Contactless nondestructive method for determination of the carrier diffusion length in semiconductors and dielectrics

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Abstract. We propose the contactless nondestructive method for determination of the carrier diffusion length in semiconductors and dielectrics. The method is based on optical generation of non-equilibrium carriers at one point of the studied sample and the laser interference measurement of their concentration at another point. When changing the distance between these points, a decrease in the carrier concentration is observed. It depends on the carrier diffusion length, which is determined by comparing the experimental and theoretical dependences of the probe signal on the divergence of the injector and probe beams. We have studied silicon samples protected by an insulator layer and without any covering. The method can be used in scientific research and the electronics industry.

1. Introduction
The carrier diffusion length is an important physical characteristic of a material and it governs operation of a great number of electronic devices. At present, a number of methods for measuring the diffusion length are known [1, 2]. The guided probe method is often used. However, using this and many other methods requires an electrical contact between the sample and the probe. It is impossible to investigate dielectric samples as well as semiconductor samples with a dielectric coating by using contact methods. We propose a contactless laser method for the investigation of the carrier diffusion length. This method allows one to avoid destruction of material and not to disturb the electron system. The proposed method is based on optical generation of non-equilibrium charge carriers in the sample using one laser beam and nonintrusive optical data reading with the help of another laser probe beam with the photon energy less than the energy gap of the material to be investigated.

2. Interference modulation mechanism
The data on the excess carrier diffusion length are obtained through the interference modulation of the monochromatic long-wave IR radiation for which the material being tested is transparent ($\lambda > hc/E_g$). Here, h is the Planck's constant, c is the speed of light, E_g is the semiconductor gap width. This radiation passes through the sample as an optical probe. The samples are plane-parallel wafers with parallel edges forming a Fabry-Perot interferometer for the probe beam. The passing probe beam intensity depends on the sample refractive index and its absorption coefficient. Simultaneously, the sample is exposed to the optical injector which is the source of radiation with the photon energy sufficient for the intrinsic photoeffect ($\lambda < hc/E$), generating excess carrier pairs. The excess

concentration of electrons (ΔN) and that of holes (ΔP) depend on the fluid density of the injector photons absorbed in the sample. The changing carrier concentration results in the change of the refractive index $\Delta \eta$ and that of the absorption coefficient $\Delta \alpha_\rho$ for the probe laser wavelength. According to this, the intensity of probing light passing through the sample is changed by the value of ΔI and thus the modulation coefficient $M = \Delta I/I$ depends on the excess carrier concentration. This interference mechanism was proposed in [3] and used in [4-7] for investigation of different parameters of semiconductors such as the lifetimes of the excess electrons and holes, the surface recombination velocity, the recombination centers concentration, the capture coefficients for electrons and holes, etc.

3. Experimental set-up

To test this method for the diffusion length determination, we have developed an experimental apparatus which is shown in figure l. A long wave infrared laser LG-GNIK-1 was used as a source of a probing beam (1). The wavelength of this laser is 3.39 μm, the power is 6 mW, the noise/signal ratio is < 0.001. The beam of this long wave IR laser (1) transmits through the studied sample (2) and is measured by a photodetector FE-724-1 (3). The intensity I of the probing light passing through the sample is changed by the value of ΔI and depends on the excess carrier concentration at the point to be tested.

We use a semiconductor laser module KLM-H980-200-5 as an injecting radiation source (4). The wavelength of this radiation is 0.980 μm, the power is 200 mW. The modulation frequency is 1400 Hz. Due to their diffusion, non-equilibrium charge carriers, generated by this radiation at one point of the material surface, change the carrier concentration at another (tested) point located at a distance r. This distance may be regulated by a special precise stage (5). By changing the distance r between the carrier generating and probing points, it is possible to decrease the carrier concentration at the probing point.

So, the carrier concentration measured at the probing point is a function of a distance r and a carrier diffusion length L. The carrier concentration results in the change of the refractive index $\Delta \eta$ and the absorption coefficient $\Delta \alpha_\rho$ for the probe laser wavelength. As a result, the photodetector signal and the carrier concentration depend equally on the distance r.
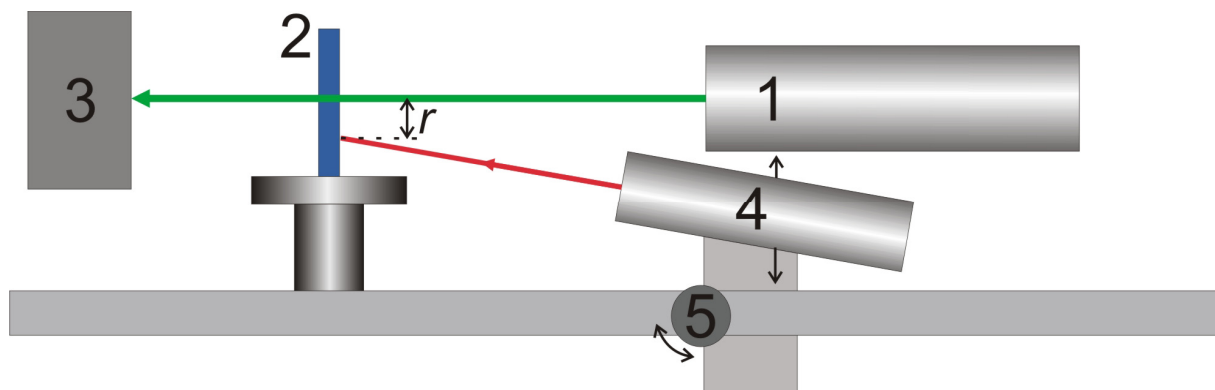

Figure 1. Schematic diagram of the experimental setup: 1 - source of probe beam, 2 - sample, 3 - photodetector, 4 - injecting radiation source, 5 - precise stage.

4. Measurements

The series of experiments has been carried out based on the method presented here. The samples made of Si crystal of a resistivity of 160 Ω·m were investigated. They were divided into two lots. Samples of one lot had a clean surface; samples of another lot were covered with an insulating layer of silicon dioxide. Such samples are used in electron device manufacturing. They are parallel enough to be used for interference measurements due to a long wavelength of the probe beam. The dependences of the photodetector signal on the distance r between the carrier generating and probing points $U(r)$ were measured. Each sample was tested several times at different points of generation.

Similarly to the contact methods [1,2], to determine the carrier diffusion length L we compared the experimental curve $U(r)$ with the dependences calculated theoretically for different values of L. Figure 2 shows that theoretical and experimental data correspond well only for large values of the distance r between the points of carrier generating and probing. This is because the diameter of the generation area is not small enough to neglect it. So, the experimental values of the carrier diffusion length L were determined in the range of large r values. These values agree well for different samples of each lot and for different points on each sample. However, they differ significantly for the samples covered with a dielectric ($L = 530$ μm) and uncovered ones ($L = 400$ μm). The carrier diffusion length L is much longer in covered samples due to low surface recombination. The statistical error of the experiments is 5 to 7 %.
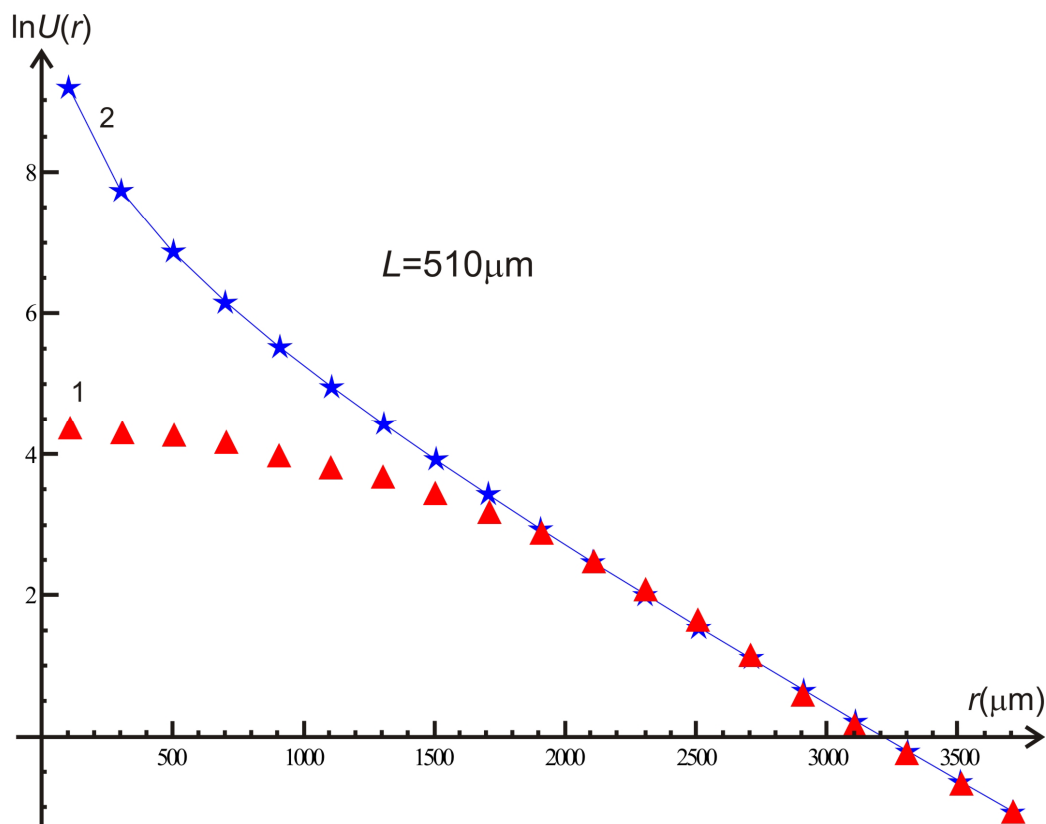
Figure2. Typical superposition of the experimental (1) and calculated (2) curves lnU(r).

5. Conclusion

The efficiency of the proposed contactless nondestructive method for determination of the carrier diffusion length in semiconductor and dielectric samples was experimentally demonstrated in a series of experiments. The method does not require special sample preparation and can be used not only for scientific and technological research but also in the production of electron devices.

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