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Extraction of recombination properties from lifetime data

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Abstract

Extraction of recombination properties like the recombination pre-factor J_0 and the Shockley-Read-Hall base lifetime from photoconductance data on test structures and half-fabricates of photovoltaic cells is not always straightforward and unambiguous. In this paper the well-known “slope method” of Kane and Swanson will be compared to the method offered by the Quokka code. The Quokka code numerically solves the distribution of the excess carrier concentration over the thickness of the wafer at several injection levels. In this way artefacts due to transport limitations are avoided and the analysis does not rely on data at a single injection level. This gives more reliable results for J_0 and the base lifetime. A method to determine the base lifetime from the implied V_{OC} at 1 Sun illumination values is also presented.

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1. Introduction

Solar cell optimization requires good, quantitative knowledge of the recombination parameters in a cell. These are e.g. the recombination pre-factor J_0 of the diffused regions and τ_{SRH} , the Shockley-Read-Hall lifetime of the base. The Sinton WTC-120 lifetime tester is a convenient and fast instrument that from quasi steady state photoconductance (QSSPC) measurements provides the effective lifetime τ_{eff} for a range of excess carrier densities

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Δn [1]. From these data the recombination parameters J_0 and τ_{SRH} can be extracted. The conventional method to do this is the slope method by Kane and Swanson [2]. This method has been implemented in the Sinton WTC-120 software. Recently this method was adapted to partially account for bandgap narrowing that occurs in the base at high injection levels [3].

The Kane and Swanson method has been proven to be very useful for extraction of J_0 data. Values of the base lifetime τ_{SRH} extracted by this method are usually not reported. The τ_{SRH} is usually determined from measurements on structures where diffused regions have been stripped off and subsequently given an excellent surface passivation. While this method gives reproducible data, it gives only limited information of any impact the diffusion processes may have on the τ_{SRH} . One reason why the τ_{SRH} values by the Kane and Swanson are not often reported may be that they depend strongly on the selected point of analysis and that the τ_{SRH} values are much more sensitive to this selection than the J_0 values. This often results in a large scatter of the τ_{SRH} values.

There are several causes for this strong dependence on the selected point of analysis.

- The carrier dependency of J_0 and τ_{SRH} itself. According to the Shockley-Read-Hall (SRH) theory the τ_{SRH} of the base will vary with the injection level depending on the relative values of the capture time constants τ_{0p} and τ_{0n} [4]. This transition takes place when going from low level injection conditions to high level injection and is usually within the injection level range where lifetime data are taken. Also the J_0 will be carrier dependent, e.g. due to the non-uniform quasi-Fermi levels in the diffused regions at high injection, or due a breakdown of field-induced surface passivation at high injection levels [5].
- Bandgap narrowing in the base. The effect of bandgap narrowing in the base was recognized by Kimmerle et al. [3]. The authors proposed a correction which was recently implemented in the standard Sinton WTC-120 software.
- A non-uniform distribution of the carrier density in the sample that increases with injection level. This occurs e.g. in samples with a high J_0 because of transport limitations [6-8]. These transport limitations cause Δn values at the interfaces of the base and the heavily doped region to be lower than the average Δn . This results in an apparent decrease of J_0 with the injection level.

In this paper we will compare the standard Kane-Swanson slope method and recent modifications with the Quokka method presented by Fell et al. [9,10]. The Quokka code is used to calculate the effective lifetime in a sample by numerical solving the distribution of Δn over the base. In this way transport limitations are included. In this paper the method using Quokka will be demonstrated further for test structures and half-fabricates with the emphasis on determining the τ_{SRH} . Furthermore we will demonstrate that by using the implied V_{oc} values at one sun illumination the scatter often observed in the τ_{SRH} is already significantly reduced.

Nomenclature

G	total photogeneration rate
J_0	recombination prefactor, with subscripts front, rear or base to designate region of origin
$J_{ph,1Sun}$	generated photocurrent at 1 Sun illumination
Δn	excess carrier concentration
N_D	doping concentration of the base material
n_i	intrinsic carrier concentration
$n_{i,eff}$	intrinsic carrier concentration with correction for bandgap narrowing
q	magnitude of elementary charge
S	surface recombination velocity
W	thickness of the wafer
τ_{eff}	effective lifetime in the base material
τ_{SRH}	Shockley-Read-Hall lifetime
τ_{0p}	capture time constant of holes
τ_{0n}	capture time constant of electrons
τ_{intr}	intrinsic lifetime associated with radiative and Auger recombination in the base
τ_{corr}	effective lifetime after correction for intrinsic lifetime

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