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Soft breakdown behavior of interdigitated-back-contact silicon solar cells

Haifeng Chu*, Lejo J. Koduvelikulathu, Valentin D. Mihailetchi, Giuseppe Galbiati, Andreas Halm, Radovan Kopecek

ISC Konstanz e.V., Rudolf-Diesel-Str. 15, 78467, Konstanz, Germany

Abstract

The soft reverse IV characteristic of interdigitated-back-contact (IBC) silicon solar cells consisting of contiguous p^+ and n^+ regions on the rear side (Figure 1) was investigated in this study. Our IBC cell concept, which is a 6-inch IBC cell with a diffused phosphorous BSF and a boron front floating emitter, features a relatively low breakdown voltage of about - 3.7 V. We measured a negative temperature coefficient at reverse bias in the dark. The low breakdown voltage and the negative temperature coefficient both support the hypothesis that the high reverse current is caused by the tunneling effect [1]. We demonstrated that by changing the doping profiles, the breakdown voltage of the IBC cells can be modified. Our simulations show that the reverse bias current is mainly caused by the band-to-band tunneling across the borders of the p^+ and n^+ regions, and that the breakdown voltage changes with doping profiles. Furthermore, a qualitative agreement is found between the experimental and simulated reverse currents. In principle, the same theory may apply for studying the early breakdown behavior of MWT, EWT or any other cells that feature p^+n^+ junctions.

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Keywords: Silicon solar cell, IBC, breakdown voltage, band-to-band tunneling

* Corresponding author. Tel.: +49 (0) 7531 / 36 183 - 371; fax: +49 (0) 7531 / 36 183 - 11
E-mail address: haifeng.chu@isc-konstanz.de

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1. Introduction and advantages of soft breakdown

The IBC cell concept has captured considerable attention thanks to its potential to achieve high efficiency. For IBC cells that consist of contiguous p^+ and n^+ regions on the rear side (Figure 1), a soft reverse IV characteristic has been observed [2-4]. The reverse breakdown of this type of cells usually takes place at a low breakdown voltage *Vr* (|*Vr*| < 5 V), and more importantly, it is non-destructive and uniform over the entire cell.

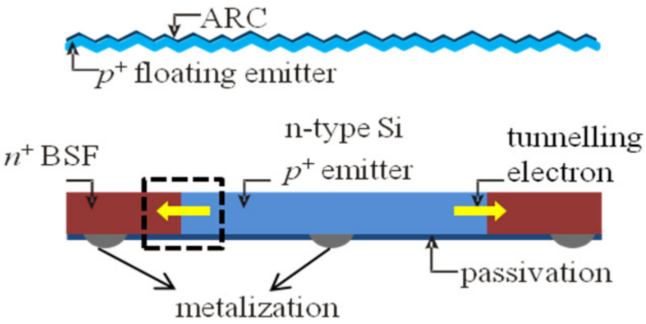

Fig. 1. IBC cells with contiguous p^+ and n^+ regions on the rear side.

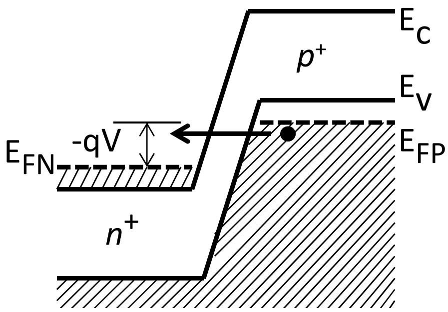

Fig. 2. Energy-band diagram of a heavily doped p^+n^+ junction at reverse bias. (Adapted from [1])

In stark contrast, the breakdown of standard front-contact solar cells usually takes place at a high voltage (|*Vr*| > 10 V) and at one or several local breakdown sites, where the overwhelming current might lead to non-reversible damage to the cell. Therefore bypass diodes are introduced to the module to prevent the front-contact cells from being operating at a high reverse voltage. But once the bypass diode is turned on, the power generated by the other cells from the same string is wasted.

As for IBC cells that feature soft breakdown, partial or complete shadowing of one cell does not necessarily turn on the bypass diode and therefore the energy yield of the PV system could be increased. In addition, a cell with a lower breakdown voltage is preferred, because when it is shadowed, it would consume less power generated from the illuminated cells [2, 3, 5].

In this paper we firstly studied the cause of the soft breakdown and verified it for our IBC cells by measurement. Secondly we fabricated IBC cells with different doping profiles, which led to different breakdown voltages. Simulation study was also performed to model the band-to-band tunneling effect that is responsible for the soft breakdown.

2. Cause of the soft breakdown

2.1. Theory

Figure 2 shows that when a highly doped p^+n^+ junction is reverse biased, electrons can tunnel from the valence band into the conduction band. The tunneling current follows

$$J_t \propto AFV\exp(-B/F)\ , \tag{1}$$

where F is the average electric field inside the junction, V is the applied voltage, A and B are positive quantities that are related to material properties, such as the band gap and the effective mass of carriers [1]. Hence a higher electric field shall lead to a higher tunneling current. The same phenomenon may occur in IBC cells, if the doping concentration of the p^+ emitter and n^+ BSF is heavy enough to enable the tunneling current. This tunneling current could lead to the desired soft breakdown characteristic [2, 3, 6].