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GaNAs/AlGaAs with Close-to-Ideal Absorption Energies for Intermediate Band Solar Cell Application

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The Intermediate Band Solar Cell (IBSC) concept employs intermediate energy states within the band gap of a host solar cell material to increase the photocurrent generation by an additional two-step absorption process of sub-band gap photons of different wavelength. To achieve high conversion efficiencies of theoretically up to > 60%, intermediate energy states need to be formed deep inside the host semiconductor band gap to match the transition energies to the respective parts of the solar spectrum, ideally 1.9 eV for valence band (VB) – conduction band (CB), 1.2 eV for VB – IB, and 0.7 eV for IB – CB transition.

However the fabrication of such quantum heterostructures with large band gap difference in high quality is difficult due to the generally large lattice mismatch. Here, we focus on heterostructures of AlGaAs and N-incorporated GaAs making use of its extremely large bowing factor which allows the growth of very deeply confined structures with only low lattice-mismatch. Furthermore, N forms localized states which are expected to act as zero-dimensional quantum structures and are necessary to isolate the intermediate energy states from the VB and CB.

P-i-n AlGaAs solar cells were grown on n-GaAs (001) substrate using a solid source molecular beam epitaxy machine equipped with a radio frequency plasma source for N supply. The quantum structure consisting of ten periods of 4 nm GaNAs quantum wells (QWs) and 20 nm AlGaAs barrier layers were embedded in the middle of the 600-nm-thick i-region of the solar cell. Samples with different N concentrations were fabricated by using growth interruptions during GaNAs deposition during which only N and As was supplied [1]. The GaNAs are doped with Si to provide electrons as majority carriers in the quantum structure.

Figure 1 shows the photoluminescence (PL) emission of the AlGaAs/GaNAs solar cell with N concentration of ~2%. A clear emission of the GaNAs QWs is observed at room temperature indicates a high crystal quality. The GaNAs QW emission energy of 1.18 eV confirms that deep intermediate energy states formed. Together with the AlGaAs host material emitting at 1.86 eV, its band gap energy, the fabricated solar cell has close to ideal IBSC transition. Photocurrent spectrum measurements of the samples show that the quantum structures are effective in extending the absorption spectrum which can be precisely tuned by adjusting the N concentration, and confirm that the GaNAs QWs efficiently absorb sub-band gap energy photons. The current-voltage characteristics under GaNAs QW excitation exhibits a strongly bias-dependent photocurrent generation which vanishes under forward bias condition where carries cannot escape the intermediate energy states by thermal activation or tunneling, a necessary condition for IBSC operation. Depending on the nitrogen concentration we demonstrate that part of these confined carriers can be excited by second photon absorption of different wavelength and generate an additional photocurrent, the key operating principle of IBSCs. At present the two-step photocurrent generation is stronger in the lower nitrogen concentration samples, which is assumed to be related to an increasing recombination rate with increasing N concentration, which will be reduced in the future by optimizing and modifying the growth technique. The AlGaAs/AlGaAs material system has huge potential for IBSC application with the advantages (close-to-ideal energies, low strain, two-step photocurrent) demonstrated in this report.

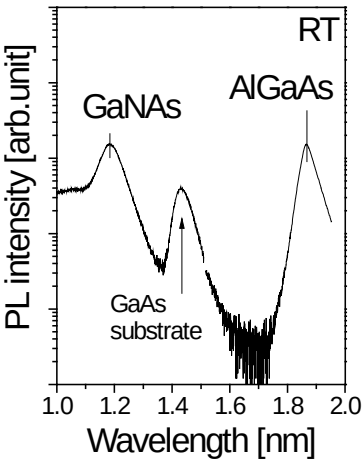

Fig. 1: PL spectrum at room temperature.

[1] T. Mano et. al, APEX 4, 125001 (2011).

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