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Simulation study of InGaN/GaN multiple quantum well solar cells

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Abstract
It's known that indium gallium nitride InGaN alloys has a direct band gap varying from 0.7 to 3.4 eV which covers nearly the whole solar spectrum making it material of choice to make tandem solar cells. In other hand, it's experimentally known that uses of InGaN/GaN multiple quantum well MQW structures in GaN based devices decreases surface recombination and, thus, enhances devices performance. Here, we present a simulation study of multiple quantum well MQW InGaN/GaN solar cells, where cell's active region is formed by a number of InGaN quantum wells (QWs) separated byGaN quantum barriers (QBs). We will present indium element content of $In_xGa_{1-x}N$ wells and number of InGaN/GaN periods impacts on solar cell parameters.
Key words:solar cell, InGaN/GaN MQWs, photovoltaic parameters.

1. Introduction

III-nitrides compound semiconductors (GaN, InN, AlN) and their alloys have excellent physical properties, mainly, good thermal conductivity and high stability under extreme conditions of irradiation. They were find application in fabrication of blue and ultraviolet LEDs and lasers, and, since the 2000s were begun to be studied as photovoltaic materials. This came to the facts that this semiconductors have direct gaps covering the entire solar spectrum, for example, InN have optical gap of 0.7 eV (1771nm) and GaN a gap of 3.4 eV (366 nm), and theoretically a multijunction cell formed by the stacking of three $In_xGa_{1-x}N$ cells can yield 70% of conversion efficiency [1]. In other hand, single junction *p-i-n* solar cells with multiple quantum wells InGaN / GaN have same potential of multijunction cells with a less complicated structure and, also, higher open circuit voltage [2] and less surface recombination velocities.

In this work we will look at photovoltaic properties of InGaN/GaN MQW solar cells, especially, band structure, I-V characteristics and quantum efficiency.

2. Studied cells structure

Simulated cells structure (figure 1) consists of a 0.25 micron p type GaN top layer with doping level of $3\ 10^{17} cm^{-3}$ and a 2 micron n type GaN bottom layer with doping level of $10^{18} cm^{-3}$. Between top and bottom layers exist an undoped (experimentally, undopedGaN layers are lightly n type due to structure defects) multi-quantum wells MQW region where InGaN quantum wells QWs of 3nm thick are separated by GaN quantum barriers QBs of 7nm thick. We note that, thickness of QWs and QBs are fixed in all subsequent simulations.

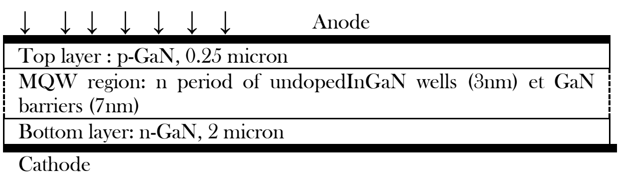

Fig.1 Schematic of simulated InGaN/GaN MQW solar cells.

In our simulation using SilvacoAtlas software package we have tacking into account spontaneous and piezoelectric polarizations that naturally occurs in devices grown by Metal-Organic CVD technique on substrates with different lattice parameter [3]. Band structure of above simulated cell is presented below in figure 2 for 20% of indium element content.

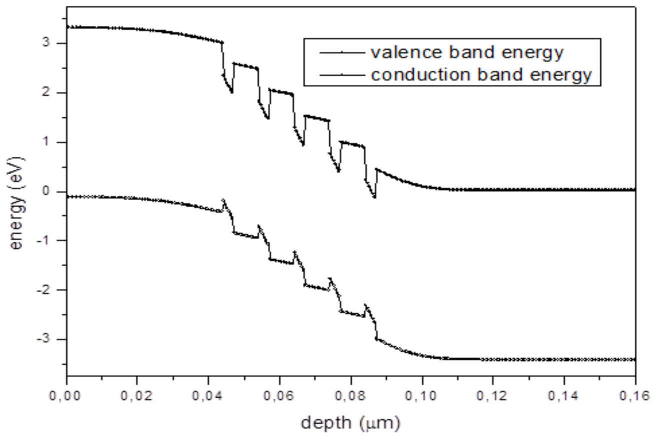

Figure. 2. Band structure of 5 period $In_{0.2}Ga_{0.8}N$/GaN MQW solar cell.

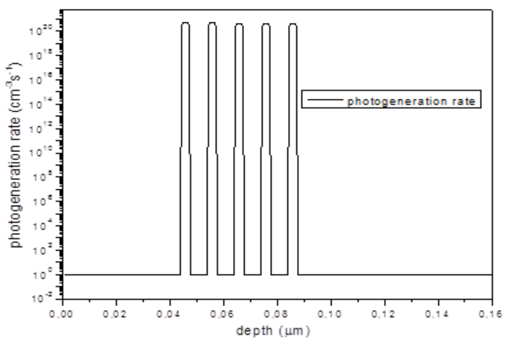

Figure 3. Photogeneration within a 5 period $In_{0.2}Ga_{0.8}N$/GaN MQW cell under AM1.5 spectrum.

3. Results and discussion

In figure 3 is shown photogeneration rate versus depth under AM1.5 spectrum where charge carriers are, namely, generated within InGaN quantum wells regions.

To our knowledge the best yield obtained experimentally on such cells is achieved by Dahl is around 2.95 persent under AM 1.5 irradiation [4]. Figure 4 shows dark and light (under AM1.5 illumination conditions) J-V characteristics as well as power versus bias curves of above cell, where shortcurrent is find to 0.112mA, open circuit voltage is 2.78V and conversion efficiency of 2.96 percent.

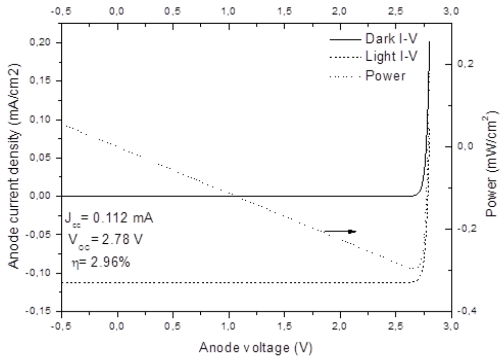

Figure 4. J-V characteristics of 5 period $In_{0.2}Ga_{0.8}N$/GaN MQW solar cell

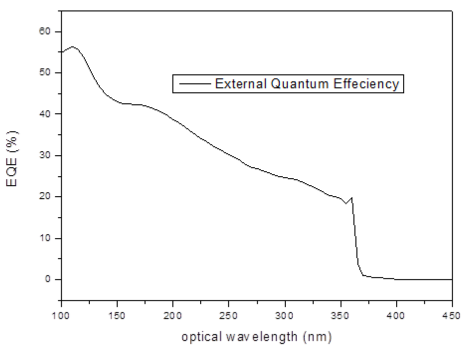

Figure 5. Calculated quantum efficiency of 5 period $In_{0.2}Ga_{0.8}N$/GaN MQW solar cell

We after checked possible influence of indium content and number of InGaN/GaN pairs on cell parameters. In Table 1 are listed cell parameters for various contents of indium, where we find that there not any variation until 25% of indium. But, on the contrary, increasing numbers of QW/WB periods enhances cells photovoltaic parameters, Table 2.

x.comp	0.15	0.2	0.25
Jcc (mA)	0.112	0.112	0.112
Voc (V)	2.78	2.78	2.78
Conversion efficiency (%)	2.96	2.96	2.96

Table 1.Photovoltaic parameters of InGaN/GaN MQW cell for different fractions of indium element.

Number of periods	single well	5	10	15
Jcc (mA)	0.108	0.112	0.212	0.284
Voc (V)	2.72	2.78	2.81	2.81
Conversion efficiency (%)	2.80	2.96	5.63	7.56

Table 2. Photovoltaic parameters of InGaN/GaN MQW cell for different numbers of QW/QB periods.

We are also performed external quantum efficiency calculation, figure 5, to see spectral response of cell. Where, comparing to crystalline cells, InGaN/GaN MQW cells present a higher efficiency in UV region and a sharp decrease beyond 0.37 µm. This means that, for example, a tandem cell containing GaN top cell and Silicon bottom cell will have broader and higher quantum efficiency.

4. Conclusion

III-nitrides are very interesting materials in photovoltaic point of view, and multiple quantum wells based solar cells structures have potential to achieve high efficiencies. We are find that more number of wells causes more efficiency and there are no impact of indium element content of well on cells parameters within 15-25% frame.

Acknowledgment

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