Concentration Enhancement of Current Density and Diffusion Length in III–V Ternary Compound Solar Cells

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Abstract. Current density and output power of solar cells, respectively, made from different materials combinations:

GaAsP (Zn)/GaAsP (Te)/GaAs – CVD
GaAs (Zn)/GaAs (Te)/GaAs – CVD
GaAlAs (Zn)/GaAs (Si) – LPE
Silicon, p on n (commercial grade)

have been compared at increasing light levels, i.e. solar concentrations from 1 sun to 100 suns. A strongly super-linear increase in output (current density) is found for the ternary compound cells in agreement with earlier measurements.

The faster rate of increase of the current with concentration in ternary compounds as compared to silicon can be explained by a trap-filling mechanism at higher injection levels.

A Gaussian distribution of compensated donor states can explain the superlinear current increase.

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As is well known, the optimum conditions for photovoltaic solar cells cannot be generated by the use of only one type of semiconductor. While the properties of silicon with respect to bandwidth $E_g$ and carrier lifetime are near the optimum range, it is rarely possible to operate under best conditions with respect to filling factor (surface conduction), reverse saturation current, diffusion length $L_p$, open circuit voltage, photon absorption, etc.

III–V compound semiconductors as GaAs allow for higher efficiency due to a wider forbidden zone (1.5 eV has been derived as optimum gap) [1]. However, surface state density and stoichiometric defect density interfere with the layer perfection of normally diffused devices. Therefore, heterojunctions produced by LPE (Liquid Phase Epitaxy) between a larger gap ternary compound, lattice matched to the GaAs-substrate have proved to be most efficient.

This is due to a number of factors, among these the decrease in surface state density and the more efficient use of the solar spectrum. The so-called “multicolor structure” or layered structure of variable band gap is the most efficient solar cell.

In plotting the solar energy distribution in W cm$^{-2}$ over the wavelength $\lambda$ in $\mu$, we see that only a succession of materials of increasing cut-off wavelength (long wavelength absorption edge) can utilize the entire solar spectrum (see Fig. 1).
4.1 Solar I Energy

Fig. 1. The energy spectrum of the sun on a clear day at sea level: solar energy in \(10^{-2} \text{ W/cm}^2\) versus wavelength in \(\mu\text{m}\) and eV above. Also shown are the parts

\[
\Delta E = \int_{o}^{\lambda} E(\lambda)d\lambda
\]

of the spectrum, utilisable for the generation of electron-hole pairs in different semiconductors with different cutoff wavelength \(\lambda_o\).

Materials combinations especially suitable for this purpose are

GaAlAs on GaAs
GaAsP on GaAs

and

GaAsP or GaP on silicon substrates
GaAsP on GaAs on germanium substrates.

The latter combination would efficiently fill the entire solar spectrum and be adaptable with respect to lattice constants. As in the production of red LED's, GaAs\(_{1-x}\)P\(_x\) would be ramped from \(x=0\) to \(x=0.4\), starting at the GaAs substrate [2]. CVD-deposition of GaAs on Ge is sufficiently developed as well [2]. GaAlAs on GaAs has successfully been used in solar cells and has occasionally yielded very high efficiency when LPE was used. This results in layers of high perfection and a heterojunction band profile suitable for field-enhanced carrier separation when the top \(p\)-layer is, e.g., the wider gap semiconductor [3].

The application of LPE is a limiting factor for mass production for these cells. Application of CVD (Chemical Vapor Deposition) to GaAlAs has been based on organometallic compounds of aluminum. Results are good, but not quite comparable to those based on LPE [4]. CVD allows large volume batch processing of wafers as in LED production and is a desirable technique in this case.

GaAsP-Solar Cells

We have produced solar cells based on the GaAsP/GaAs-CVD process. The cell structure is similar to the base wafers for red LED's (Fig. 2). The top layer with a gap \(E\) is transparent for the lower energy photons within the main absorption band of the GaAs layer. With GaAs\(_{0.6}\)P\(_{0.4}\), a top layer gap in the 1.9 eV range is produced on a ramped layer with decreasing