Optimization of AlSb/AlGaSb quantum well based up converter for Si solar cells

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Abstract

One of the major obstacles for high efficient power conversion of the sun light with conventional semiconductor materials is that only photons with energies close to that of the semiconductor energy gap (Eg) are effectively converted into electron-hole pairs. Photons with lower energy than Eg are simply lost (the semiconductor is transparent to them); and out of the photons with higher energy (> Eg), only a part i.e., those with energy almost equal to Eg are best suited for absorption. The majority of high energy electrons generated by photons with > Eg, (hot carriers) decay thermally to the Fermi level of the conduction band before they can contribute to the output current.

The principal aim here must be to make better use of the solar spectrum [1,2].One of promising concepts is to place another device component, "light converter", in front of an existing solar cell (SC). If luminescent materials, either bulk or nanostructured, are placed in a layer to absorb short (long) wavelength light from the sun - a region where many commercially-produced PV modules exhibit a poor spectral response - and re-emit this light at longer (shorter) wavelengths to match the region where SC exhibits a very good spectral response, it is possible to enhance the conversion efficiency of the SC device [1]. Up- or down- conversion occurs in the three- level quantum mechanical systems simultaneously.

In this paper the optimization procedure for up- converter, based on AlSb/AlGaSb quantum well structure, for silicon solar cells is proposed. Up- conversion entails the conversion of low frequency photons, whose energy is insufficient for silicon interband transitions, into higher frequency photons which can be absorbed by Si solar cell. Such low frequency photons can be converted by utilizing nonlinear effects in quantum well based structures. To allow for sufficient output photon energy of the converter, we consider the asymmetric step quantum well (AlSb/AlGaSb) which is deep enough to accommodate two bound states. The continual part of the spectrum is used as the third "state, in particular the lowest resonant state which effectively "selects" the photon frequencies involved in optical transitions as it maximizes the dipole matrix elements with bound states. Optimization of up-converter is performed by maximization of the second order susceptibility derived from the density matrix formalism. In our procedure, based on the use of global optimization tools (combined simulated annealing and genetic algorithm) [3], we vary the well structural parameters which affect the nonlinear

susceptibility. To minimize overall computational load, starting for 8-band k.p Hamiltonian, we have derived one band model, that takes into consideration effects like strain, band mixing, and band nonparabolicity. This model is used in combination with the optimization algorithm for calculation of electronic states in the quantum well and dipole matrix elements dependent nonlinear susceptibility.

Specifically, for one-step quantum wells we have four input arguments of susceptibility: the widths of step and well layers, the content of AlSb in the step region and the height of the outer barrier. These input parameters are subject to physical and technological constraints, which enable us to obtained a realistic optimized AlSb/AlGaSb quantum-well structure which supports three states with suitable energy spacings for up-conversion.

Key References

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