Stability Analysis of Solar Cell Characteristics Above Room Temperature Using Indium Nitride Based Quantum Dot

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ABSTRACT

This study represents the improvement of stability of solar cell characteristics above room temperature. We have analyzed theoretically the temperature dependence of three major characteristics of solar cell using Ge and InN based quantum dot in the active layer of the device structure. Among the major characteristics of solar cell we have investigated the rate of change of open circuit voltage, short circuit current and the output power of solar cell with respect to temperature. Numerical results obtained are compared. The comparison results reveal that the rate of change of open circuit voltage, short circuit current and output power have been reduced significantly using InN based quantum dot in the active layer of the solar cell. Hence the improvement in stability of these characteristics above room temperature has been achieved by using InN based quantum dot in the active layer of the solar cell.

Keywords: Quantum Dot, Solar Cell, Open Circuit Voltage, Short Circuit Current, Output Power

1. INTRODUCTION

Power crisis has become a severe problem all over the world. Different sources of energy pollute our environment in different ways and in different degrees (Mahrane *et al.*, 2010). Therefore researchers are looking for more environment friendly sources of energy. In earlier studies, (Al-Badi, 2013; Jwo *et al.*, 2013) reported that solar energy is the cleanest form of energy. The proper utilization of solar energy is the major challenge to the researchers in the era of modern science and technology particularly to protect global warming and fossil fuel depletion (Chiaro *et al.*, 2008; Jangra *et al.*, 2012).

The solar cell is used to convert the most environmental friendly energy ever discovered i.e. solar energy into the electrical energy (Hepbasli and Alsuhaibani, 2011). It has been reported that the active layer of the earlier solar cells was mainly fabricated with semiconductor elements like Si and Ge (Fan *et al.*, 2010). The active layer of the advanced solar cells is composed of binary semiconductor compounds like GaAs, InAs, GaSb and so on (Andreev *et al.*, 2009; Huang *et al.*, 2011) Recently researchers have found that InN offer substantial potential in developing high efficient devices, both because of measurements indicating that the band gap on InN is lower than other group-III nitrides materials and also due to other unique material properties, such as the strong polarization and affiliation piezoelectric effects (Hwang *et al.*, 2012; Humayun *et al.*, 2012a). Additionally in the last few years, self-organized Quantum Dots (QDs) have been used in Photovoltaic (PV) devices to increase the sub-band-gap photon absorption and the energy conversion efficiency (Guimard *et al.*, 2009). InN based quantum dot is considered as the best alternative active layer material for the enhancement of the stability of the device characteristics.

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2. MATERIALS AND METHODS

The temperature plays an important role on the open circuit voltage, short circuit current and the power output of the solar cell. The rate of change of these characteristics has been analyzed theoretically in this present research work.

Rosli *et al.* (2013) reported that the open circuit voltage of solar cell is related to the bandgap energy of the active layer semiconductor material of the solar cell by the following equation:

$$V_{oc}(T) = \frac{E_g(T)}{q} - V_{ocdeficit} \tag{1}$$

where, $E_g(T)$ is the bandgap energy of the active layer semiconductor material of the solar cell at any temperature T, q is the charge of electron and $V_{ocdeficit}$ is the open circuit voltage deficit.

Again the effect of temperature on the bandgap energy of semiconductor is described by Varshni's equation (Humayun *et al.*, 2012b), which is written as:

$$E_g(T) = E_g(0) - \frac{\gamma T^2}{T + \beta} \tag{2}$$

where, $E_g(0)$ is the energy band gap at T = 0 K. In this present research work we have used InN and Ge based quantum dot in the active layer of the solar cell structure. The band gap and other parameters of InN and those of Ge are given in **Table 1 and 2** (Zeghbroeck, 2007; Humayun *et al.*, 2012a).

To investigate the effect of temperature on the fluctuation of open circuit voltage we used Equation (1) and (2). We have put the value of $E_g(T)$ from Equation (2) into Equation (1) then taking the first derivative on the both side of the obtained Equation with respect to temperature we get:

$$\frac{dV_{oc}(T)}{dT} = -\frac{\gamma}{q} \frac{T(T + 2\beta)}{(T + \beta)^2} \tag{3}$$

Here the (-ve) sign indicates that the open circuit voltage of the solar cell decreases with the increase in temperature or vice versa. Now considering only the magnitude of the rate of change of band gap energy with respect to temperature we have:

$$\left| \frac{dV_{oc}(T)}{dT} \right| = \frac{\gamma}{q} \frac{T(T + 2\beta)}{(T + \beta)^2} \tag{4}$$

Table 1. Parameters used for Ge and InN

Material	Ge	InN
Eg(0)(eV)	0.7437	0.700
γ(meV/K)	0.477	0.414
β(K)	235.000	545.000

Table 2. Values of parameters used in this research work

Symbol s	Parameter s	Value
q	Charge of electron	1.6×10^{-19} C
K	Boltzmann's Constant	1.38×10^{-23} J/K

The short circuit current of solar cell is given by the following Equation (Zeghbroeck, 2007):

$$I_{SC} = I_S e^{\left(\frac{qV_{OC}}{KT} - 1 \right)} \tag{5}$$

In order to investigate the rate of change of short circuit current with respect to temperature we need to differentiate on the both side of Equation (5) with respect to temperature. By taking first derivative on the both side of the Equation 5 we get:

$$\frac{dI_{SC}(T)}{dT} = -\frac{q}{KT^2} \frac{dV_{OC}(T)}{dT} I_S e^{\left(\frac{V_{OC}q}{KT} - 1 \right)} \tag{6}$$

Then putting the value of $\frac{dV_{oc}(T)}{dT}$ from Equation (3) we get:

$$\frac{dI_{SC}(T)}{dT} = \frac{\gamma}{KT} \frac{(T + 2\beta)}{(T + \beta)^2} I_S e^{\left(\frac{qV_{OC}q}{KT} - 1 \right)} \tag{7}$$

The output power of solar cell is given by the following equation:

$$P_{out} = V_{oc} I_{SC} \tag{8}$$

Now to investigate the rate of change of output power of the solar cell with respect to temperature we need to differentiate on the both side of Equation (8) we obtain:

$$\frac{dP_{out}(T)}{dT} = V_{oc}(T) \frac{dI_{SC}(T)}{dT} + I_{SC}(T) \frac{dV_{OC}(T)}{dT} \tag{9}$$

Now using Equation 1-6 and putting the values in Equation (9) we get Equation 10:

$$\frac{dP_{OUT}(T)}{dT} = \frac{\gamma}{KT} \frac{(T+2\beta)}{(T+\beta)^2} I_s \left(\frac{E_g}{e} - V_{OCdeficit} \right) e^{\left(\frac{V_{OC}q}{KT} - 1 \right)}$$

$$+ I_s \frac{\gamma}{q} \frac{T(T+2\beta)}{(T+\beta)^2} e^{\left(\frac{V_{OC}q}{KT} - 1 \right)} \qquad (10)$$

3. RESULTS

This section presents the comparative analysis of the effect of temperature on the rate of change of the major characteristics of solar cell using Ge and InN based quantum dot in the active layer of the solar cell. The fluctuation of open circuit voltage of solar cell with respect to temperature has been analyzed by using Equation (4). This characteristic has been presented in **Fig. 1**. Then we have analyzed the variation of short circuit current and output power using Equation (6) and (10). These characteristics are shown in **Fig. 2 and 3**, respectively. Different parameters used in the numerical calculation is given in **Table 1 and 2**.

Figure 1 presents the fluctuation of the open circuit voltage of solar cell with respect to temperature. The

solid line and the dashed line represents the rate of change of open circuit voltage of solar cell using InN and Ge based quantum dot in the active layer of the solar cell respectively. The rate of change of open circuit voltage of solar cell increases with the increase of temperature both for using Ge and InN based quantum dot in the active layer of the solar cell. However, from the numerical result it is ascertained that the rate of change of open circuit voltage of solar cell has been reduced significantly by using InN based quantum dot in the active layer of the solar cell.

Figure 2 is plotted using Equation (1), (2) and (7). It shows the variation of the short circuit current of solar cell with respect to temperature. The solid line and the dashed line represents the rate of change of short circuit current of solar cell using InN and Ge based quantum dot in the active layer of the solar cell respectively. The rate of change of short circuit current of solar cell decreases exponetially with the increase of temperature both for applying Ge and InN based quantum dot as the active layer material of the solar cell as shown in figure.
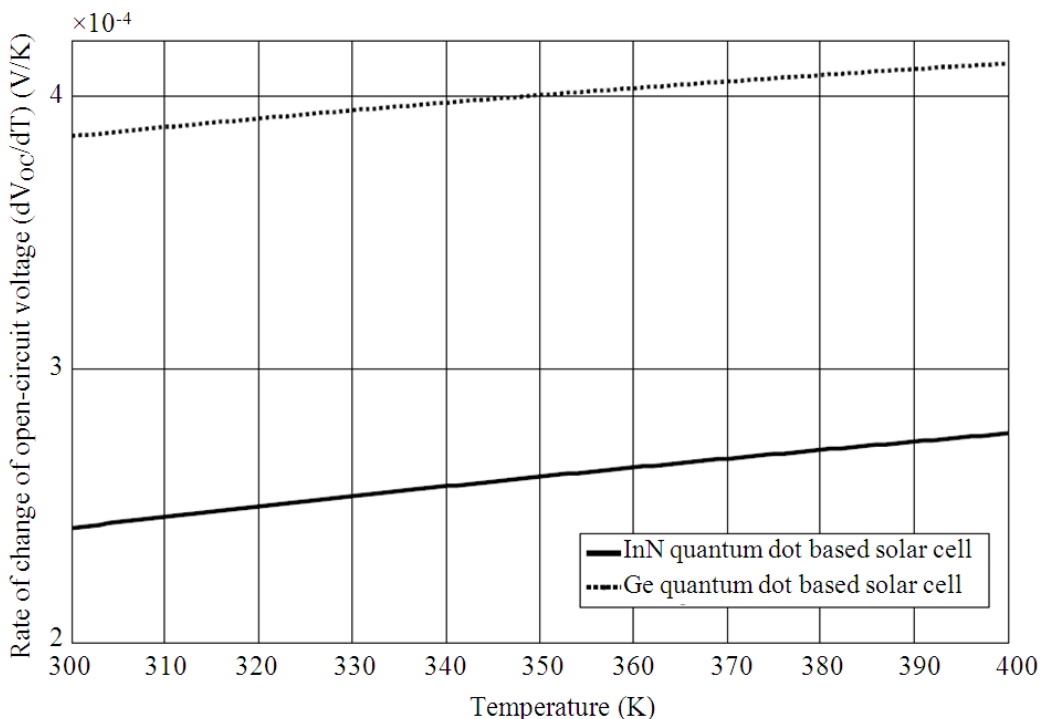

Fig. 1. Fluctuation of open circuit voltage of solar cell with respect to temperature. The solid line and the dashed line represents the open circuit voltage fluctuation using InN and Ge based quantum dot in the active layer of the solar cell structure respectively
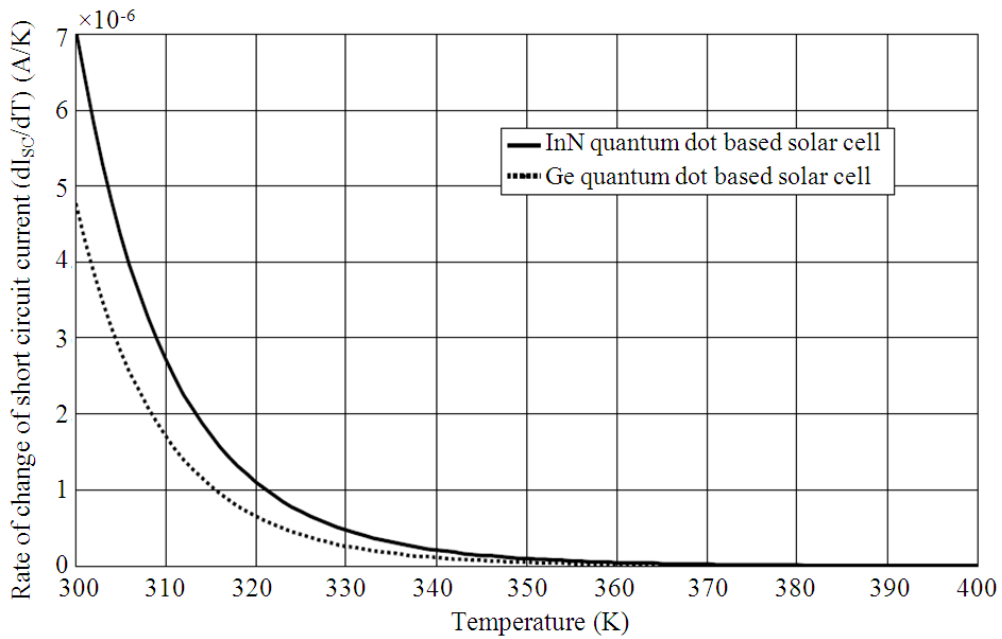
Fig. 2. Variation of short circuit current of solar cell with respect to temperature. The solid line and the dashed line represents the short circuit current variation using InN and Ge based quantum dot in the active layer of the solar cell respectively
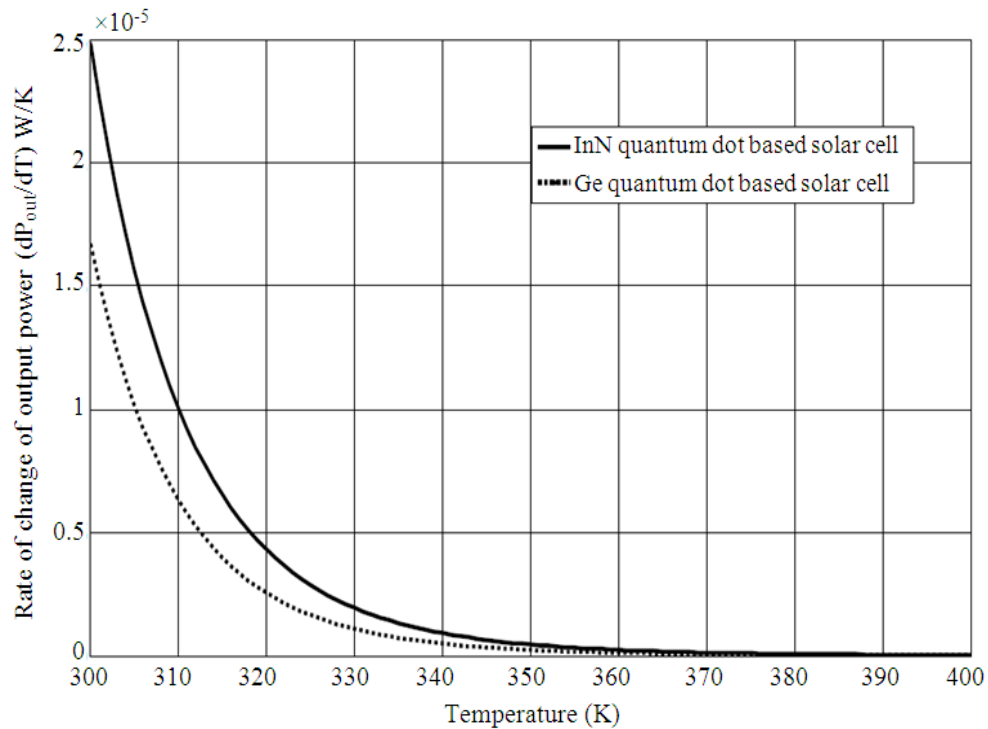

Fig. 3. Rate of change of output power of solar cell with respect to temperature. The solid line and the dashed line represents the output power fluctuation using InN and Ge based quantum dot in the active layer of the solar cell respectively

However graph presented in **Figure 2** clearly shows that the rate of change of short circuit current using InN based quantum dot is less than that obtained using Ge based quantum dot in the active layer of the solar cell structure at high temperature.

Figure 3 shows the rate of change of the output power of solar cell with respect to temperature. The solid line and the dashed line represents the rate of change of output power of solar cell using InN and Ge based quantum dot in the active layer of the solar cell respectively. The rate of change of output power of solar cell decreases nonlinearly with the increase of temperature both for Ge and InN based quantum dot based solar cell as shown in figure. However from the comparative result shown in **Fig. 3** it is revealed that the rate of change of output power has been reduced notably using InN based quantum dot in the active layer of the solar cell structure high temperature.

Finally from the above discussion it is ascertained that InN based quantum dot provides the higher stability of the solar cell characteristics at high temperature.

4. DUSCUSSION

Previous stuides show that the performance improvement of optoelectronic devices can be achieved by using quantum dot as the active layer material (Humayun *et al.*, 2013). The authors were motivated to invetigate the performance improvement of solar cell characteristics applying quantum dot. In this work, we have analyzed the rate of change of open circuit voltage, short circuit current and power output of solar cell with respect to temperature using Ge and InN based quantum dot in the active layer of the solar cell. It has been proved theoritically that InN based quantum dot improves the stability of the major characteristics of solar cell. The theoritical findings of this research work can be a doorway for the researchers to facilate the InN quantum dot based solar cell in real life after the experimental validation.

5. CONCLUSION

This study highlights the improvement of the stability of the major three characteristics of quantum dot based solar cell above room temperature. We have studied extensively the rate of change of all these characteristics of solar cell with respect to temperature using Ge and InN based quantum dot in the active layer of the solar cell structure. The comparison of the numerical results ascertain that the rate of change of

open circuit voltage, short circuit current and the output power have been reduced appreciably above room temperature by using InN based quantum dot in the active layer of the solar cell structure. Therefore it is ascertained that InN based quantum dot will be a suitable material for the improvement of solar cell characteristics above room temperature.

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