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A new method to determine the diode ideality factor of real solar cell using Lambert W-function

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Abstract

A new method using Lambert W-function is presented to determine the diode ideality factor of real solar cell.

Keywords: Ideality factor; Lambert W-function; Solar cell

1. Introduction

The diode ideality factor has been introduced for a p–n junction solar cell after consideration of the physical phenomenon that occurs in diode. Several theories have been published to account for the introduction of ideality factor. Sah et al. [1] analyses generation/recombination in space charge layer to predict $n \leqslant 2$. Shockley [2] diffusion theory based on minority carrier diffusion predicted, n should equal to 1. Considering the traps situated in localized region of depletion layer, Faulkner and Buckingham [3] proposed a theory giving values of n between 1 and 2, that was further verified experimentally by Naursabum [4]. As the density of recombination is increased, Ashburn et al. [5] showed an increase of n from 1 to 2. n equal to 2 is

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predicted by Hall [6] at high injection levels whereas it is close to unity at low injection levels and is likely due to recombination. Values of n greater than 2 have been observed owing to various phenomenon including shunt resistance effects [7], or non-uniformities in distribution of recombination centres [8]. Hall [9] also predicted n less than 1 in a junction under high-level injection conditions with saturation current determined by Auger recombination. Nakumara et al. [10] have found that redistribution of heavy metal impurities (gettering) can take place during device processing with strong increases of impurity densities near the surface; this would tend to increase measured recombination currents and measure values of n above values predicted by theory. Sah has postulated that high n values can arise in planar p–n junction devices due to surface channels caused by surface states. In solar cells these channels would live along the device edges and extend into base.

According to Shockley the value $n = 1$ is associated with next to an ideal junction. An increase of n leads to degradation of cell efficiency. Several techniques are available in the literature to determine the value of ideality factor. Some of them include: (a) determination through graphical techniques: a plot of (I_{ph}-I) versus V results in straight line with slope $\varepsilon/\,(nkT)$ that gives value of n. ln I_o is corresponding intercept on current axis. (This method is referred as the direct measurement method, DMM) [11]; (b) determination through the use of numerical analysis (referred to as the normal parameter coordinate method (NPCM) [12–13] and (c) direct method to measure n from illuminated output J–V curve [14].

In this paper a method is described to determine value of ideality factor of solar cell from I–n plot using Lambert W-function. An explicit relation between n and I is determined at $V = V_{oc}$ for plot.

2. Theory

The current–voltage relation for a solar cell modified by the diode ideality factor is given by

$$i = -\frac{V + iR_s}{R_{sh}} - \mathrm{I_o}\left(\mathrm{e}^{\frac{(V+iR_s}{nV_{th}}} - 1\right) + I_{ph}, \tag{1}$$

where n is the diode ideality factor, V_{th} is thermal voltage.

Solution of equation, which is transcendental in nature using Lambert W-function, is as follows [15]:

$$i = -\frac{V}{R_s + R_{sh}} - \frac{\text{Lambert } W\left[\dfrac{R_s I_o R_{sh}\mathrm{e}^{\left[(R_{sh}(V+R_s+I_o+R_s+I_{ph}\big/ nV_{th}(R_s+R_{sh})\right]}}{nV_{th}(R_s+R_{sh})}\right] nV_{th}}{R_s} + \frac{R_{sh}(I_o + I_{ph})}{R_s + R_{sh}}. \tag{2}$$