PERGAMON

Solid-State Electronics 45 (2001) 2017–2021

SOLID-STATE ELECTRONICS

Comparative study of metal–semiconductor contact degradation by current pulses on silicon solar cells with two contact types

I. Perez-Quintana [a], A. Martel [a,b], L. Hernández [a,*,1]

[a] *Facultad de Física, Universidad de La Habana, Colina Universitaria, 10400 La Habana, Cuba*
[b] *CICATA-IPN Unidad Altamira, Km 14.5 Carretera Tampico-Puerto Industrial 89600 Altamira, Mexico*

Received 17 March 2001; received in revised form 21 April 2001; accepted 14 May 2001

Abstract

This work accomplishes a comparative study of metal–semiconductor contact degradation on two different types of silicon solar cells contacts. One of them was a thermally vacuum-evaporated Ti/Pd/Ag contact, and the other one was a screen-printed contact. An experimental and theoretical methodology was applied in order to study the degradation due to periodic hot/cool switching and knowledge about all fundamental parameters from *I–V* characteristics of both types of solar cells was obtained. The periodic hot/cool process was carried out by current pulses and the double exponential model of *I–V* characteristic was used to acquire all fundamental parameters of the solar cells. We found that all fundamental parameters of both types of cells were degraded with the application of current pulses in the time studied, but in any case, the screen-printed contacts were degraded more smoothly than the thermally vacuum-evaporated front contacts of Ti/Pd/Ag. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: *I–V* solar cells characteristics; Metal–semiconductor contact

1. Introduction

Contact resistance losses occur at the interface between the silicon solar cell and the metal contact, and it is one of the most important parameters in the solar cell performance. Contact resistance has also a significant effect on the current–voltage characteristic (*I–V*) since it modifies the series resistance values. The main impact of series resistance increase is to reduce the fill factor (FF), although excessively high values may also reduce the short-circuit current. The *I–V* characteristic is the most important theoretical and experimental technique to research any solar cell independently of its interface, of utilized materials on fabrication, of technological design, of illumination levels and so on. The theoretical models that describe the experimental current–voltage curve are of particular interest on the research of these devices, because from the experimental measurements it is possible to obtain immediate information about the essential parameters, which characterize the solar cell performance. The other physical parameters can also be obtained from measured *I–V* characteristic, but it is necessary to use extraction mathematic algorithms.

Several models have been developed to describe experimentally the current–voltage characteristic in solar cells. A complete physic-mathematical approach to the *I–V* characteristic can be represented by the two-diode model where the diffusion current and the recombination current are represented by two diodes with different exponential behavior and become more closely related to the physical phenomena. This model was proposed by Wolf [1] to silicon solar cells working under low illumination conditions, and the relation *I–V* is expressed, by the implicit equation

* Corresponding author.
E-mail address: luisman@ff.oc.uh.cu (L. Hernández).
[1] Also at Departamento de Física. CINVESTAV. A.P. 14740 Mexico, D.F. Mexico.

PII: S0038-1101(01)00203-9

$$I(V) = I_L - I_d\left[\exp\frac{q(V+IR_s)}{n_d kT} - 1\right] - I_r\left[\exp\frac{q(V+IR_s)}{n_r kT} - 1\right] - \frac{V+IR_s}{R_{sh}} \quad (1)$$

In this equation, I_L is the photo-current, I_d exponential term is the Shockley diffusion current which includes the electronic conduction phenomena in the quasi-neutral region of the junction and the I_r exponential term corresponds to the carrier recombination trough deep levels in the space–charge region of the junction and in the device surface. In addition, the model includes the series and shunt resistance, R_s and R_{sh} respectively, and other classical diffusion and recombination diode ideality factors, n_d and n_r respectively.

It has been demonstrated that the values of the solar cell parameters calculated by double-exponential models agree well with the measured ones [2–4]. Alternative analytical expressions for the *I–V* characteristic have been reported [5,6]. In all cases, the accuracy of the expressions has been examined as a function of the voltage drop through each cell constituent, the electrical and geometrical parameters, the concentration factor of light, and so on.

A recent report [7] describes the use of two new techniques for obtaining photovoltaic solar cells parameters by fits to *I–V* characteristics. The first one, which consists of the simultaneous fitting of more than one *I–V* characteristic of the same or different type, allows more reliable parameters to be obtained than those secured by means of a single fit of a single characteristic. The second technique consists of making a series of single or simultaneous fits to different *I–V* characteristics, transferring the parameters resulting from one fit to the next one to be used as the starting or reference data. This technique is valid for those cases in which a parameter diverges to a large extent from its normal values and where single or simultaneous fits are not very reliable or even fail to converge during fitting process.

In a previous work [8], we have presented a method to degrade the metal–semiconductor contacts by current pulses and searched the influence of the series and shunt resistances in different analytical models. In particular the two-exponential model was applied for its simplicity, reliability and extended use, together with the technique for the determination of series resistance, suggested by Rajkanan and Shewchun [9]. The shunt resistance was evaluated by the expression reported in Ref. [10]. The purpose of this work is to extend our reported experimental and theoretical methodology [8] to degrade the metal–semiconductor contacts in solar cells by current pulses and then to make a comparative study in two different types of silicon solar cell contacts.

2. Experimental details

Two types of contact silicon solar cells were processed:

- thermally vacuum-evaporated front contacts of Ti/Pd/Ag (cell 1 or C1);
- screen-printed front contacts of Ag paste (cell 2 or C2).

Starting from a 1.5 Ω cm resistivity p-type silicon wafer a standard 3 in. diameter n^+–p silicon solar cell was processed like C1 cell. Front radial contacts were fabricated of Ti(0.5 μm)/Pd(0.5 μm)/Ag(3 μm) thermally vacuum-evaporated and a SnO_2 layer of 80 nm thickness was deposited as antireflection coating.

The C2 cell, was also n^+–p silicon solar cell. The preparation of C2 cell involved the use of a standard 10×10 cm^2 area and 1 Ω cm resistivity p-type silicon wafer. The ohmic contacts were fabricated by screen-printed technique and the following technological steps were taken:

- deposition of silver/aluminum paste like back contact;
- deposition of silver paste like front contact;
- deposition of aluminum paste on the back contact.

This contact requires subsequent thermal annealing, for this reason after each deposition, the paste was dried at 100°C on air atmosphere and finally a thermal annealing between 700°C and 800°C was made.

To avoid the strong effects on leakage currents of environmental factors, electrical isolation of the solar cells were achieved by edge sealing with transparent polymer materials, ethyl–vinyl acetate, with high elasticity and flexibility properties. The sealed cells were mounted on fiberglass and the temperature of each cell was monitored with a cromel–alumel thermocouple placed in good thermal contact with the back surface of each one of both cells.

Current pulses were applied on the cells in forward bias. These pulses were formed applying current to the circuit for 5 min and followed by 5 min without current. During the test time, we applied an equivalent current to 10 times the short-circuit current at 100 mW/cm^2. In this regime, the stationary temperature increased to 30°C and 3°C above room temperature with on/off current, respectively. Because of the thermal conductivity difference between metallic contacts and silicon semiconductor, the thermal cycles causes the degradation of the series and shunt resistances. The loss of metal–semiconductor adherence by current pulses, increases the contact resistances to the front and back as well as the surface leakages along the cell edges, by diffusion spikes along dislocations or possibly by fine metallic bridges