April. 2015. Vol. 6. No. 4 ISSN2305-8269
International Journal of Engineering and Applied Sciences

www.eaas-journal.org

MEASUREMENT OF THE LIFETIME OF NONEQUILIBRIUM CHARGE CARRIERS IN SILICON USING PHOTOELECTRIC METHODS

[1]ALEKSANDER GRAF, [1]ALEKSEI GAVRILOV and [1]PAVEL SUURVARIK

[1]Departement of Physics, Tallinn University of Technology
Email: [1]aleksei.gavrilov@ttu.ee

ABSTRACT

In the work was measured the lifetime of nonequilibrium charge carriers in n- type silicon. The results obtained using different photoelectric methods : frequency, phase and method of photoconductivity decay were compared with each other. It is shown that the results of the measurements quite well coincide with each other.The estimated accuracy of measurements was not worse than 15%. Stress the advantages of the frequency measurement method

Keywords*: methods of measuring, nonequilibrium charge carriers, lifetime of carriers***.**

INTRODUCTION:

Possibilities and limits of application of semiconductor materials depend on their basic parameters – the energy gap, resistivity, concentration and mobility of charge carriers, as well as the lifetime of nonequilibrium carriers. Research last parameter usually pays be less attention than the measurement of the above characteristics.

Methods of measuring the lifetime of nonequilibrium carriers can be divided into two groups depending on how these carriers are injected into the semiconductor – using electric field or irradiation of a sample.

In our work we tried to check how consistent the results of measurements of the lifetime of nonequilibrium carriers received on the same semiconductor sample by different methods. For this, we chose three photoelectric methods: photoconductivity decay, frequency and phase methods. The sample was n - type silicon.

For irradiation of silicon, the energy gap which is at room temperature of 1.1 eV, was used GaAs – LED, emitting light with a quantum energy of 1.4 eV. To obtain a modulated light intensity in the first two methods we connected the LED to the source of unidirectional square AC voltage.

It was assumed that dominates one mechanism of generation of the additional carrier concentration $\Delta n = \Delta p$, where Δn - concentration of nonequilibrium electrons and the Δp - concentration of nonequilibrium holes. It was also assumed that $\Delta n \ll n_0 + p_0$, where n_0 and p_0 are the equilibrium concentrations of electrons and holes. Then the lifetime of nonequilibrium carrier τ is the same for electrons and holes. In this case, the decrease in the concentration of nonequilibrium carriers after termination of the light pulse can be expressed by the exponent [1]:

$$\Delta n = \Delta n_{stats} \exp\left(-\frac{t}{\tau}\right),$$

where Δn_{stats} - the steady-state value of the concentration of nonequilibrium carriers after the beginning of the light pulse, t - time and τ - lifetime.

Similary, changes and additional, due to the irradiation of a sample, the photoconductivity. If in series with the sample to include a resistor and connected to this circuit DC voltage, from the pulse voltage on this resistor can determine the lifetime of nonequilibrium carriers.

Schematic diagram of the measurement is given in Fig.1. The light emitted from the LED falls simultaneously on the sample and fast-response photodiode (its rise/fall time is $5\,ns$). The signals from the sample and from the photodiode feed in two inputs of the oscilloscope.

Figure 2 given the form of the voltage pulse obtained with resistor R_s1 (with a fast photodiode). The decline of the trailing edge of the pulse is quite well approximated by an exponential curve with a relaxation time of $\approx 400\,ns$. Research has shown that by the LED due to the approximately $300\,ns$, and the rest falls on electronics - primarily on the generator of square pulses.

The sample was doped with a phosphorus silicon. Its thickness was $0{,}6\,mm$. The resistivity, measured by the method Van-der-Pauw, amounted $68\,\Omega \cdot cm$. Two contacts for the lifetime measurement were applied either through In + Ga paste or by vacuum evaporation In (substantial differences in the final results was not observed).

Pulse voltage with resistor R_s2 shown in Fig.3. Falling edge of this pulse in a larger time scale shown in Fig.4. The points in this figure represent an exponential curve with a relaxation time of 36 μs. Thus, the lifetime of nonequilibrium carriers, as measured by method of the decay of the photoconductivity is $36\,\mu s$.

On the same sample, the lifetime of carriers was measured using the frequency method.

If the sample is irradiated sufficiently low frequency light pulses, the voltage signal from the sample has a well-pronounced saturation U_{stats} U_{stats} on the ``ceiling`` of the pulse. This can be seen in Fig.5. With increasing frequency f saturation pulse disappears, the pulse shape changes and their amplitude decreases. The amplitude of the voltage pulses U_f theoretically should decrease according to the following law [2] :

$$U_f = U_{stats} \cdot \tanh\,(4f\tau)^{-1}$$

Figure 6 given the oscillogram of the pulses at repetition frequency 4.6 kHz. The lifetime calculated from the decrease of the amplitude of the pulses is equal to $35\,\mu s$. Thus, measured using the frequency method, the lifetime very well coincides with the value measured using the decay of photoconductivity.

Next was applied phase method. Theoretically, in this method, when the irradiation is sinusoidal light signal between the signals from the sample and from the fast-response photodetector must exist such a phase shift [1,2] :

$$\tan\theta = 2\pi f\tau\,,$$

where θ angle of phase shift.

In our case, because of the reluctance to complicate the scheme of measuring the angle θ was calculated in two, shifted relative to each waveform. One picture was a signal with fast-response photodiode, and the other signal from the sample (with resistors R_s1 and R_s2 − see Fig.1). If the oscillation period is T , and the time shift − t_n , the angle of shift is equal to :

$$\theta = \left(\frac{t_n}{T}\right) \cdot 360°.$$

Knowing this angle and the frequency of the signal from this formula we can determine the lifetime of carriers. Said illustrated by Fig.7 , wich shows two experimental waveforms for frequency 2.0 KHz. Similar measurements were made at four different frequencies. The average lifetime value was equal to $39\,\mu s$.

Thus, the lifetime of nonequilibrium carriers in n – type silicon, as measured by three different photoelectric methods are sufficiently well coincide with each other. The percentage error of the measurements, as we believe, is a value not greater then 15%. It may also be noted that of the three considered methods of measuring the lifetime of nonequilibrium charge carriers the fastest and most convenient is the frequency method.

References

[1] L.P.Pavlov ‘’Methods for the determination of the main parameters of semiconductor materials’’ Moscow. Publishing house of the Higher school. 1987

[2] S.I. Rembeza ‘’Methods for measuring basic parameters of semiconductors’’ Voronezh. Voronezh University Publishing house. 1989

Figure captions

Fig.1. Electric circuit for measuring the lifetime of nonequilibrium charge carriers in the semiconductor sample.

Fig.2. The voltage pulse from the fast-response photodetector. Voltage vs Time. Horizontal scale 1.0 µs /div.

Fig.3. The voltage pulse from the sample semiconductor. Voltage vs Time. Horizontal scale 100 µs/div.

Fig.4. The rear edge of the pulse shown in Fig.3. Voltage vs Time. Horizontal scale 20 µs/div.

Fig.5. The voltage pulses from the sample semiconductor. The pulse repetition frequency equal 1.0 kHz. Voltage vs Time. Horizontal scale 200 µs/div.

Fig.6. The voltage pulses from the sample semiconductor. The pulse repetition frequency equal 4.6 kHz.Voltage vs Time. Horizontal scale 200 µs/div.

Fig.7. The phase shift between the signals from the sample semiconductor and signals with fast-response photodiode. Voltage vs Time. Horizontal scale 200µs/div.

Estonia. Tallinn. Ehitajate tee 5. Tallinn University of Technology. Institute of physics.

Aleksander Graf, Aleksei Gavrilov , Pavel Suurvarik

Corresponding author Aleksei Gavrilov e-mail: aleksei.gavrilov@ttu.ee

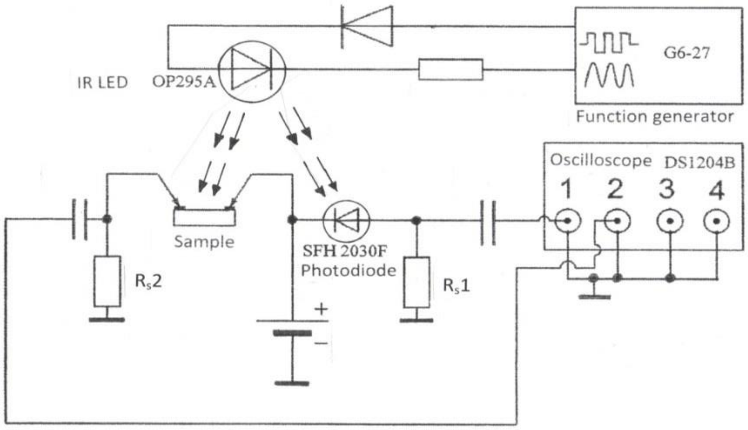

Fig.1

Fig. 1 . Electric circuit for measuring the lifetime of nonequilibrium charge carriers in the semiconductor sample

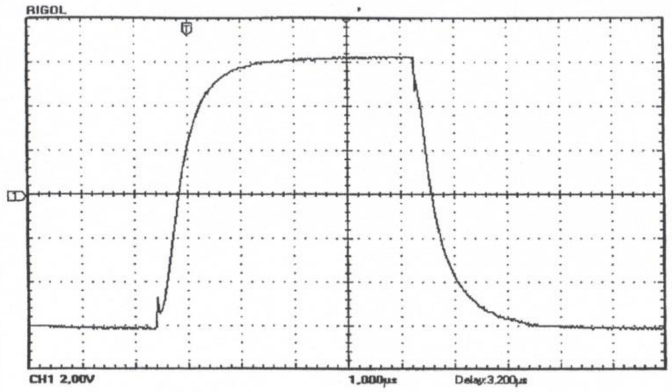

Fig.2

Fig. 2 The voltage pulse from the fast-response photodetector. Voltage vs Time. Horizontal scale 1.0 µs /div

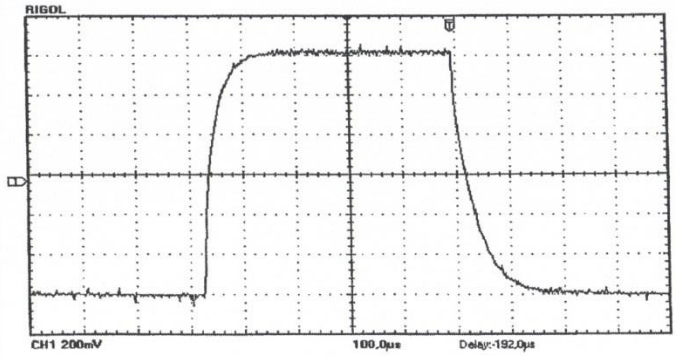

Fig.3

Fig. 3 The voltage pulse from the sample semiconductor. Voltage vs Time. Horizontal scale 100 µs/div.

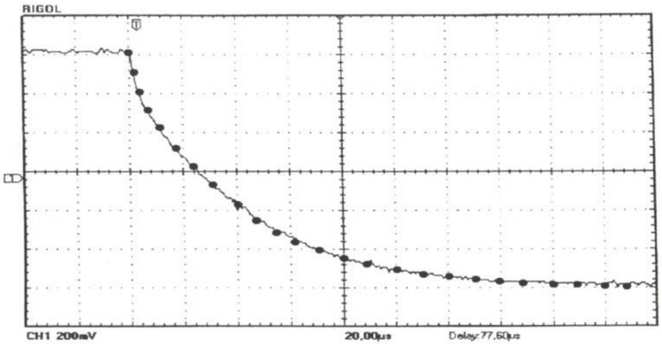

Fig.4

Fig. 4 The rear edge of the pulse shown in Fig.3. Voltage vs Time. Horizontal scale 20 μs/div.

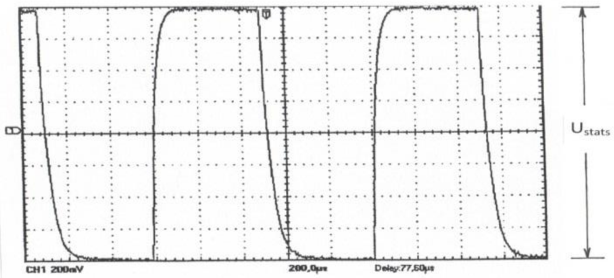

Fig.5

Fig. 5 The voltage pulses from the sample semiconductor. The pulse repetition frequency equal 1.0 kHz. Voltage vs Time. Horizontal scale 200 μs/div.

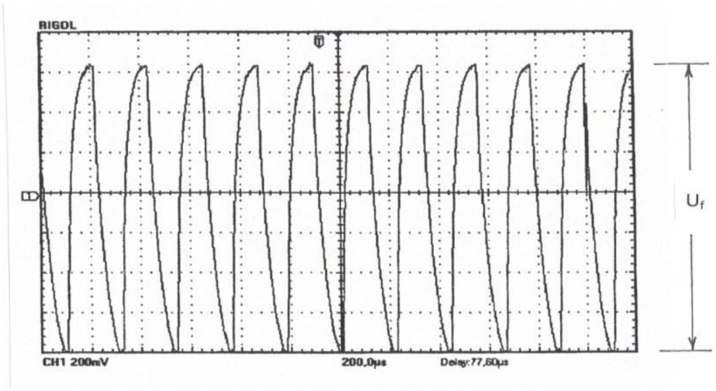

Fig.6

Fig. 6 *The voltage pulses from the sample semiconductor. The pulse repetition frequency equal 4.6 kHz.Voltage vs Time. Horizontal scale 200 µs/div.*

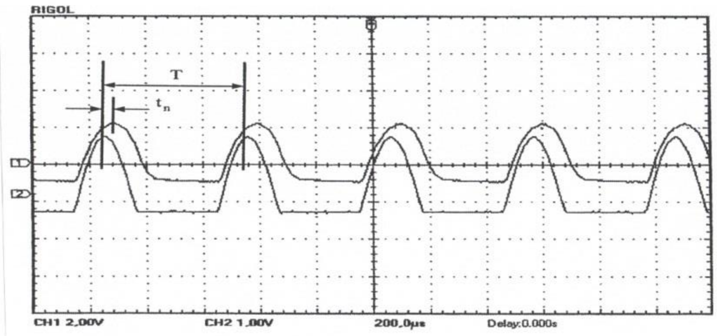

Fig.7

Fig. 7 *The phase shift between the signals from the sample semiconductor and signals with fast-response photodiode. Voltage vs Time. Horizontal scale 200µs/div.*