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Measurement of silicon and GaAs/Ge solar cell device parameters

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Abstract

The device parameters (carrier lifetime, ideality factor), and physical parameters (built-in voltage, doping concentration) of silicon (Si) and gallium arsenide (GaAs/Ge) solar cells are measured at different temperatures using time domain technique. Carrier lifetime is calculated from open circuit voltage decay (OCVD). Built-in voltage and doping concentration are derived from the cell capacitance measured at different bias voltages. Ideality factor is derived from the *I–V* characteristics of solar cell. Carrier lifetime increases while built-in voltage decreases with increase in temperature. Ideality factor of the solar cell decreases with temperature.

Keywords: Si and GaAs/Ge solar cells; Device parameters; Temperature

1. Introduction

The device parameters like carrier lifetime and ideality factor give the qualitative estimation of the efficiency of the solar cell. In terrestrial applications, the solar cell is exposed to temperatures varying from 10 to 50 °C. Hence, it is important to study the effect of temperature on the device parameters. A detailed experimental investigation is conducted on silicon (Si) and gallium arsenide (GaAs/Ge) solar cells and the

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obtained results are presented in this paper. Mahan et al. [1] measured the carrier lifetime of the solar cell from photo-induced open circuit voltage decay method using a flash from stroboscope. Lederhandler et al. [2] measured the carrier lifetime of germanium diodes using forward current-induced voltage decay. In the present paper, the minority carrier lifetime (τ) and built-in voltage (V_{bin}) are derived from open circuit voltage decay (OCVD) by inducing the current equal to short circuit current into the solar cell. The other parameters like diffusion length and surface recombination velocity can be determined from minority carrier lifetime with the knowledge of device constants such as diffusion coefficient and cell thickness. The ideality factor (η) is measured using I–V characteristics of solar cell.

2. Experimentation

The set-up [3] for the measurement of the voltage decay consists of constant current source, electronic switch and reverse blocking diode. The short circuit current (I_{SC}) and open circuit voltage (V_{OC}) for Si solar cell are 74.05 mA and 0.5 V, respectively. For GaAs/Ge solar cell, the values are $I_{SC} = 255.3$ mA and $V_{OC} = 1.02$ V. The following procedure is followed for the measurement of voltage decay under dark condition:

i. Constant current source is set to pass the current equal to short circuit current, I_{SC} of the solar cell with the help of a potentiometer.
ii. Open circuit voltage (V_{OC}) is built up across solar cell from the input current.
iii. Square wave input is applied to the gate of MOSFET.
iv. Voltage decay is observed and acquired with the help of the digital storage oscilloscope (Tektronix TDS 3014B).
v. The observed waveform is transferred to the computer through a serial communication port (RS 232).
vi. Acquired data is processed with the Savitzky–Golay algorithm.

The OCVD of Si solar cell measured under dark at 25 °C is shown in Fig. 1. OCVD of Si solar cell is also measured at different temperatures viz., 15, 40, 50 and 60 °C. The solar cell is covered with a black mask during I–V characteristics measurement so that the cell is not exposed to stray light present in the ambience. Input voltage is applied to the solar cell from a DC voltage source (0–30 V DC). It is varied from 0 V to its open circuit voltage (V_{OC}). The current through the solar cell is measured for every 0.01 V step change in the input voltage or bias voltage. The voltage and current are measured with the voltmeter and ammeter (Kiethely 196 system DMM), respectively. Fig. 2 shows the typical I–V characteristics of Si solar cell in dark at 25 °C.

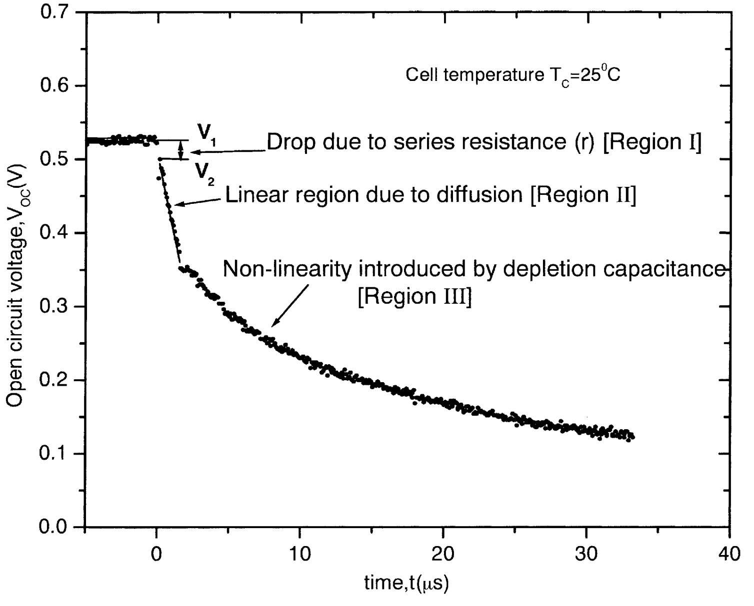

Fig. 1. Open circuit voltage decay of Si solar cell.

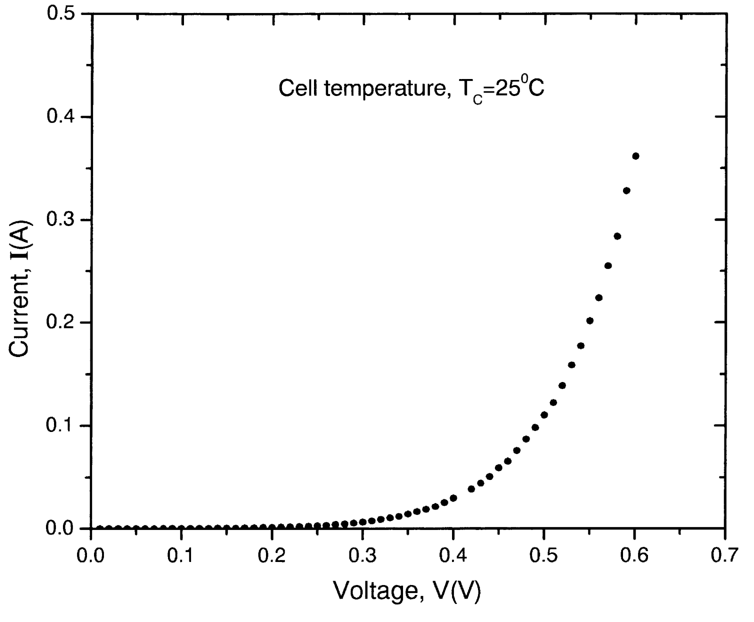

Fig. 2. *I–V* characteristic of silicon solar cell.

3. Results and discussion

Carrier lifetime of the solar cell is calculated from the linear region (Fig. 1) of the OCVD using the following equation [4]:

$$\tau = \frac{\eta kT}{q}\frac{1}{\mathrm{d}V_{\mathrm{OC}}/\mathrm{d}t} = \frac{\eta V_{\mathrm{T}}}{\mathrm{d}V_{\mathrm{OC}}/\mathrm{d}t}, \tag{1}$$

where η is the ideality factor, k is Boltzman's constant, $8.617 \times 10^{-5}\,\mathrm{eV/K}$. T is absolute temperature in K, q is charge of electron, $1e = 1.602 \times 10^{-19}\,\mathrm{C}$, $V_{\mathrm{T}} = kT/q$ is the thermal voltage, V, and $\mathrm{d}V_{\mathrm{OC}}/\mathrm{d}t$ is the rate of linear voltage decay in V/s calculated from voltage decay.

The values of carrier lifetime of Si and GaAs/Ge solar cells calculated at various temperatures are plotted in Fig. 3. It shows that carrier lifetime increases with increase in temperature. Carrier lifetimes of Si as well as GaAs/Ge solar cells have shown low values [5] indicating higher surface recombination and they are found to increase with temperature. This is because the carrier lifetime varies inversely to the effective area of the trap and the effective area decreases with increase in temperature. Therefore, the surface recombination of solar cell decreases with increase in temperature. The ideality factor of the solar cell is calculated from the solar cell I–V characteristics at different temperatures using the

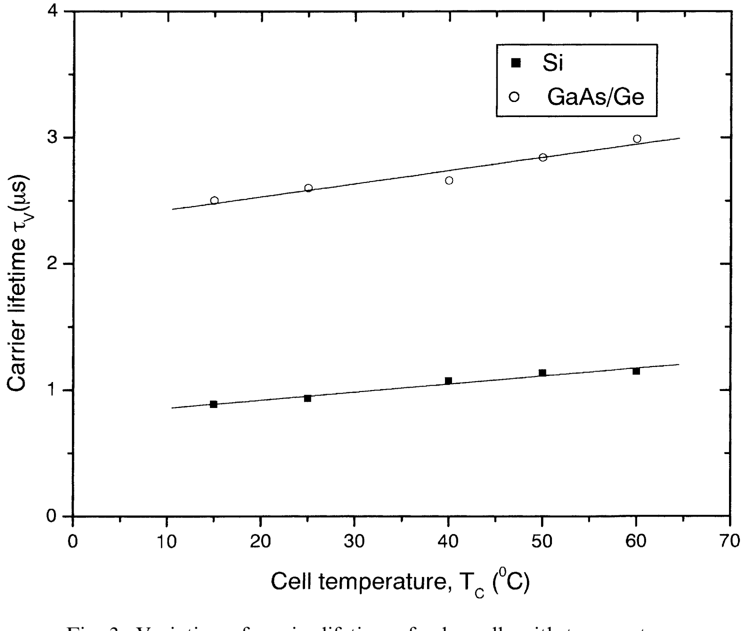

Fig. 3. Variation of carrier lifetime of solar cells with temperature.

following equation [6]:

$$\eta = \frac{1}{mV_T}, \tag{2}$$

where m is the slope of the $\ln I$ vs. bias voltage, and V_T is the thermal voltage.

The variation of ideality factor with temperature, at voltages near V_{OC}, for Si and GaAs/Ge solar cell is shown in Fig. 4. It shows that the ideality factor decreases with increase in temperature. The high value of ideality factor signifies high surface recombination, whereas the decrease in ideality factor confirms that the surface recombination decreases with increase in temperature. The decrease in the value of ideality factor with increase in temperature in case of GaAs/Ge solar cell is large when compared with Si solar cell. The built-in voltage of solar cell is calculated from the $1/C_P^2$ vs. bias voltage graph at different cell temperatures by comparing the slope and intercept of $1/C_P^2$ vs. bias voltage with the following equation [6]:

$$\frac{1}{C_T^2} = \frac{2}{A^2}\frac{V_{bin}}{e\varepsilon_0\varepsilon_r N} - \frac{2}{A^2}\frac{V_d}{e\varepsilon_0\varepsilon_r N}. \tag{3}$$

The variation of the built-in voltage of Si and GaAs/Ge solar cell is shown in Fig. 5. It shows that the built-in voltage decreases with temperature. This signifies the decrease in the band-gap energy of the solar cell due to thermal energy provided by the increase in temperature. The value of built-in voltage of GaAs/Ge solar cell at 15 °C is more than the open circuit voltage at room temperature as energy required for carriers to overcome the band gap of solar cell is more, whereas in case of Si solar cell the built-in voltage is marginally less than its open circuit voltage due to the surface recombination.

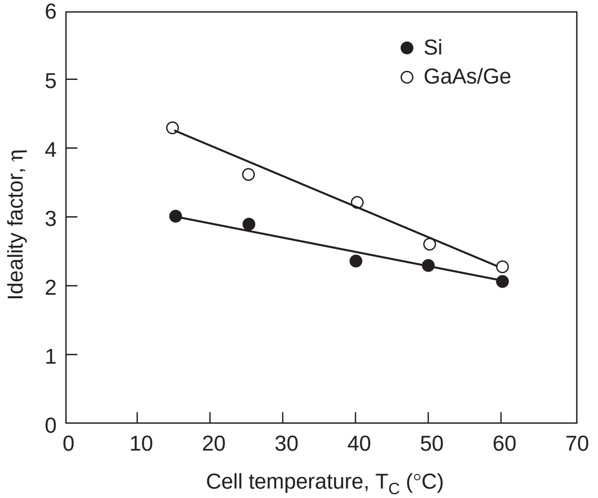

Fig. 4. Variation of ideality factor of solar cell with temperature.

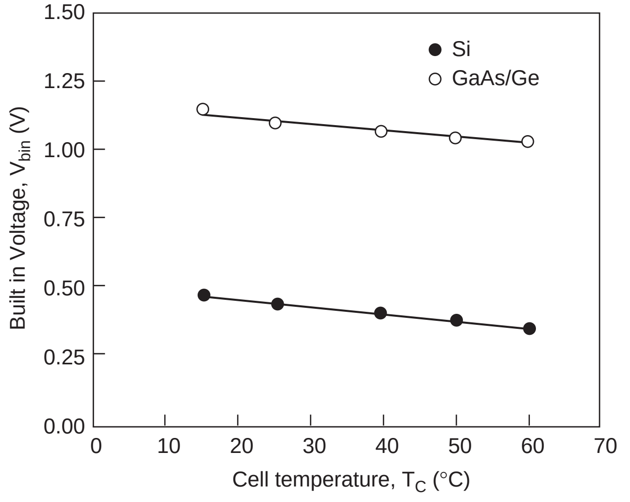

Fig. 5. Variation of built-in voltage of solar cell with temperature.

4. Concluding remarks

Carrier lifetime of Si and GaAs/Ge solar cell decreases with increase in temperature. The ideality factor decreases with increase in temperature. The built-in voltages of both Si and GaAs/Ge solar cells decrease with increase in temperature.

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