Computer Simulations of a P ($Al_{0.30}Ga_{0.70}As$)-I (GaAs)-N (GaAs) Solar Cell

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Abstract: - In this communication computations of several solar cell parameters are provided, namely, (a) photogeneration-recombination and (b) mobility profiles are obtained for a realistic P-I-N solar cell. The model of the device in mind combines the properties of two kinds of layers of direct gap semiconductors, by employing AlGaAs (at 30% molar ratio of aluminum and 70% of gallium) as a wide gap material and GaAs as a narrow gap one. This design has important advantages over GaAs p-n designs: (1) the p-layer of AlGaAs provides a wider window for the incoming solar photons, thus increasing overall carrier collection (2) the p-layer is kept narrow and the GaAs layers are being selected long, in order to provide chances for higher mobility values (as it is to be shown in the paper) (3) incorporation of GaAs in the intrinsic layer reduces scattering of excited carriers.

Key-Words: - Solar Cells, intrinsic semiconductors, mobility, generation, recombination

1 Introduction and Modeling

The design modeled here includes an AlGaAs p-layer with thickness of 0.5μm, an intrinsic GaAs region of 6.0 μm length, and a 1μm GaAs layer of n-type doping. Alloy selection and distances are such that (a) wider gap window, through the AlGaAs layer, is provided for wider incident wavelength absorption (b) narrow window layer selected for excess photogenerated carriers to avoid recombination. The rest of the device includes regions 2 and 3 out of GaAs, the latter ensuring high mobility values and thus higher collection currents. Computations are based on classical bulk solution of excess carrier dynamics (under illumination) and provide, as a function of distance:

(1) Generation-recombination profiles as a function of position everywhere in the device
(2) Detailed energy band profiles (conduction band vs valence band) as functions of distance along with Quasi-Fermi level positions anywhere in the device
(3) Base current against base voltage
(4) Carrier mobility values
(5) Carrier velocities
(6) Selected doping levels for each region
(7) Electric field
(8) Diffusion lengths
(9) Cumulative conductivity

2 Device design and Computed Results

Details of device design approach are considered as follows:

Device area $10 cm^2$, front surface texture depth 3.00 μm, exterior front reflectance 10%, No exterior rear reflectance, no internal optical reflectance, emitter contact enabled, base contact enabled, with no internal shunt elements.

Region 1: Thickness 0.5 μm, material AlGaAs (30% Al, 70% Ga), dielectric constant 12.24, band gap 1.817eV, intrinsic concentration at room temperature (300K) 1754 cm^{-3}, refractive index 3.81. P-type background doping 10^{17} cm^{-3}, peak front diffusion 10^{20} cm^{-3}, bulk recombination times for electrons and holes at 1000 μs.

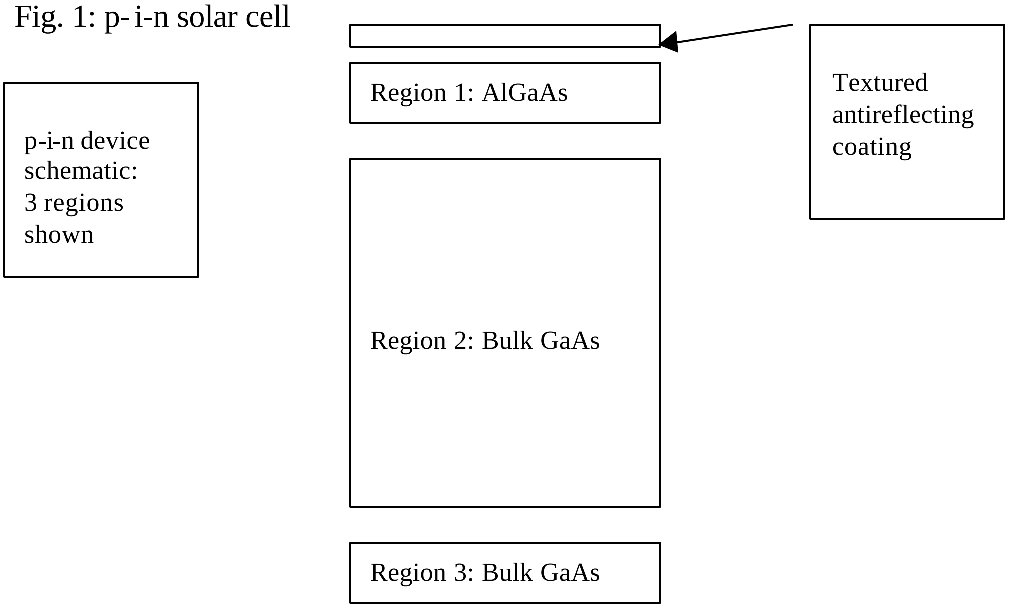
Region 2: Thickness 6 μm, material GaAs, dielectric constant 13.18, band gap 1.424 eV, intrinsic concentration (at 300K) 2.59×10^6 cm^{-3}, refractive index 3.66, n-type background doping 2.33×10^6 cm^{-3}, first front n-type diffusion peak 10^{20} cm^{-3}, bulk recombination times 1000 μs, with rear-surface recombination.

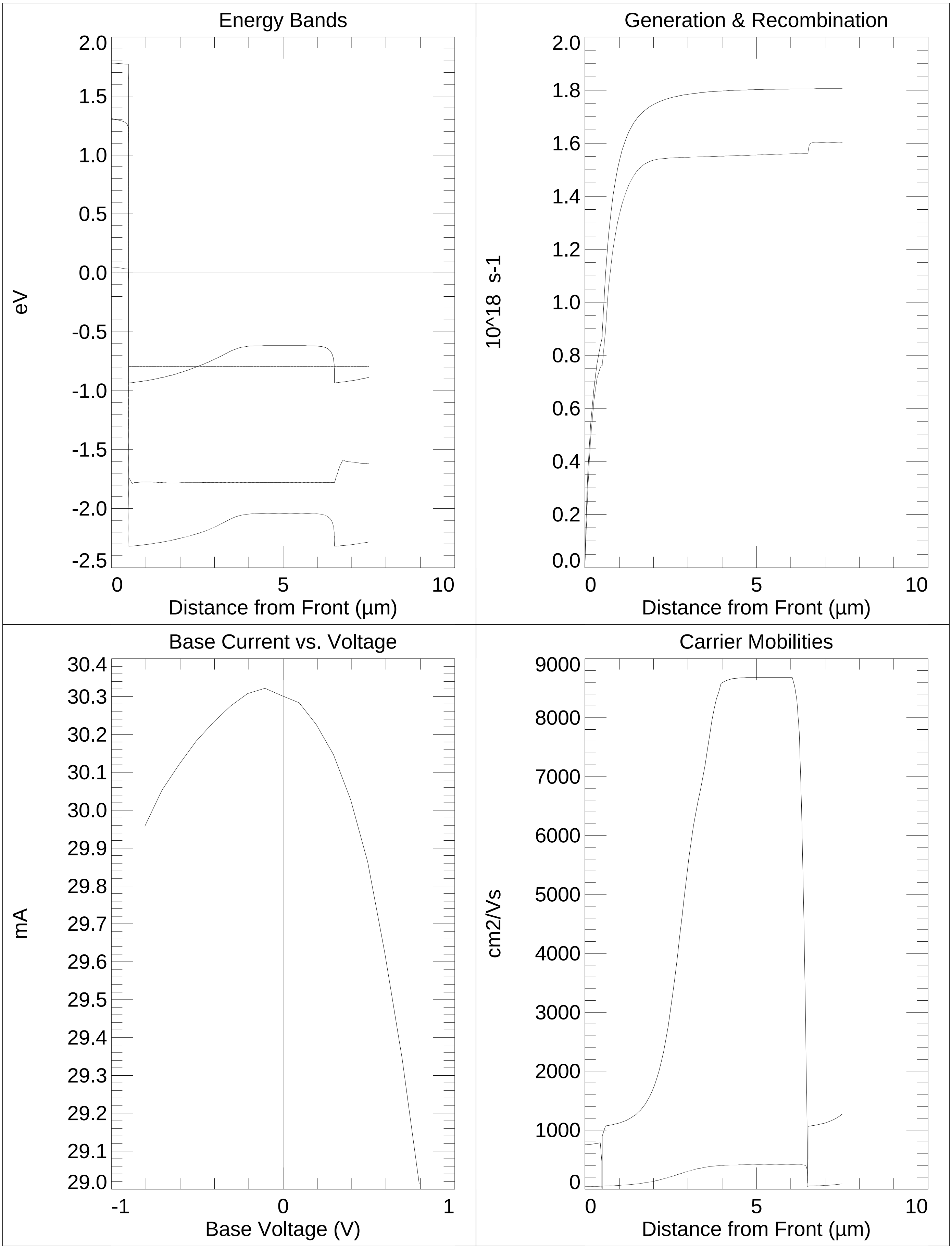
Region 3: Thickness 1.00 μm, material GaAs, dielectric constant 13.18, band gap 1.424 eV, Intrinsic concentration 2.59×10^6 cm^{-3}, n-type background doping 10^{17} cm^{-3}, bulk recombination times 1000 μs.

Excitation: Constant intensity 100 mW/cm^2

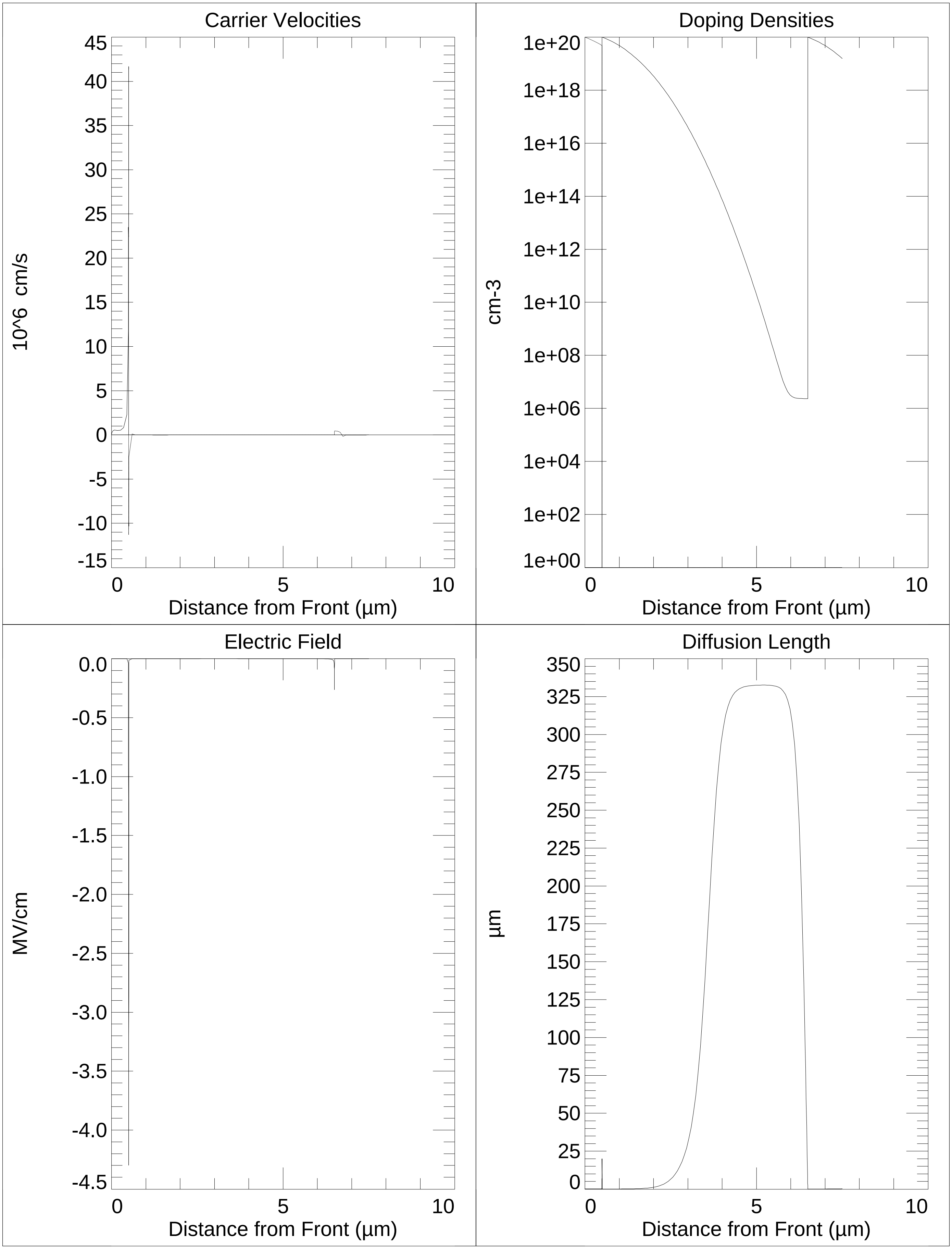
Results: Short circuit current: 30.2 mA, Maximum power output: 24.5 mW

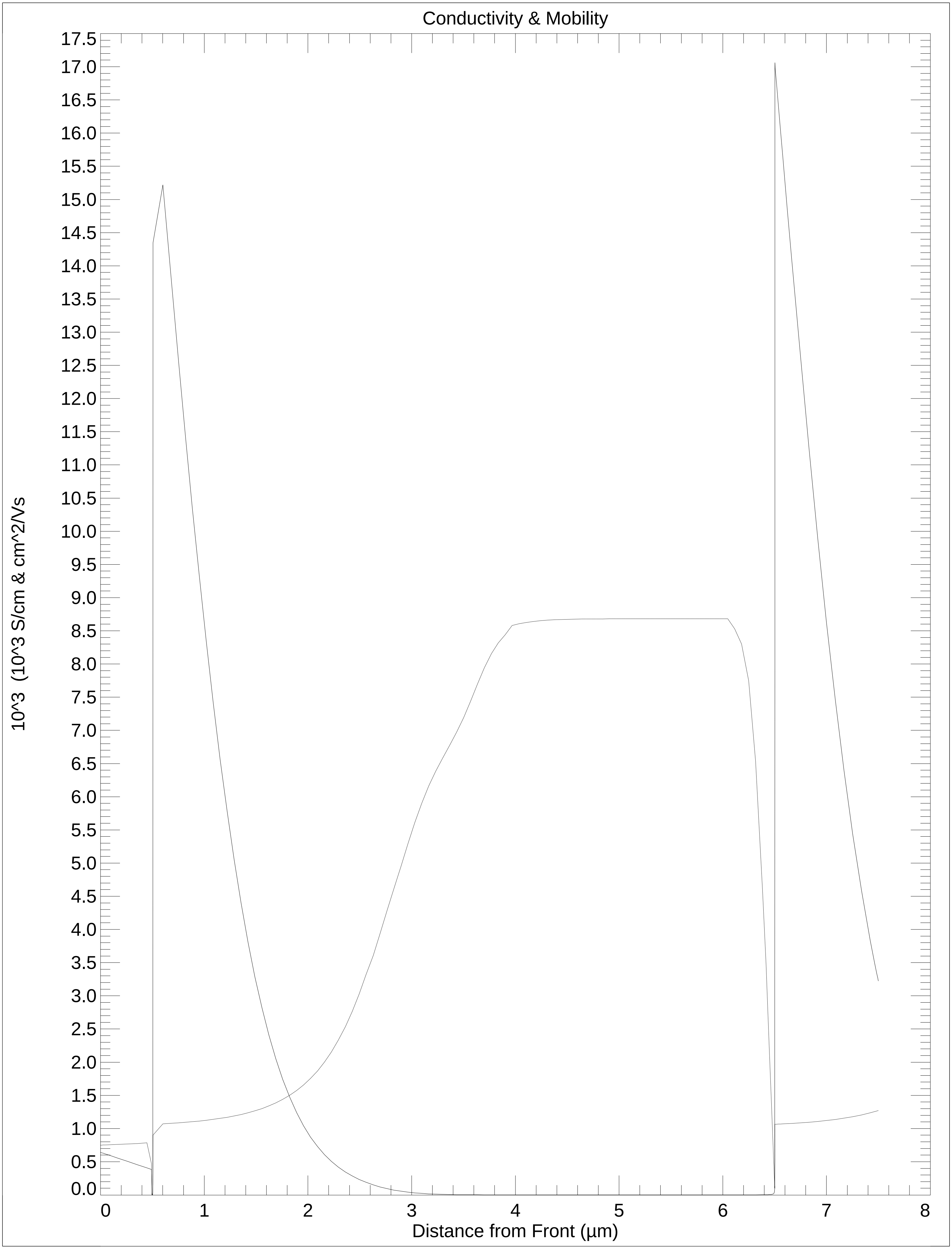
Fig. 1: p-i-n solar cell





Energy Bands
eV
Distance from Front (µm)
Generation & Recombination
10^18 s-1
Distance from Front (µm)
Base Current vs. Voltage
mA
Base Voltage (V)
Carrier Mobilities
cm2/Vs
Distance from Front (µm)


Carrier Velocities
10^6 cm/s
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
0
5
10
Distance from Front (µm)
Doping Densities
cm-3
1e+20
1e+18
1e+16
1e+14
1e+12
1e+10
1e+08
1e+06
1e+04
1e+02
1e+00
0
5
10
Distance from Front (µm)
Electric Field
MV/cm
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
-4.0
-4.5
0
5
10
Distance from Front (µm)
Diffusion Length
µm
350
325
300
275
250
225
200
175
150
125
100
75
50
25
0
0
5
10
Distance from Front (µm)



Conductivity & Mobility
10^3 (10^3 S/cm & cm^2/Vs
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
16.5
17.0
17.5
0
1
2
3
4
5
6
7
8
Distance from Front (µm)

3 Conclusions

Thin p- and n- layers and long intrinsic regions is the design choice in this communication, where lattice matched alloys of gallium arsenide are considered as proposed materials for solar cell performance.

Detailed computations of the dynamics of a pin-type solar cell have been performed for a GaAs-alloy (30% Al content). Energy band structure along with detailed quasi-Fermi distribution has shown dramatic effects of energy profile variations along the growth direction of the device. Thin optical window layer made out of wide gap AlGaAs (@ 30% Al) against GaAs subsequent layers have caused smooth variations of quasi-Fermi levels leading to open circuit voltage values of the order of 0.8 Volts as seen from Fig 2(a) (top left corner of page 3). Continuing clockwise on the same figure, generation and recombination levels have been found to be $1.8 \times 10^{18}\ s^{-1}$ to $1.6 \times 10^{18}\ s^{-1}$ respectively (Fig. 2(b)). Maximum short circuit currents are in excess of 30 mA (Fig. 2(c)), and electron carrier mobilities exceed 8,000 cm^2/Vsec in the intrinsic region (Fig. 2(d)). Overshoot of carrier velocities in excess of 40×10^6 cm/sec, for electrons, is observed at the alloy/GaAs interface (Fig. 3(a), top page 4 and clockwise). Electronic diffusion lengths maximize along the intrinsic region (minimum scattering), where doping profiles are at minimum values (Fig. 2(b),(c)), while electric field overshoot is observed at the alloy interface as well. Fig. 4 depicts the variation of cumulative conductivity as a function of distance along the device, and with the variation of electron mobility: two conductivity overshoots are observed at the two interfaces (alloy-GaAs, and GaAs-GaAs). Calculations for other material combinations are under way, especially for competing materials (silicon and/or germanium, along with indium phosphide and alloys)

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