Cells

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1) Impurity photovoltaic effect

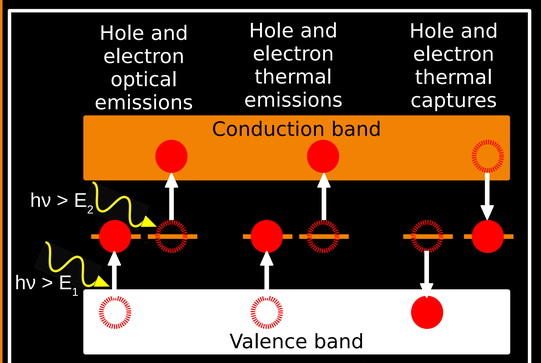


Fig. 1: Deep-impurity mediated processes.

- Concept: to take advantage of mid-gap energy levels created by deep-impurity doping;
- 3 deep-impurity-mediated processes for holes and electrons: thermal and optical emission, and thermal capture;
- Absorption of lower-energy photons ► current (J_{SC}) increase;
- Deep-impurity-mediated recombination ► voltage (V_{OC}) loss;
- Technical challenge: finding a compromise between J_{SC} enhancement and V_{OC} degradation.
- Objective: to assess the viability of GaAs impurity solar cells (ISCs) by means of numerical simulations.

2) Method

$$U = \frac{np - (n_1 + \tau_{n0} g_{nt})(p_1 + \tau_{p0} g_{pt})}{\tau_{n0}(p + p_1 + \tau_{p0} g_{pt}) + \tau_{p0}(n + n_1 + \tau_{n0} g_{nt})} \quad \text{(I)}$$

$$\alpha_{tot} = \alpha_{e-h} + \alpha_n + \alpha_p \quad \text{(II)}$$

$$\alpha_n = f_t N_t \sigma_n^{opt}(\lambda) \qquad \alpha_p = (1 - f_t) N_t \sigma_p^{opt}(\lambda) \quad \text{(III)}$$

[1] A. Niemegeers, M. Burgelman, Numerical modelling of ac-characteristics of CdTe and CIS solar cells, 25th PVSC (1996) 901.

- Method: numerical solution of a system composed of transport, continuity, and Poisson equations for carriers [1];
- The impurity photovoltaic effect is included in the continuity equations using eq. (I), which describes all processes in Fig. 1;
- Total absorption (eq. II) is the sum of band-to-band, valence-band-to-impurity, and impurity-to-conduction-band processes.
- The impurity-mediated absorption depends on the occupation probability of the impurity level f_t (eq. III).

3) GaAs:Ti, GaAs:Fe, and GaAs:Cu

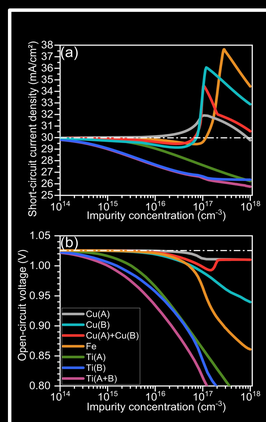


Fig. 2a and 2b

- p+/n/n+ ($10^{18}/10^{17}/10^{18}$ cm^{-3}) junction GaAs solar cells having Ti, Fe and Cu impurities in the middle layer were simulated.
- Maximum current (J_{SC}) occurs when the impurity concentration is slightly higher than the shallow-dopant concentration (Fig. 2a).
- Clear voltage (V_{OC}) degradation (Fig. 2b).

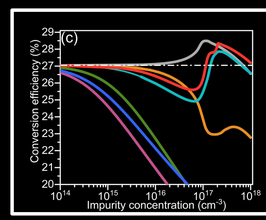
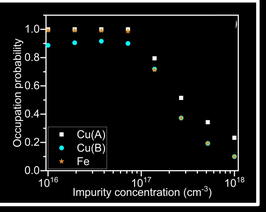


Fig 2c

- GaAs:Ti and GaAs:Fe perform poorly; GaAs:Cu may be more efficient than conventional solar cells (represented by dashed line).

Fig. 3

- The peak efficiency (Fig. 2c) occurs when the occupation probability is not close to 1 nor to 0.



4) Mapping

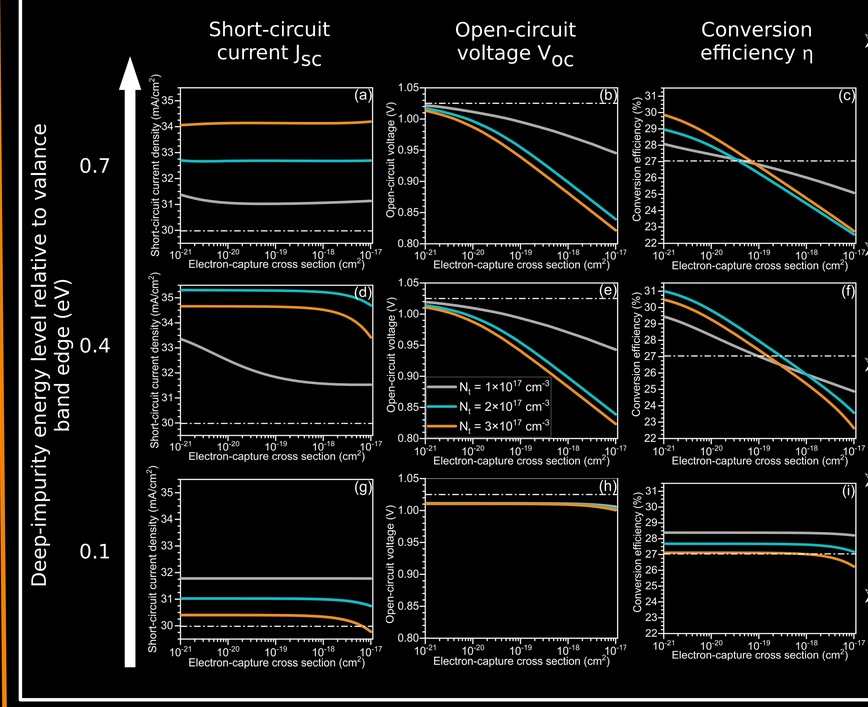


Fig. 4

- GaAs ISCs having generic impurities were simulated varying the impurity concentration (colors), the impurity energy level (outer left vertical axis), and the electron-capture cross section (horizontal axis).
- Low energy levels (0.1 eV) lead to small current increase and small voltage degradation.
- The trade-off between current and voltage is best when the energy is around 0.4 eV.
- The optimum impurity concentration increases as the energy of the Impurity level increases.
- Levels closer to the middle of the band gap require smaller electron-capture cross sections.

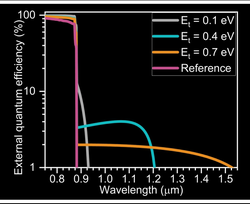


Fig. 5

- Quantum-efficiency spectra are drastically modified due to the presence of impurities.
- The maximum wavelength the device can absorb equals the wavelength defined by the energy difference between the conduction-band edge and the impurity level.

5) Conclusion

- GaAs:Cu impurity solar cells are promising; GaAs:Fe and GaAs:Ti are not (Fig. 2c);
- Our results on GaAs:Ti ISCs are compatible with previously published experimental works [2].
- We have shown that GaAs impurity solar cells may be substantially more efficient than their conventional counterparts (Fig. 4);
- GaAs ISCs are especially useful when more infrared radiation is present (Fig 5).
- Our results serve as a guideline for future experimental research on GaAs ISCs.

[2] P. G. Linares et al., Extreme voltage recovery in GaAs:Ti intermediate band solar cells, Sol. Energ. Mat. Sol. C. 108 (2013) 175.

Acknowledgments

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