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Development of Novel Solar Cell Design based on Current Energy Converted from Phonon Energy by Controlling the Phonon Transport

Hsu Myat Tin Swe, Hla Myo Tun*, Devasis Pradhan, Lei Lei Yin Win, Ei Ei Khin, Khaing Thandar Soe

***Abstract*—The paper mainly focuses on the Development of Novel Solar Cell Design based on Current Energy Converted from Phonon Energy by Controlling the Phonon Transport. The research challenges in this study are: to find a means of the control of phonon transport or phonon accumulation and propose a novel solar cell structure to convert the phonon energy to the current energy; to study phonon control method for III-nitrides and the properties of phonon transport; to analyze the phonon absorption in a short time for III-nitrides is higher than gallium arsenide by one order, which makes it possible to extract higher current than previous materials. The research objectives are: to design the novel solar cell structure to convert Phonon Energy to Current Energy; to analyze the physics of solar cell structure with numerical approaches; to model the Quantum Well in the proposed solar cell structure; to set the experimental measurement system for physical characteristics of novel solar cells; to confirm the results from the analysis of Control of Phonon Transport. The conversion of current energy from the phonon energy by controlling the phonon transport depends on the structure of the solar cell stacking system. The implementation of this study was accomplished based on the specific model, especially Quantum Well Structure. The results confirm that the performance specification of targeted solar cell structures in real-world applications.**

***Index Terms*— Current Energy, Novel Solar Cell, Phonon Energy, Phonon Transport, Photonic Devices**

I. INTRODUCTION

AS for recent solar cells in the research field, the energy conversion efficiency has been improved to approximately 45 %, while the improvement in the light–electric energy conversion efficiency is only a few percent in the past ten years. The solar system directly converts sunlight into electricity. The basic device of a solar system is the solar cell. Solar Cells could be grouped to create panels or arrays. The voltage and current observed at the terminals of a solar device may directly feed small loads such as lighting systems and motion control. More complicated applications require electronic converters to process the electricity from the PV device [1-2].

These Solar cells convert solar energy, in the form of electromagnetic radiation, into electrical energy. Sunlight is incident on the surface covered by a metallic electrode acting as an electrical contact. Between the grid lines photons are absorbed in a semiconductor which is covered by an anti-reflective coating to reduce reflection. Photons with energies larger than the energy band gap EG of the semiconductor generate electrons to the hole of the solar cell structure, resulting in free charge carriers; electrons, and holes. The charge carriers are apart from either a slope in the charge carrier density or an electric field [3-4].

Solar cells are made of different types of semiconductor materials using different manufacturing schemes. The monocrystalline and polycrystalline solar cells are the only ones found at commercial scale in current times. Silicon solar cells consist of a thin layer of bulk Silicon or a thin Silicon film connected to electrode terminals. One of the semiconductor sides of the Silicon layer is doped to create the p–n junction. A thin metallic network is embedded in the Sun-facing layer of the semiconductor solar cell [1].

The incidence of light on the solar cell produces charge carriers that originate an electric current if the cell is short-circuited [5-7]. Charges are observed when the energy of the incident photon is enough to detach the covalent electrons of the semiconductor—this process depends on the semiconductor material and on the specific wavelength of the incident light. Fundamentally, the PV process may be expressed as the absorption of solar radiation, the generation of free carriers and transport of current energy at the p–n junction structure, and the collection of such electric charges at the terminals of the solar cell device [8-9].

The increase in the number of stacking cells leads to a drastic decrease in the conversion efficiency by the small spectrum variation of the sunlight on the earth because of the current conservation through the cells. The countries in south or east Asia including Japan and Myanmar have very humid climates in a certain season, which means the variation of solar spectrum [10-13]. The paper is organized as follows. Section II presents the materials and methods. Section III mentions the Implementation of Phonon Measurement Analysis on Solar cells. Section IV expresses the Results and Discussions. Section V concludes the research study.

II. RESEARCH METHOD

There are several procedures for implementing the design of the optimal structure of novel solar cells based on the physics of semiconductor devices [14-23]. Fig. 1 illustrates the design flow for research works in this study. The important one is the Physical Properties Investigation.

III. IMPLEMENTATION OF PHONON MEASUREMENT ANALYSIS ON SOLAR CELL

A. Mathematics for Kronig-Penney Model

The one-dimensional Schrodinger Equation is

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$$-\frac{\hbar^2}{2m}\frac{d^2\psi(x)}{dx^2}+u(x)\psi(x)=\varepsilon\psi(x) \quad (1)$$

Where u(x) is the periodic potential energy and ε is the energy eigenvalue [18, 22, 23].

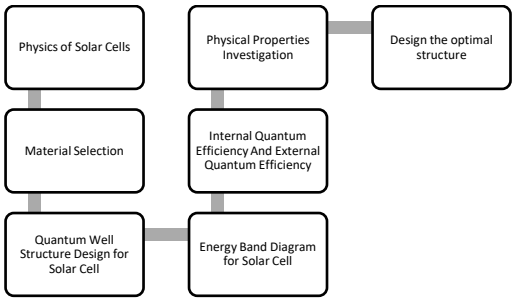


Fig. 1. Design Flow for Research Works

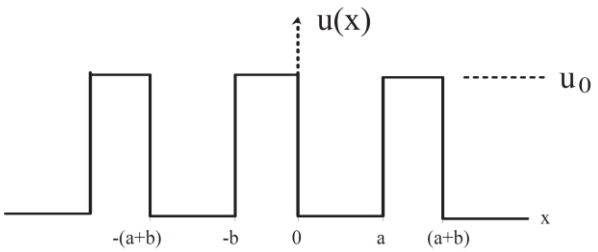


Fig. 2. Periodic Potential Energy

Fig. 2 shows the Periodic Potential Energy. In the region 0 < x < a we have that u(x) = 0 and the wavefunction is a linear combination of plane waves passing through to the right and to the left or

$$\psi_I(x)=Ae^{ikx}+Be^{-ikx} \quad (2)$$

Where the wavevector k is related to the energy as

$$k=\sqrt{2m\varepsilon/\hbar^2} \quad (3)$$

The vanishing of the determinant provides a condition for the allowed values of k which in turn are related to the allowed values of ε.

Separating the real and imaginary parts of the determinant and setting each to zero leads to the eigenvalue equation

$$\left(\frac{q^2-k^2}{2qk}\right)\sin ka\sinh qb+\cos ka\cosh qb=\cos k'(a+b) \quad (4)$$

B. *Electron in a General Periodic Potential - the Central Equation*

The Kronecker delta function property

$$a\frac{\hbar^2k'^2}{2m}C_{k'}=a\sum_G u_G C_{k'-G}=a\varepsilon C_{k'} \quad (5)$$

Dividing this by a, replacing the symbol k′ back to k, and using

$$\lambda_k\equiv\hbar^2k^2/2m \quad (6)$$

$$(\lambda_k-\varepsilon)C_k+\sum_G u_G C_{k-G}=0 \quad (7)$$

C. *Phonon Energy Calculation*

The spin-spin relaxation that arises from the interaction between different parts of the spin system is modeled by T2 [18]. If it could be combined both the effects of thermal equilibrium and torque, the set of Bloch equations shown below in vector form.

$$\frac{d\vec{M}(t)}{dt}=\underbrace{\gamma_n\left(\vec{M}(t)\times\vec{B}(t)\right)}_{\text{precision}}-\underbrace{\frac{1}{T_2}\left(M_x\hat{i}+M_y\hat{j}\right)}_{\text{spin-spin relaxation}}-\underbrace{\frac{1}{T_1}\left(M_z+M_{z0}\right)\hat{k}}_{\text{spin-lattice relaxation}} \quad (8)$$

Or, in component form

$$\frac{dM_x}{dt}=\gamma_n\left(\vec{M}\times\vec{B}_a\right)_x-\frac{M_x}{T_2}$$

$$\frac{dM_y}{dt}=\gamma_n\left(\vec{M}\times\vec{B}_a\right)_y-\frac{M_y}{T_2} \quad (9)$$

$$\frac{dM_z}{dt}=\gamma_n\left(\vec{M}\times\vec{B}_a\right)_z-\frac{M_z-M_{z0}}{T_1}$$

D. *Dependent Displacement x(t) of the Electron*

The Drude–Lorentz oscillator model [22-23] of the optical properties of an insulator is shown in Fig. 3.

$$\underbrace{m_e\frac{d^2x}{dt^2}}_{\text{acceleration}}+\underbrace{m_e\gamma\frac{dx}{dt}}_{\text{damping}}+\underbrace{m_e\omega_0^2x}_{\text{restoring force}}=-e\mathrm{E}(t) \quad (10)$$

Where m_e is the electron mass, ε is the magnitude of the electron charge, γ is the damping rate, and E(t) is the time-dependent electric field of the incident light wave.

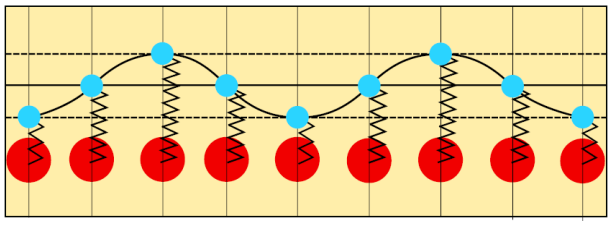


Fig. 3. Drude–Lorentz oscillator model of the optical properties of an insulator

IV. Results And Discussion

In this section, the results are interpreted, and the a complete discussion on the outcomes of the analyses. Results are illustrated in the appropriate figures.

A. *Results for Kronig-Penney Model*

The left panel shows the possible energy solutions within the allowed region; that is, within a maximum and minimum range of the RHS of the eigenvalue equation of -1, respectively (dashed line). In the plot of the LHS of the eigenvalue equation, the solid dots are the source of the energy solutions that lead to the band structure. The smooth solid line is the full plot of the LHS. The right panel shows the actual band structure associated with the Kronig-Penney model, for the shown range, for the potential parameters of u0 = 150εb = 571.5eV, a = 2Å and b = 0.025 Å.

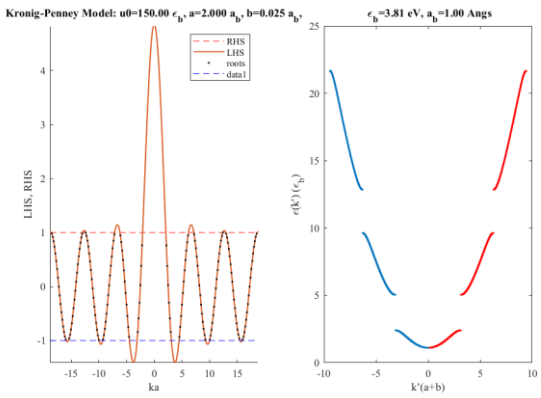


Fig. 4. Results for Kronig-Penney Model

B. *Results for Central Equation on Phonon Measurement*

The numerical results for the bands corresponding to the 2×2 system were obtained by finding the numerical eigenvalues of the Kronecker delta function Equation versus k. The energy unit is

$$\varepsilon_b = \hbar^2 / \left(2ma_b^2\right) = 3.81eV \tag{11}$$

the wavevector unit is

$$k_b = 1\text{Å}^{-1} \tag{12}$$

and the value of potential used is

$$u_g = 2\varepsilon_b \tag{13}$$

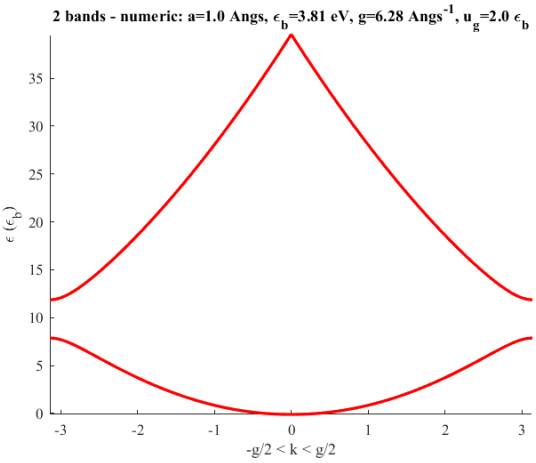


Fig. 5. Results for Central Equation on Phonon Measurement

C. *Conductivity with respect to Carrier Concentration*

A few illustrative room temperature conductivity values (circles) for metals and semiconductors versus their corresponding carrier concentration, assuming no impurities. The metals and semimetals are found above the dashed line, while semiconductors lie approximately between the dotted and the dashed lines. The region below the dotted line is presumably the insulator region. The carrier concentrations of InGaN and GaN materials are quite similar for creating the QW [16, 19-21].

D. *Phonon Energy with respect to Measurement Time (2D View)*

The phonon energy with three effects with precision, spin-spin relaxation, and spin-lattice relaxation with respect to time is evaluated by using Mx, My, and Mz parameters from the materials from QWs layers. The main measurement results come from the precision and the spin-spin relaxation for phonon energy in the solar cell layers. After a specific time, the solar cell can convert phonon energy to current energy in the solar cell.

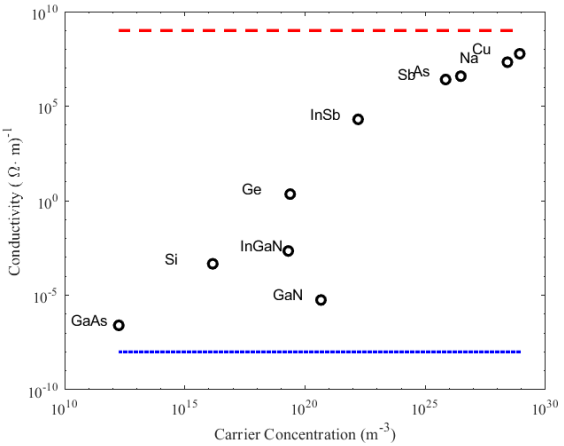


Fig. 6. Conductivity with respect to Carrier Concentration

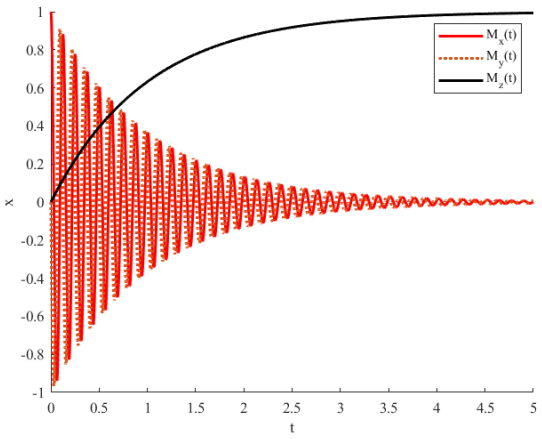


Fig. 7. Phonon Energy with respect to Measurement Time (2D View)

E. *Phonon Energy with respect to Measurement Time (Isoview)*

The isoview could easily observe the stable conversion energy from phonon to current in the center of the orbit of vibration energy or phonon energy. The specific time could be no more than 1 minute. According to the QWs structure of the 3rd Generation Solar Cell, the conversion of phonon energy to current energy could be observed with the current density in the layers.

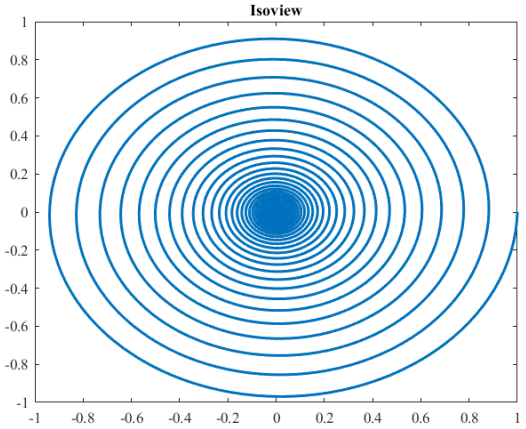


Fig. 8. Phonon Energy with respect to Measurement Time (Isoview)

F. *Frequency Dependent of the Real and Imaginary Parts of the Dielectric Constant*

The dielectric constant of the complex plane for the frequency-dependent parameters directly affected to conversion rate of the phonon energy to the current in the solar cell. The stable mode of current energy from the conversion of phonon energy could be observed in the intersection points of susceptibility or dielectric constant in the figure. The current density could be achieved from the specific region in the solar cell by controlling the phonon transport.

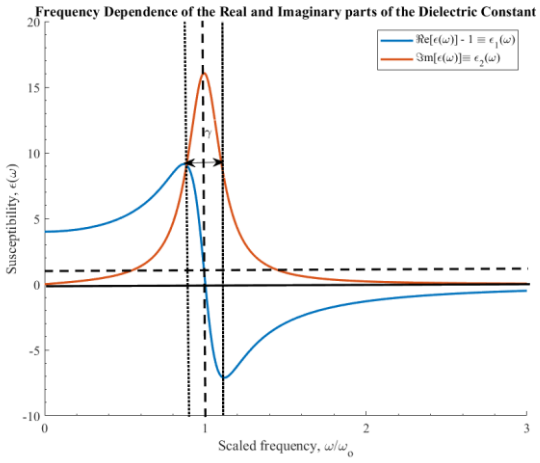


Fig. 9. Frequency Dependent of the Real and Imaginary Parts of the Dielectric Constant

G. *Analysis of Solar Cell Characteristics with Proposed Materials (Current Energy from Phonon Energy)*

V_{oc} depends on the photo-generated current density and can be calculated assuming that the net current is zero.

$$V_{OC} = \frac{k_B T}{q} \ln\left(\frac{J_{ph}}{J_0} + 1\right) \approx \frac{k_B T}{q} \ln\left(\frac{J_{ph}}{J_0}\right) \qquad (14)$$

where the approximation is justified because of $J_{ph} >> J_0$

The equation shows that V_{oc} depends upon the saturated current density of the third-generation solar cell and the photo-generated current or control of phonon transport.

The open-circuit voltage is the voltage at which zero current flows through the whole circuit. It is the maximum value of voltage that a solar cell can deliver. V_{oc} relatives to the forward bias voltage, at which the dark current density compensates the photocurrent density. Fig. 10 shows the 3rd Generation Solar Cell Characteristics with V_{oc}=764mV and J_{sc}=42mA/m^2.

While J_{ph} typically has a small variation, the key effect is the saturation current, since this may vary by orders of magnitude. The saturation current density, J_0, depends on the recombination in the solar cell. However, V_{oc} is a measured value of the amount of recombination in the device. Fig. 11 shows the 3rd Generation Solar Cell Characteristics with Voc=746mV and J_{sc}=46mA/m^2.

H. *Design the Optimal Structure*

Thin outstanding small-bandgap materials surrounded by a bigger-bandgap material are grown in the intrinsic region (i-region), which is viewed as wells on a band diagram, to create the multi-quantum well structures [17]. If the total thickness of each quantum well layer and the spacer layer between two junctions and the next is equivalent to the de Broglie wavelength of the carriers, it forms mini-band energy levels that span the entire MQW region. The thickness of N-Type and P-Type GaN must be 500µm, respectively and the thickness of QWs with two InGaN and GaN layers must be 100 µm, respectively (According to the calculated parameters with control of phonon transport).

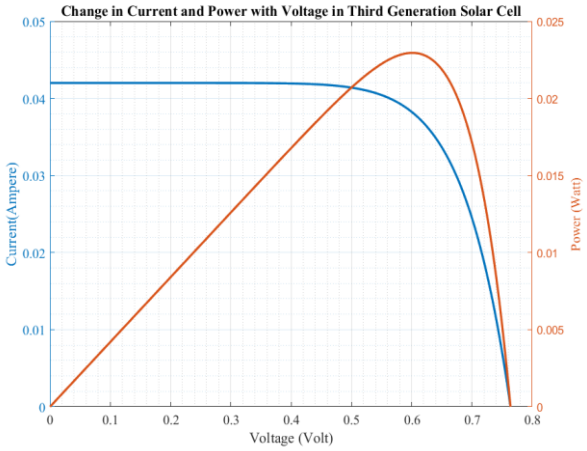


Fig. 10. Result of Analysis of Solar Cell Characteristics with Proposed Materials (Current Energy from Phonon Energy) Condition 1

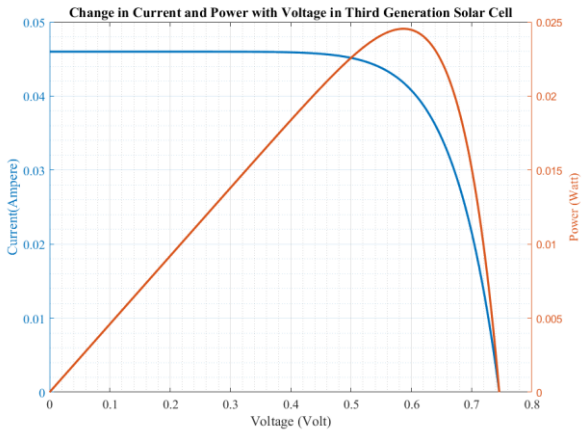


Fig. 11. Result of Analysis of Solar Cell Characteristics with Proposed Materials (Current Energy from Phonon Energy) Condition 2

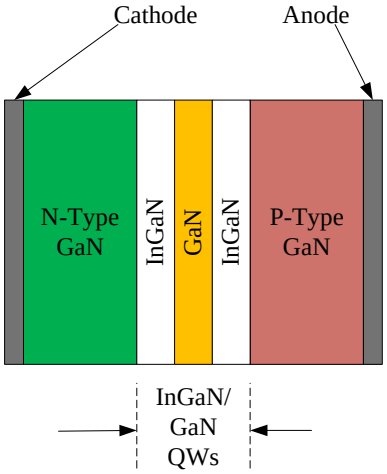


Fig. 12. Targeted Novel Solar Cell Structure

V. Conclusion

Phonon Measurement Analysis on Solar Cell could be focused on the Kronig-Penney Model, Electron in a General Periodic Potential, Crystal Properties Analysis, Conductivity concerning Carrier Concentration, Phonon Energy Calculation, and Frequency Dependent Analysis for solar cell design. Analysis of Solar Cell Characteristics with Proposed Materials (Current Energy from Phonon Energy) could be evaluated by using the characteristics parameters such as open circuit voltage and short circuit current. The optimal structure of the proposed solar cell could be observed based on the specific thickness of quantum well layers by controlling the phonon transport. According to the physics of solar cell design, the Quantum Well structure is a very efficient design for modeling the high-performance solar cell. Quantum well solar cells have been analyzed based on the various conditions to meet the high-performance results based on the physical parameters. The energy efficiency for designing quantum well solar cells could be observed based on the energy band diagram and energy band structure design for the specific measurement.

Conflicts Of Interest

The authors declare that there is no conflict of interest concerning the publication of this article.

Author Contributions

This study mainly focuses on the Development of a Novel Solar Cell Design based on Current Energy Converted from Phonon Energy by Controlling the Phonon Transport. The theoretical analyses on mathematical modeling for Semiconductor Photonic Devices play a vital role in enhancing the high performance of Semiconductor Electronics systems for future photonics technology. This work could be provided to find the solution for research problems in advanced solar cell design under the photonics system design in reality.

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