Modeling Si/SiGe/Si Quantum Well Solar Cell Using Different Well Width and Mole Fraction

Raden Arief Setyawan

***Abstract*— Quantum Well Solar Cell (QWSC) was proposed as a means to achieve higher efficiencies compare with conventional monolithic solar cell structures. Quantum well formed by adding lower band gap material within intrinsic region of p-i-n solar cell with less than 100 A° thicknesses. In this research, five structure of QWSC device were designed with different quantum well thickness. Each structure using different SiGe mole fraction in order to achieve the influence of mole fraction variation to quantum efficiency (QE). Parameters of SiGe in simulations were obtained from various references to use with PC1D and Simwin Software. From simulation result, quantum efficiency will increase from mole fraction 0.2 (84.5135 %) until reaching maximum efficiency at mole fraction 0.75 (91.5703 %). Quantum efficiency begin to decrease at mole fraction higher than 0.75. At mole fraction 0.85 quantum efficiency equal to 90.4830 % and at mole fraction 0.95 quantum efficiency sharply become 71.6327 %.**

***Index Terms*— Solar cell, quantum well solar cell, SiGe.**

I. Introduction

Nowadays, the technology of quantum well solar cell is considered as promising way to enhance the solar cell efficiency. Many researches have been done using different type of materials. Most researches using $Al_xGa_{1-x}As$ and InGaAsP system. Previous work shows that inserting a thin layer of AlGaAs Quantum Well in p-i-n will increase quantum efficiency about 20% [1].

In this work we analyze the influence mole fraction and thickness of SiGe quantum wells layers on the photovoltaic processes in thin film solar cells. Photocurrent and external quantum efficiency of thin film solar cell based on p-i-n junction with quantum wells inserted into the intrinsic regions were simulated. For the simulation we applied the program PC1D solar cell modeling simulation from UNSW, and SimWindows that is based on the solution of diffusion-drift and current continuity equations and is elaborated for 1D simulation of semiconductor structures with quantum wells.

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For well widths Lqw less than the carrier's de Broglie wavefunctions (~ 100Å at room temperature) a QW structure imposes a confinement on the motion of the electrons and holes in the growth direction (z). However, in the x-y plane the carriers are still free to move. Solving the separated Schrödinger equation for either carrier type in the z direction shows that only discrete, quantized energies are allowed for the energy subbands of the carriers in the wells.

II. Design of Si/SiGe/Si Solar Cell

Figure 1 show solar cell structure used in this research. Five different thickness of SiGe layer were used in this research to find optimum thickness of quantum well which produce better quantum efficiency. These five different thicknesses shown in table 1.

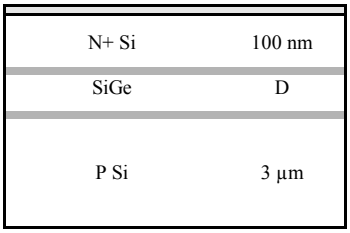

Figure 1. Structure of SiGe Solar cell

Table 1. Five different thicknesses of SiGe Layer

Device No	D
1	1 nm
2	2 nm
3	4 nm
4	6 nm
5	8 nm

The most important parameters of this simulation are band gap [2], absorption coefficient [3], dielectric constant [4] and electron affinity [2]. The smaller mole fraction, SiGe materials will become Si like characteristic. Mole fractions of SixGe1-x used in this research are: 0.2, 0.5, 0.70, 0.75, 0.80, 0.85, 0.90 and 0.95.

One most important parameter of this simulation is absorption coefficient. Absorption coefficient shows percentage of incoming photon that absorbed and contributes to photo current. Absorption parameter used

in this simulation came from previous research of Virginia semiconductor. Graph of SiGe absorption coefficient displayed on figure 2. Although some references present numerical formula to get absorption coefficient of SiGe, we use real data from the result of Virginia semiconductor research to get better result..

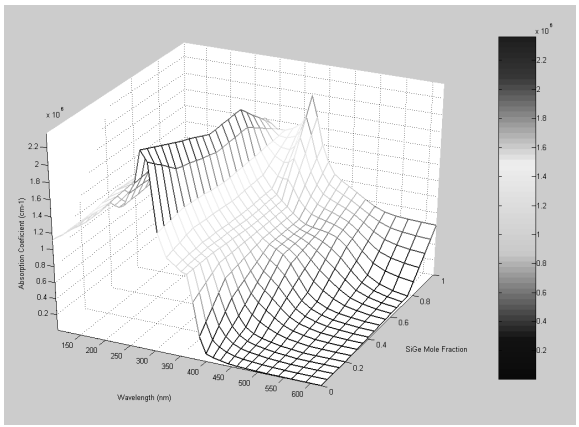

Figure 2. SiGe Absorption Coefficient

III. RESULT AND DISCUSSION

Using SimWindows simulation, we get band diagram of device shown in figure 3. That figure shows that quantum well was staid near n+. In this location, photo current increase sharply, shown in figure 4. This significant increment really affect to whole system quantum efficiency

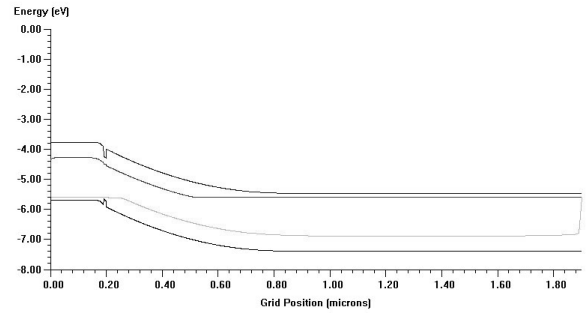

Figure 3. Band Diagram

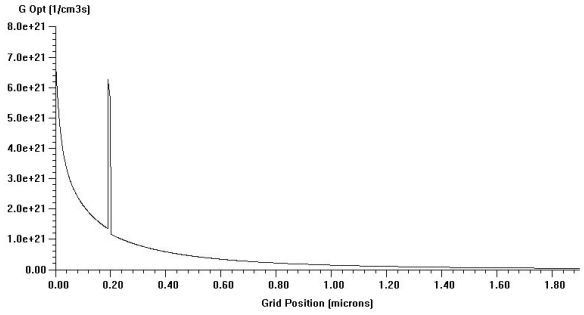

Figure 4. Optical Generation

PC1D simulation was used to get system quantum efficiency. Figure 5 shows the result from performing this simulation using device 1 parameter. Quantum Efficiency more than 80% achieved when wavelength of incoming monochromatic light between 750nm and 950 nm/ maximum values of quantum efficiency for each SiGe mole fraction shown in figure 5.

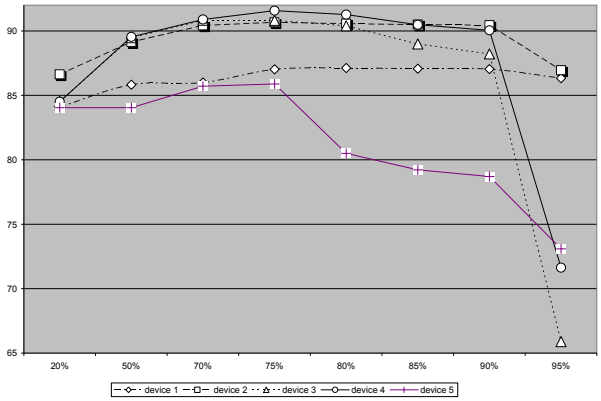

Figure 5. Quantum Efficiency maximum for each mole fraction For device 1 to 5

Quantum efficiency of device 1 increase from mole fraction 20% (84.0962) until reaching maximum value at mole fraction 80%. With mole fraction more than 90%, this value become 87.0409% and at mole fraction 95%, quantum efficiency value decrease sharply to 86.3386%. Maximum value of quantum efficiency from device 1 is on mole fraction 80%, 87.1255%.

In device 2, quantum efficiency increase from mole fraction 20% and reach the maximum value at mole fraction 75% (90.669&). For mole fraction more than 95%, QE sharply decrease become 86.9528%. For device 3, QE increasing from mole fraction 20% until maximum value at mole fraction 70% (90.8294%). Between mole fractions 70% and 80%, QE seems to be constant, but decreasing sharply at mole fraction 95% (65.8863%).

For device 4, QE maximum reached at mole fraction 75% (91.5793%). Between 75% and 80% QE decrease only about 1.5 % and sharply decrease when mole fraction is 95% (71.6327%). QE maximum for device 5 slightly decrease than device 4. At mole fraction 75%, QE value is 85.8864%.

Quantum well structure affect the density of states inside well. Furthermore the density of states determines the form of the absorption coefficient. This result influences the result of this simulation.

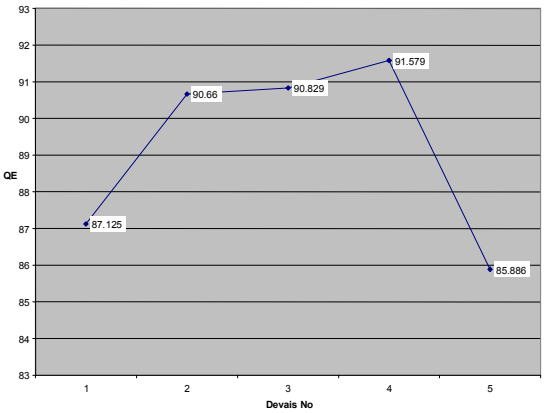

Figure 6. Quantum Efficiency Maximum for Each Device

To get more information about relationship between well width and QE solar cell, we made compartion to the result of previous simulation. Figure 6 shows the influence of well width to QE system.

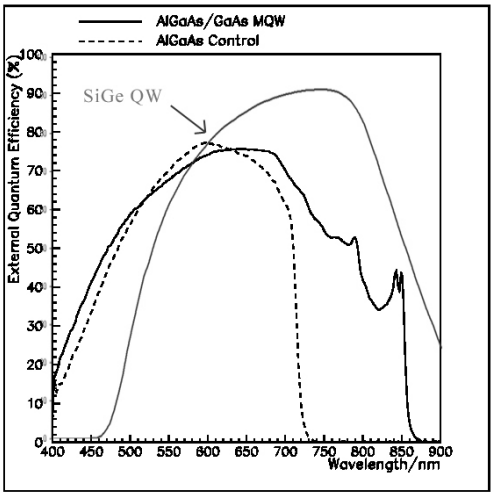

Figure 7 Comparison of simulation result with previous research by Nicholas J. Ekins-Daukes [13].

QE Maximum from this works came from device 4 with well width 6nm as shown in figure 6. These results give a conclusion that in the model proposed, 6nm well width is the optimum well width for S/SiGe/Si in this device structure. Using QE result from device 4, we try to compare with recent works using AlGaAs/GaAs Quantum Well Solar Cell. Result of this comparison shown in figure 7.

Thin gray line is the result of this works, using device 4. These simulations give better QE than previous works, but it also shows that Si/SiGe/Si solar cell works optimum at wavelength higher than AlGaAs.

IV. CONCLUSION

We have presented a simulation of Si/SiGe/Si solar cell with different SiGe mole fraction and different quantum well width. We used PC1D and SimWindows as a device simulation program. We showed that incorporating a thin layer Quantum Well SiGe to Silicon solar cell increase the value of Quantum Efficiency system. This could be explained from the result of SimWin Simulation that optical generation increasing sharply at quantum well area. Our simulation finds that optimal mole fraction of SiGe for solar cell is about 70% – 80%. Maximum QE from this simulation achieved from device 4 with 6nm Quantum Well width.

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