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Microarticle

A simplified formulation for calculation of minority-carrier effective lifetime

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ABSTRACT

An improved simple equation to calculate the minority-carrier effective lifetime in photoconductance measurements is proposed by the perturbation method. When the given constraints are satisfied, the given formulation leads to a fast and accurate determination of effective lifetime from the bulk lifetime, surface recombination velocity, the thickness of the wafer, and diffusion coefficient.

Introduction

A fast and accurate estimation of the minority-carrier effective lifetime (τ_{eff}) plays an important role in photoconductance measurements [1–9]. The widely used simple equation is [5]

$$\frac{1}{\tau_{eff}} = \frac{1}{\tau_b} + \frac{2S}{W} \tag{1}$$

where τ_b is the bulk lifetime, S is the surface recombination velocity, W is the thickness of the wafer.

Though Eq. (1) is simple but its applications are limited due to poor accuracy. For a transient condition, we have the following inexplicit formulation to calculate τ_{eff} [5]:

$$S = \sqrt{D\left(\frac{1}{\tau_{eff}} - \frac{1}{\tau_b}\right)} \tan\left\{\frac{W}{2}\sqrt{\frac{1}{D}\left(\frac{1}{\tau_{eff}} - \frac{1}{\tau_b}\right)}\right\} \tag{2}$$

where D is the diffusion coefficient. It is not an easy work to have a fast determination of τ_{eff} from Eq. (2).

The above equation assumed that the surface recombination velocity is large. In fact for the some polished and etched compound semiconductors, the velocity is very small and the measured lifetime is the bulk lifetime. As a rule, polished and etched silicon surfaces have medium to high surface recombination velocity. The same holds for silicon wafers with a state-of-the-art surface passivation layer [10,11].

An explicit formulation

Though the inexplicit formulation given in Eq. (2) gives a high accuracy for τ_{eff}, a photoconductance measurement always requires a fast estimation of τ_{eff} with a relatively high accuracy. Approximating the tangent function to third order, we obtain

$$\begin{aligned} S &= \sqrt{D\left(\frac{1}{\tau_{eff}} - \frac{1}{\tau_b}\right)}\left\{\frac{W}{2}\sqrt{\frac{1}{D}\left(\frac{1}{\tau_{eff}} - \frac{1}{\tau_b}\right)} + \frac{1}{3}\left[\frac{W}{2}\sqrt{\frac{1}{D}\left(\frac{1}{\tau_{eff}} - \frac{1}{\tau_b}\right)}\right]^3\right\} \\ &= \frac{W}{2}\left(\frac{1}{\tau_{eff}} - \frac{1}{\tau_b}\right) + \frac{W^3}{24D}\left(\frac{1}{\tau_{eff}} - \frac{1}{\tau_b}\right)^2 \end{aligned} \tag{3}$$

We assume that

$$\frac{W^3}{24D} = \varepsilon << 1 \tag{4}$$

Using perturbation method [12–17], we assume that

$$\frac{1}{\tau_{eff}} - \frac{1}{\tau_b} = a_0 + a_1\varepsilon + a_2\varepsilon^2 + \cdots \tag{5}$$

Submitting Eq. (5) into Eq. (3), expanding the resultant equation, and equating coefficients of equal powers of ε result in the following equations for $a0$ and $a1$, respectively,

$$a_0 = \frac{2S}{W} \tag{6}$$

and

$$\frac{W}{2}a_1 + a_0^2 = 0 \tag{7}$$

It is easy to find that

$$a_1 = -\frac{2}{W}a_0^2 = -\frac{8S^2}{W^2} \tag{8}$$

We have, therefore, the zero-th order approximation:

$$\frac{1}{\tau_{eff}} - \frac{1}{\tau_b} = \frac{2S}{W} \tag{9}$$

and the first-order approximation:

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$$\frac{1}{\tau_{eff}} - \frac{1}{\tau_b} = \frac{2S}{W} - \frac{WS^2}{3D} \tag{10}$$

It is not difficult to have higher order approximations if we continue the solution process.

Discussion and conclusion

This paper is to extend the validity of Eq. (1), the obtained formulation given in Eq. (10) is as simple as Eq. (1) with an improved accuracy, and it should follow the following conditions:

$$\frac{W^3}{24D} < < 1 \tag{11}$$

and

$$\frac{2S}{W} - \frac{WS^2}{3D} > 0 \text{ or } \frac{W^2S}{D} < 6 \tag{12}$$

Our formulation given in Eq. (10) predicts a higher accuracy than that by Eq. (1), however, it becomes invalid for very large surface recombination velocity. When Eqs. (11) and (12) can not be satisfied, Brody et al' method has to be adopted [5].

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.rinp.2018.10.008.

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