Spectral Response of GaInNAs / GaAs Multiquantum-Well Solar Cells

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Abstract—The current-voltage and spectral response of a GaAs / $Ga_{0.96}In_{0.04}N_{0.015}As_{0.985}$ pin diode is measured. Its determined that the inclusion of GaInNAs increases the spectral response of the cell beyond that of GaAs but due to the low number of quantum wells employed the response at longer wavelengths is very low.

Keywords: Multiquantum well solar cell, GaInNAs

The efficiency of a single junction conventional solar cell is limited due to low and high wavelength cut-offs[1], for example material with band gaps of 1.42 eV yielding the highest possible efficiencies of approximately 33% for AM1.5G radiation. So far efficiencies of 25.9% have been realised for GaAs and 24.7 for single crystal Si cells, while efficiencies of 18% and 19.5% have been achieved for CdTe and CIGS thin film cells respectively[2].

A number of methods to increase efficiency further exist. One is to stack solar cells of different band-gaps connecting them in series both optically and electrically creating a tandem cell [3]. This method has so far provided the highest efficiencies with a $Ga_{0.44}In_{0.56}P/Ga_{0.92}In_{0.08}As/Ge$ cell giving an efficiency of 40.7% [4]. One significant challenge when designing tandem cells is the current of each junction must match if optimum efficiencies are to be achieved.

Another approach is to include multiple quantum wells within the intrinsic region of a p-i-n cell. The combination of the wide band gap barrier and low band gap quantum well allow the absorption of photons in a wider spectral range [5]. Such cells may prove very useful if incorporated into tandem designs as they will allow the absorption edge and hence the short circuit current of each junction to be carefully chosen. In this paper we present our results covering a GaAs pin diode which incorporates multiple quantum wells using a selection of compositions of the quaternary alloy $Ga_{1-x}In_xN_yAs_{1-y}$ (dilute nitrides).

There has been much interest in $Ga_{1-x}In_xN_yAs_{1-y}$ for solar cells due to the ability to choose both its lattice constant and band gap independently. By increasing the Indium concentration the band gap is reduced and the lattice constant is increased, while increasing the Nitrogen concentration reduces both the band gap and the lattice constant [6] However, it has not been possible to create an efficient GaInNAs solar cell as the addition of nitrogen causes imperfections and dislocations. Therefore, the carrier mobilities and lifetimes are reduced [7] leading to very low diffusion lengths [8]. This results in reduced efficiencies particularly in the bulk material where the high strain causes high dislocation densities.

In our design we chose a dilute nitride composition $Ga_{0.96}In_{0.04}N_{0.015}As_{0.985}$ which gives a band gap of 1.1eV and is lattice matched to GaAs. Our design is a p on n pin solar cell with 10 GaInNAs/GaAs quantum wells with widths varying between 38Å and 110Å included in the intrinsic region. Using the infinite barrier approach together with strain we calculated the effective gap of the widest quantum well to be 1.16 eV and that of the narrowest well is 1.25eV.

Two identical devices were grown by Molecular Beam Epitaxy at Tampere University of Technology. Beryllium and silicon were used as p and n type dopants respectively. One of the devices was annealed at 720° for 5 minutes. No antireflective coating was applied to the sample. Nickel / Germanium / Gold contacts were made to the substrate and Zinc / Gold ring contacts with a diameter of 1.4 mm were formed on the top of the structure by photolithography and then etched to give an active area of $4.52mm^2$.

Photoluminescence measurements were performed on the annealed device for temperatures between 8 and 300K and are shown in figure 1. The peak at room temperature corresponds to a value of 1.17eV, close to the calculated value.

The AM1.5G IV characteristics of the devices were measured for the AM1.5G spectrum at 25C and plotted in Fig. 2. The annealed structure has a higher short circuit current but lower open circuit voltage. This can be attributed to the red shift in bandgap which occurs during annealing. The open circuit voltage of 0.44V is low but probably due to the decrease in photocurrent and increase of dark current which occur due to surface recombination. The annealed structure also shows a better fill factor of 49% and an efficiency of 0.8%.

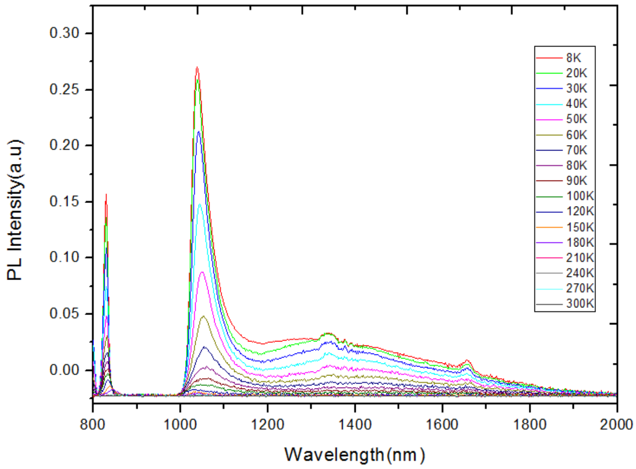

Figure 1: The photoluminescence results for the annealed structure.

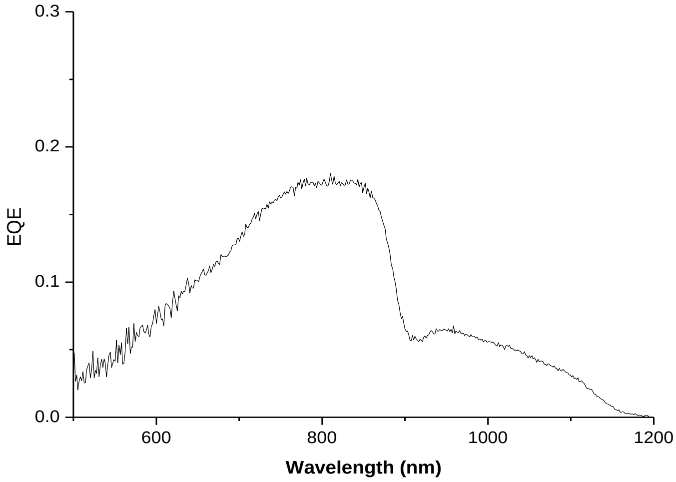

Figure 3: The spectral response for the annealed structure.

The spectral response of the device was measured by illuminating the device for the wavelength range 500 to 1150 nm using a Bentham's M300 monochromator and the IL1 white light source and measuring the current of the device produced. The results are normalised with respect to the spectral dependence of the incident light and detector. These are plotted for the annealed sample in Fig. 3. It is clear the GaInNAs quantum wells extend the cells spectral response beyond that of a GaAs cell (1.42eV) to 1.17eV. The lower achieved at low photon energies can be attributed to the low number of quantum wells. With a total thickness of 64.2 nm and assuming an absorption coefficient of $1um^{-1}$ they are likely to absorb approximately 6% of photons with energies lower than 1.42eV. This coupled with the low diffusion length explains the relatively lower powers compared to GaAs wavelengths. The photoresponse begins to decrease at 1.6eV due to the lack of a window layer and by 2.4eV almost all photons are being lost to surface recombination.

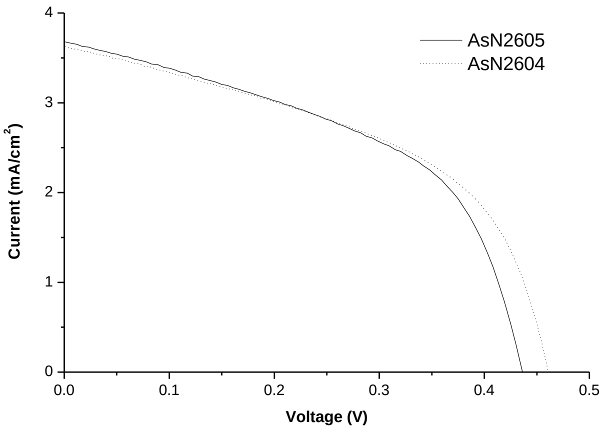

Figure 2: A graph showing the AM1.5G I-V charecteristics for the annealed (solid) and unannealed (dotted) structures

In conclusion we have demonstrated that the spectral response of a GaAs cell can be extended by the inclusion of dilute nitride quantum wells into the intrinsic region of a p-i-n GaAs cell. While the increase in photocurrent at longer wavelengths was small in this structure it maybe be possible to increase the efficiency by both increasing the number of quantum wells and designing cells with high indium and lower nitrogen in dilute nitrides to improve the optical and electrical quality. The work for this is underway and will be reported shortly.

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