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Simulation of temperature characteristics of InGaP/InGaAs/Ge triple-junction solar cell under concentrated light

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1. Introduction

Multi-junction solar cells consisting of InGaP, InGaAs, and Ge are knows as super-high-efficiency cells and are now used for space applications. Multi-junction cells lattice-matched to Ge substrates have been improved.

Light concentration is one of the important issues for the development of an advanced photovoltaic (PV) system using high-efficiency solar cells. High-efficiency multi-junction cells under high concentration have been investigated for terrestrial application [1, 2].

It is considered that the temperature of solar cells considerably increases under light concentrating operation. The conversion efficiency of solar cells decreases with increasing temperature [3, 4]. Therefore, a technique for estimation of temperature characteristics of InGaP/InGaAs/Ge triple-junction solar cells under concentrated light is necessary for the development of high-efficiency concentrator photovoltaic systems.

In this paper, temperature characteristics of the triple-junction solar cell under concentrated light conditions were calculated using temperature analysis function of the simulation program with integrated circuit emphasis (SPICE).

2. Experimental

In the SPICE diode model, DC forward current is determined by

$$I_{(forward)} = K_{inj} I_s \left\{ \exp\left(\frac{qV}{nkT}\right) - 1 \right\} + K_{gen} I_{sr} \left\{ \exp\left(\frac{qV}{n_r kT}\right) - 1 \right\} \quad (1)$$

where K_{inj}, K_{gen}, I_s, I_{sr}, n, and n_r are the high-injection factor, generation factor, saturation current, recombination current parameter, emission coefficient and emission coefficient for recombination current, respectively. The temperature dependence on I_s and I_{sr} are determined by

$$I_s(T) = I_s(T_{nom}) \left(\frac{T}{T_{nom}}\right)^{\frac{X_{ti}}{n}} \exp\left[-\frac{qE_g}{nkT}\left(1 - \frac{T}{T_{nom}}\right)\right] \quad (2)$$

$$I_{sr}(T) = I_{sr}(T_{nom}) \left(\frac{T}{T_{nom}}\right)^{\frac{X_{ti}}{n_r}} \exp\left[-\frac{qE_g}{n_r kT}\left(1 - \frac{T}{T_{nom}}\right)\right] \quad (3)$$

where T_{nom}, $I_s(T_{nom})$, $I_{sr}(T_{nom})$ and X_{ti} are room temperature, saturation current at T_{nom}, recombination current at T_{nom} and temperature exponent, respectively. If we know the diode parameters (I_s, I_{sr}, n and n_r) and X_{ti}, we can calculate the temperature characteristics of solar cells.

From dark *I-V* characteristics of each single-junction solar cell (InGaP, InGaAs, Ge solar cells), the fitting of *I-V* curve and extracting of diode parameters were carried out using the conventional equivalent circuit model for single-junction solar cell. X_{ti} of each solar cell was derived from the temperature dependence on band gap. The extracted parameters of each single-junction solar cell were used in an equivalent circuit model for the InGaP/InGaAs/Ge triple-junction solar cell, and calculations were carried out. Figure 1 shows the equivalent circuit model for triple-junction solar cell. The top, middle, and bottom are InGaP, InGaAs, and Ge solar cells, respectively. R_{SEL}, R_T and R_{sh} are resistance due to the electrodes and lateral resistance between electrodes, resistance due to the tunnel junction, and shunt resistance, respectively [5]. I_p is the photo-current from each sub cell.

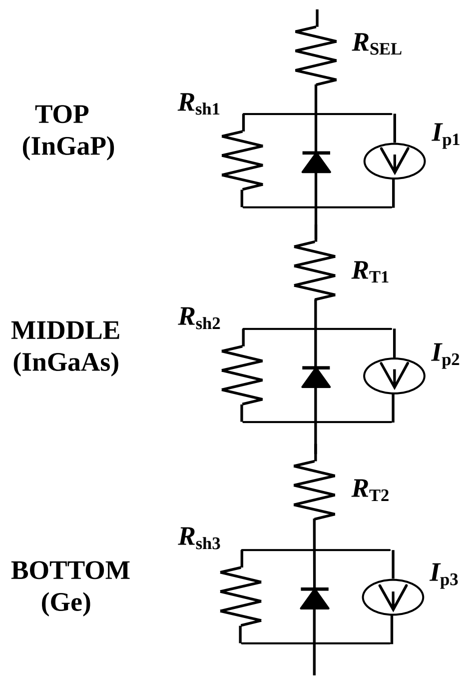

Fig.1. Equivalent circuit model for triple-junction solar cell.

3. Results and Discussion

Extracted diode parameters and X_{ti} were used in the equivalent circuit for triple-junction solar cell, and *I-V* characteristics at various temperatures under concentrated light were calculated. Figure 2 shows measured and calculated *I-V* characteristics of the triple-junction solar cell at 30°C and 100°C under 1sun and 14suns. The calculated and measured *I-V* characteristics agreed well.

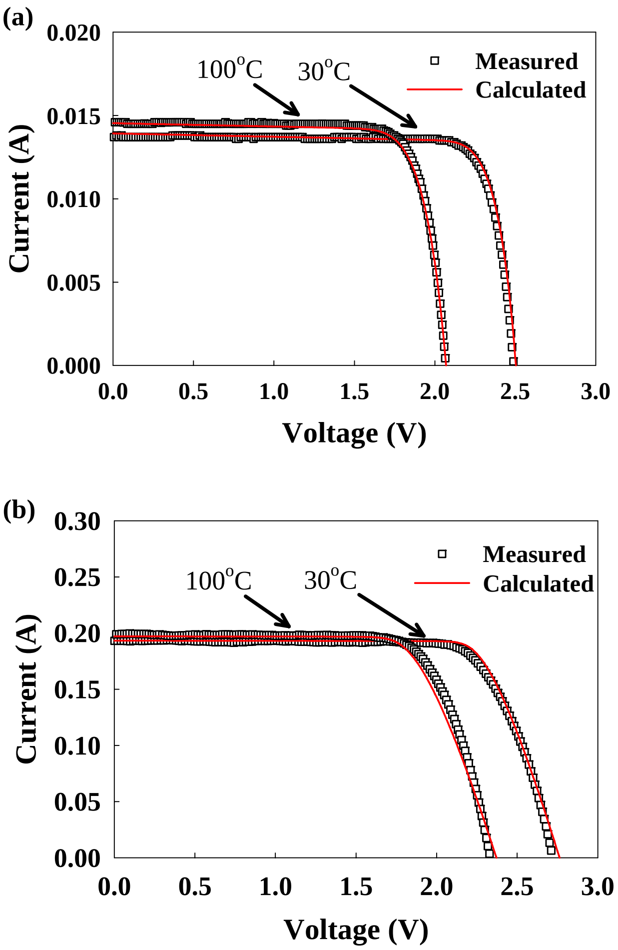

Fig.2. Measured and calculated *I-V* characteristics of triple-junction solar cell at 30°C and 100 °C under (a) 1sun and (b) 14suns.

Figure 3 shows the temperature dependence of V_{oc} for triple-junction solar cells under 1sun and 14suns. V_{oc} decreased with increasing temperature, and the measured and calculated values agreed well for all temperatures.

4. Summary

Temperature characteristics of triple-junction solar cell were estimated using equivalent circuit calculation. By extracting parameters exactly, we can accurately calculate the temperature characteristics of triple-junction solar cells under concentrated light. It is considered that this technique can be applied to output estimation and optimal design of high-efficiency concentrator photovoltaic systems.

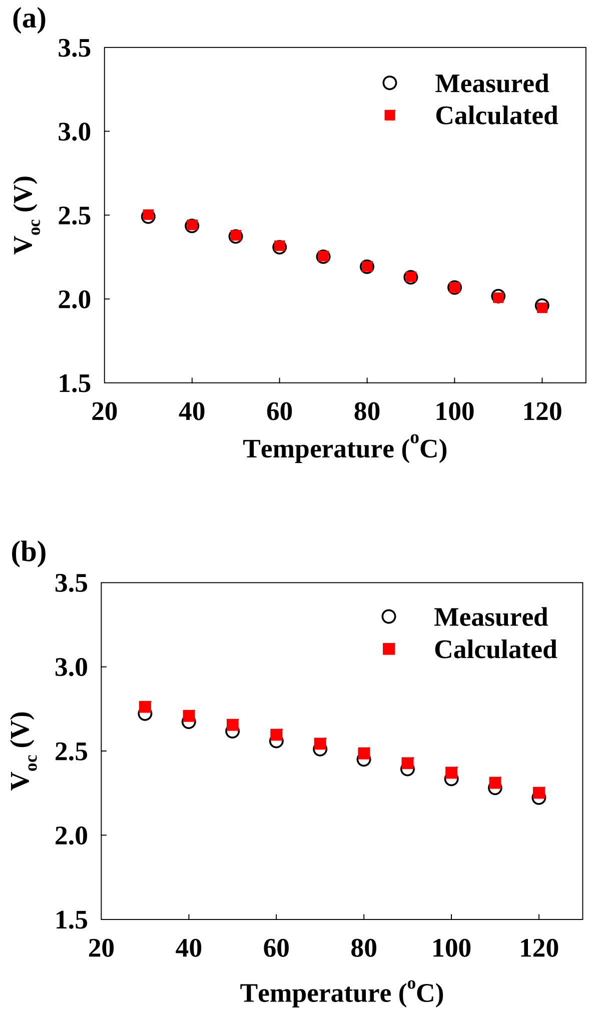

Fig.3. Temperature characteristics of V_{oc} for InGaP/InGaAs/Ge triple-junction solar cell: (a) 1sun and (b) 14suns.

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