Compact transmission-line equivalent circuit model for silicon solar cell simulation

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Abstract— **We demonstrate a compact equivalent circuit model for transmission-line representation of monocrystalline silicon solar cell. The model is suitable for solar cell characterization in terms of impedance/admittance spectroscopy. Number of coordinate partition elements necessary to adequately represent the device characteristics is reasonably comparable with the number of solar cell structure epi-layers. This makes the model convenient for transient effect simulations in external electrical circuits where fully distributed transmission-line model is too complex for direct time-domain calculations.**

Keywords—solar cells; equivalent circuit model; impedance spectroscopy; optoelectronic devices; numerical simulation

I. INTRODUCTION

Transient mode of semiconductor device operation is equally affected both by the internal carrier dynamics and by the external device circuitry. For circuit applications switching the device on and off, these two factors are often characterized by strongly different time scales: nano- or picoseconds for the internal carrier transport, and microseconds for the circuitry RC times. Such a mismatch renders the direct time-domain simulation of carrier transport impractical. The most efficient way of analyzing the complete device plus circuit system is to develop a distributed equivalent scheme for carrier transport in the semiconductor structure and then simulate it together with

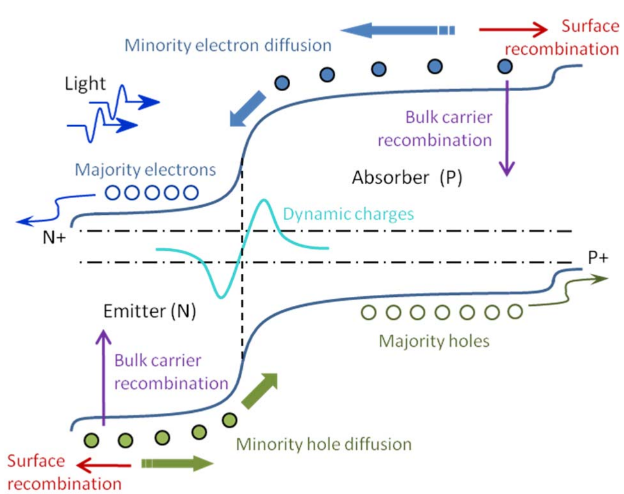

Fig.1. Scematics of silicon solar cell structure with P-type absorber (1D simulated part). Dashed line indicates the P-N junction poisition (not to scale).

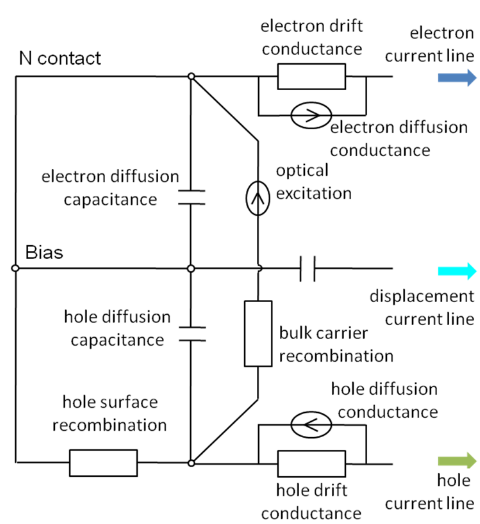

Fig. 2. First stage of the equivalent circuit adjucent to the N-contact and main physical processes included into eqivalent circuit.

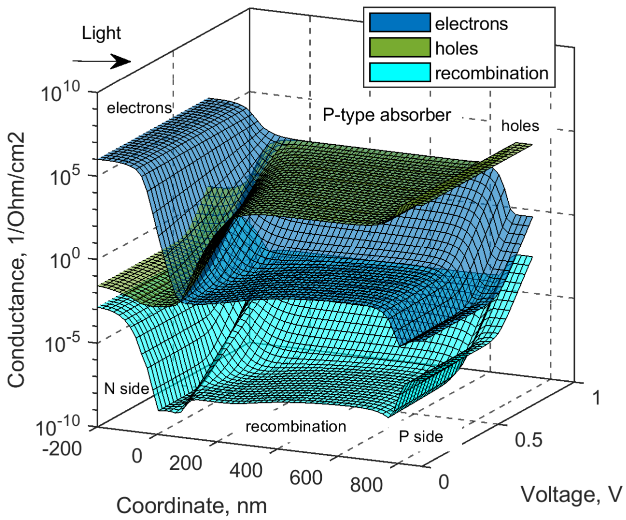

Fig. 3. Example of fully distributed transmission-line equivalent circuit characteristics: transport and recombination conductance distributions across the solar cell structure.

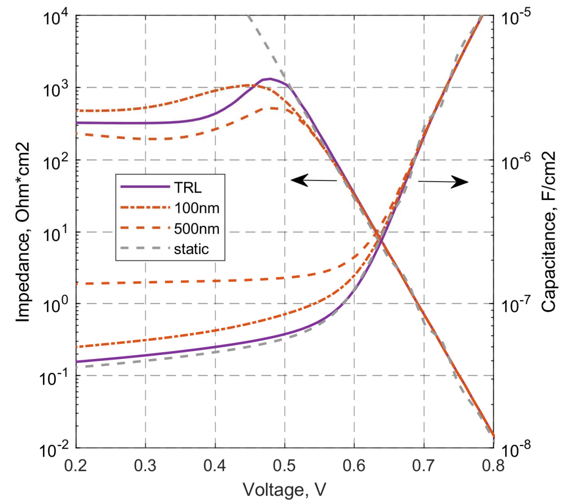

Fig. 4. Impedance and capacitance for signal frequency 1kHz obtained from transmission-line differential eqations (TRL) and from equivalent circuits with two values of coordinate partition.

the external circuit. Fully distributed transmission-line model [1] is equivalent to a system of linear small-signal differential equations but still is too complex for direct time-domain simulation. However, transmission-line approach provides a basis for building an equivalent circuit with reasonable finite number of stages [2]. For a true compact model of solar cell structure, the equivalent circuit elements should adequately represent different solar cell layers with minimal partition and be parametrically dependent on bias and illumination conditions.

II. The Model

Figure 1 illustrates the effective 1D region of solar cell structure included into simulation. Figure 2 shows the first stage of the equivalent circuit adjacent to the N-contact, and indicates the main physical processes represented by the equivalent circuit elements.

The distributed transmission-line characteristics of the solar cell structure have been calculated from stationary simulation results and, after averaging over the corresponding partition stages, represent the elements of the compact equivalent circuit. For stationary simulations we use the Comsol-based semiconductor device simulation package developed at Ostendo Technologies [3] and further adopted to solar-cell modeling [4]. Figure 3 illustrates typical distribution of transmission-line conductive elements across the solar cell structure.

Figure 4 compares the impedance and capacitance characteristics obtained from transmission-line differential equations with the corresponding results of compact equivalent circuit model with small number of stages representing the solar cell absorber: 10 stages for 100 nm partition, and only 2 stages for 500 nm partition. In this simulation, absorber width of 1µm fully accommodates all the carrier concentration inhomogeneity, so that wider absorbers can be represented simply by the last stage replication. Quasi-static storage-charge capacitance and I-V differential resistance obtained from stationary simulation of fully distributed transmission-line model are also shown for comparison. The correlation between the low-frequency characteristics is remarkably good, – both for impedance and capacitance calculations. It is interesting that even the smallest number of absorber partition stages was sufficient to adequately reproduce the high-injection part of the charge-storage capacitance related to the minority carrier accumulation (so called diffusion capacitance). Low-injection capacitance related to majority carrier storage in the vicinity of the p-n junction (depletion capacitance) is apparently more sensitive to the partition width and for the largest partition of 500 nm is represented in our model with some discrepancy.

References

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