Towards high-performance III-V solar cells on silicon

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Challenges for solar cell-relevant breakthrough technologies like the merge of the silicon and III-V technologies or the appropriate design of quantum structures such as in the tunnel junction of a multi junction solar cell are always associated with an adequate interfacial preparation. Triple junction III-V compound semiconductors grown with metal organic chemical vapour deposition (MOVPE) are today's most efficient photovoltaic devices with conversion efficiencies exceeding 40%. A next generation multijunction cell with four or more junctions and optimized band gaps is expected to break the present record efficiency surpassing the 50% mark. In our work, the above mentioned topics have been tackled and the delicate MOCVD preparation of critical interfaces was monitored on the atomic scale with optical in-situ spectroscopy and, associated to these signals, sophisticated analytic tools. Here, a quantitative in-situ measurement of the surface domain structure of GaP-films grown on silicon substrates is presented as well as the improved interface preparation of a tunnel junction in our tandem solar cell, which is supposed to replace the sub-optimum Ge bottom cell in a multi junction solar cell with an ultimate efficiency.

Optimized absorber materials with band gaps in the IR-region may be used for their application in a 4- or 5-junction solar cell, if an InGaAsP/InGaAs low bandgap tandem solar cell is combined with the well established InGaP/GaAs high bandgap tandem via a mechanical stack, wafer bonding, or splitting of the solar spectrum. The high bandgap tandem cell with bandgaps in the range of 1.9 and 1.4 eV can be grown on the lattice constant of GaAs. We have developed and realized InGaAs/InGaAsP tandem solar cells on the lattice constant of InP via metal organic vapour phase epitaxy with bandgaps of around 0.72 eV and 1.05 eV from these materials [1], which are optimized for the application in a 4-junction stack (Fig.1). In addition, double heterostructures with these low bandgap absorber materials embedded between InP barriers were grown for the photoluminescence lifetime measurements. Time resolved photoluminescence (TRPL) and transient microwave conductivity (TRMC) measurements were employed to evaluate the minority carrier lifetimes of the absorber materials grown in double hetero structures (DHS), which consisted of thick p-doped absorber layers embedded between p-InP barriers. The observed injection level dependency of the lifetime can be understood by a combination of at least two parallel recombination processes. The sum of the recombination rates gives the apparent lifetime. For most parts of the injection regime the lifetime measurements showed a mono exponential over several decades.
The observed shape of the injection level dependency of the lifetime can be understood by a combination of at least two parallel recombination processes: a fast Shockley-Read-Hall recombination that dominates at low injection levels but becomes rate limited by the capture of holes at higher intensities, and a slower recombination injection level independent process. To get meaningful results regarding the quality of our bulk material and interface formation, a precise knowledge of the excess carrier density created by the pump pulse was necessary. With our single photon counting TRPL setup that allows to quickly measure the spatial pulse profile and pulse energy at the sample position, a carrier density regime between $10^{9}cm^{-3}$ and $10^{16}cm^{-3}$ in the VIS (λ<1000nm) and $10^{13}cm^{-3}$ and $10^{16}cm^{-3}$ in the NIR (λ<1700nm) was assessed. Hence, the most relevant carrier density regimes corresponding to a solar cell at short circuit and the operating voltage and under modest concentration can be studied. Furthermore, by scanning the sample, spatial inhomogeneities in

the lifetime have been detected. Here, we show the lifetime of minority carriers in p-InGaAs and p-InGaAsP layers of different thicknesses as a function of excitation density.

For the growth and analysis of GaP on Si(100) growth, in-situ optical spectroscopy, ex-situ low energy electron microscopy, AFM, and TEM characterization of GaP layers grown heteroepitaxially on Si(100) by MOVPE were employed to evaluate the anti-phase domain (APD) content on the GaP/Si(100) surface of the same sample. The comparison of the resulting APD determinations agreed very well within the accuracy of all these techniques, which allow for the characterization of the APD content of technologically important GaP layers on Si(100) substrates. RAS is advantageous for its implicit lateral integration and its in situ applicability in chemical vapour deposition (CVD) environments, which even opens the way for in situ process control.

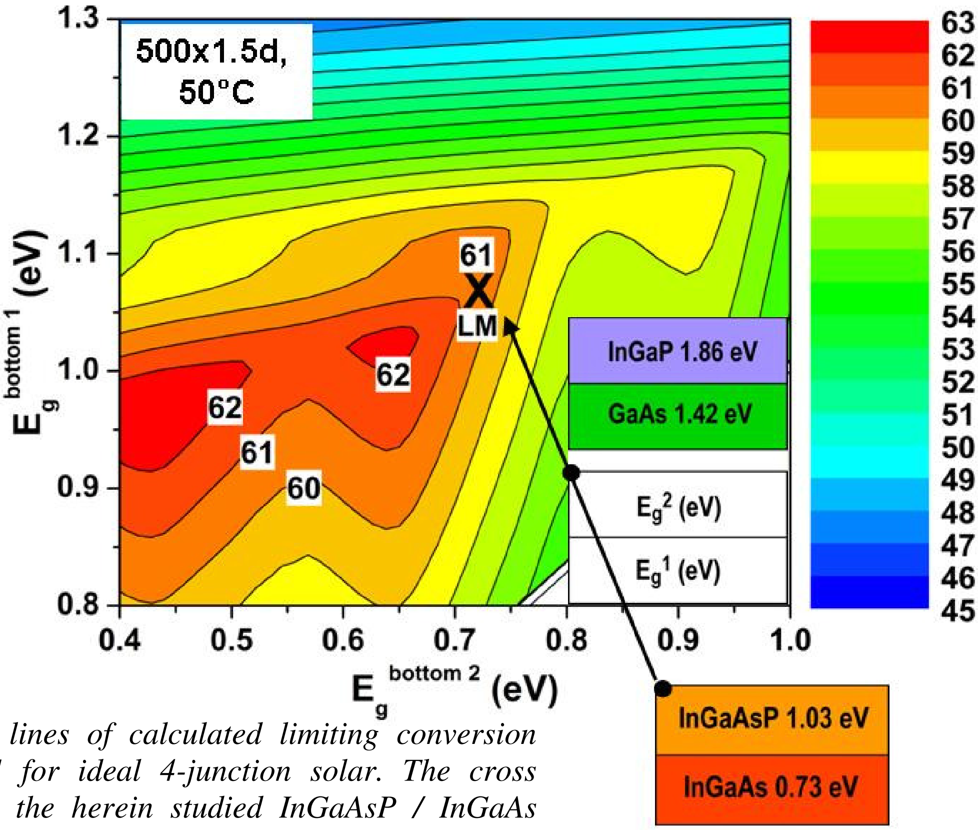

Fig.1 Contour lines of calculated limiting conversion efficiencies [2] for ideal 4-junction solar. The cross corresponds to the herein studied InGaAsP / InGaAs bottom tandem cell built under a InGaP / GaAs top cell.

References:

[1] N. Szabó, B. E. Sagol, U. Seidel, K. Schwarzburg, T. Hannappel, phys. stat. sol. (RRL) 2 (2009) 254; B. E. Sagol, U. Seidel, N. Szabo, K. Schwarzburg, T. Hannappel, Chimia 61 (2007) 775; U. Seidel, B.E. Sagol, C. Pettenkofer, T. Hannappel, Applied Surface Science 255 (2008) 722; U. Seidel, B.E. Sağol, N. Szabó, K. Schwarzburg, T. Hannappel, Thin Solid Films 516 (2008) 6723

[2] G. Létay et al., "EtaOpt – a program for calculating limiting efficiency and optimum bandgap structure for multi-bandgap solar cells and TPV cells", Proc. 17th EU PVSEC, 2001, pp. 178-181.