# GaInNAsSb-based Four Junction Solar Cells on GaAs and Ge Substrates

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Arto Aho, Riku Isoaho, Marianna Raappana, Ville Polojärvi, Lauri Hytönen, Timo Aho, Antti Tukiainen, Mircea Guina

Optoelectronics Research Centre, Tampere University of Technology, arto.j.aho@tut.fi, Tampere, Finland

## 1. Introduction

Solar cells with four or more junctions have potential to reach a conversion efficiency level beyond 46% [1]. To this end, multijunction solar cells incorporating dilute nitride junctions (i.e. GaInNAsSb) have emerged as a promising lattice-matched technology approach. We report on the progress in the development of four junction (4J) cells incorporating GaInNAsSb absorbers grown on GaAs and Ge substrates. The cells are fabricated by molecular beam epitaxy (MBE). The two designs target either high current ($4J_{HC}$) or high voltage ($4J_{HV}$) optimization strategy. Ideally, they should have similar efficiency peaking at over 47% under high concentration.

## 2. Experiments and results

The band gaps for sub-cells corresponding to the $4J_{HC}$ design on Ge are 0.7 eV, 1.1 eV, 1.4 eV and 1.9 eV. The corresponding band gaps for the $4J_{HV}$ design on GaAs substrate are 0.9 eV, 1.2 eV, 1.4 eV and 1.9 eV. The calculated short circuit current density values ($J_{sc}$) for sharing the photons equally between each sub-cell are ~14 mA/cm$^2$ and ~13 mA/cm$^2$, respectively at AM1.5D (1000 W/m$^2$) one sun. Fundamentally, the $4J_{HV}$ approach provides 0.3 V higher open circuit voltage ($V_{oc}$) when compared to $4J_{HC}$. On the other hand, the Ge-based design generates more current (~1 mA/cm$^2$ at one sun). The design $J_{SC}$ values were 13 mA/cm$^2$ and 12 mA/cm$^2$ for the 4J cells, respectively. This design ensures current over-generation for bottom cells, and effectively a higher fill factor and power than equal photon sharing between the junctions would give.

The experimental cells were first assessed under AM1.5D one sun illumination, for which they exhibited $J_{sc}$ values of 10.9 mA/cm$^2$ for $4J_{HC}$ and 10.6 mA/cm$^2$ for $4J_{HV}$. For both approaches, the $J_{sc}$ was limited by the bottom junctions, which also explains the fill factors being lower than ideal (see Fig. 1). Fig. 1 reveals also the characteristics for 100 suns concentrated illumination (AM1.5D, 1000 W/m$^2$). A linear dependence of the $J_{sc}$ vs. concentration is observed for all the cells. The $4J_{HC}$ shows only marginal improvement of $V_{oc}$ when compared to a reference 3J cell with Ge bottom junction, while the $4J_{HV}$ shows larger increase of $V_{oc}$ (0.6 V). The $4J_{HV}$ solar cell exhibits an efficiency of 38%, while the $4J_{HC}$ has clearly lower efficiency peaking at 22%. We note that Ge-based cells are in much early optimization stage compared to GaAs-based devices. The reasons for the performance degradation compared to ideal scenario and future prospects will be discussed.

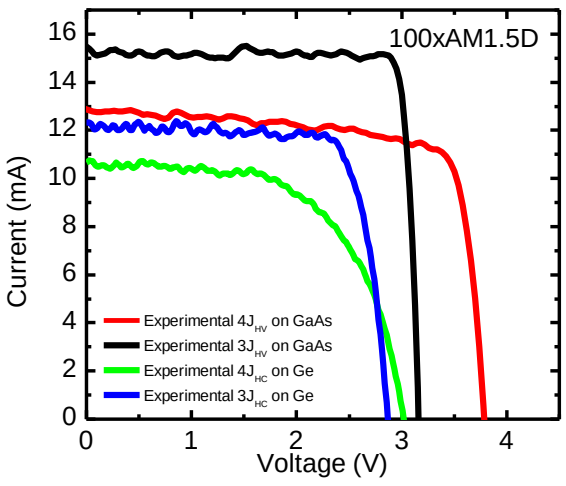


**Figure 1.** *IV-characteristics of 3J and 4J cells fabricated on GaAs and Ge substrates by MBE. The 3J cells are fabricated without the 3$^{rd}$ junction of the corresponding 4J design. The IV-measurements were biased using continuous 100 suns illumination. The cell size was 1 mm$^2$.*

## References

[1] A. Luque, Will we exceed 50% efficiency in photovoltaics?, J. Appl. Phys., 110 (2011), p. 031301