Method and device for determining of a characteristic of a semiconductor sample

Technical field

The invention relates to a method for determining a characteristic of a semiconductor sample forming a surface.

Furthermore the invention relates to a device for determining a characteristic of a semiconductor sample, comprising: means for mounting a semiconductor sample forming a surface, a plurality of light sources with different wavelengths each of the light sources generating a light beam, means for superimposing such light beams for the generation of an combined light beam simultaneously comprising the wavelengths of all light sources and falling on an area of the surface of the semiconductor sample, modulating means for modulating the light sources with different modulating functions, means for measuring the surface photo voltage generated in the area of the surface and exhibiting a signal distribution, and signal evaluation means for determining the signal distribution components of the surface photo voltage based on the various light beams with various wavelengths on the basis of the modulating functions of the various light sources.

The quality of semiconductor materials such as silicon must be monitored during the production of material and chips. An important material parameter is the diffusion length of minority charge carriers. Such diffusion length represents the average effective distance, over which excess charge carriers diffuse through a semiconductor during their life time. This diffusion length is heavily influenced by impurities and crystal disorders. Therefore the diffusion length of the minority charge carriers is a suitable measure of the degree of the impurity in the semiconductor material and of the crysalline perfection. The

effective diffusion length, which is influenced by the surface characteristics has to be distinguished from the inner diffusion length, which is based on an unlimited sample.

For the quality check of semiconductor materials a quick, nondestructive and reliable determination of the diffusion length of minority charge carriers is desireable.

A conventional method of determining of this diffusion length of minority charge carriers as well as the velocity of the surface recombination of semiconductor materials is based on the measurement of the surface photovoltage (SPV). The method makes use of the effect, that after exciting of a semiconductor sample with light having photonenergies which are higher than the energy gap of the semiconductor, pairs of electrons and holes are formed. A certain amount of such charge carriers can reach the space charge area at the surface and are separated causing a voltage drop at the surface. This is the surface photo voltage SPV. For the determination of the diffusion length this surface photo voltage is measured when it is illuminated with different light wavelengths. As the excitation with different wavelengths causes the generation of excess charge carriers in the inner part of the semiconductior sample of different depths, the amount of excited charge carriers reaching the surface varies with the exciting wavelength. Assuming the excitation is effected with a small injection level, small frequences of the light modulation and diffusion lengths of the charge carriers, which are small with respect to the sample thickness a simplified expression for the state of equilibrum can be derived (for example D.Schroder, „Semiconductor Materials and Device Characterization“, John Wiley & Sons, 1990, S.379):

$$\Delta V_{SPV} \propto \Delta n = \Phi_{eff} \frac{1}{S + D/L} * \frac{1}{1 + z/L}.$$

Therein Δn denotes the excess charge carrier-concentration at the edge of the space charge area, $\Phi_{eff} = \Phi^*(1-R)$ the effective photon flux entering the semiconductor sample and derived from the incident photon flux Φ taking into account the reflectivity R at the sample surface, S the velocity of the frontside surface recombination, z the penetration depth of the light, D the diffusion constant of the minority charge carrier and L the

diffusion length of the minority charge carrier of the sample. Using this expression the diffusion length is derived from the measurement of the voltage change ΔV_{SPV} of the surface voltage due to the excitation with modulated light of various light sources.

If the velocity of the backward surface recombination cannot be neglected, because the diffusion length of the minority charge carriers reaches the range of the thickness of the semiconductor sample, the relationship can be derived according to the above mentioned book by D. Schroder, page 425 ff:

$$\Delta V_{SPV} \propto (1-R)\Phi \frac{S_f}{C} * \frac{1}{1-z^2/L^2}\left[\left(z\frac{S_b}{D}-1\right)(\cosh[T/L]-\exp[-T/z])+\left(\frac{z}{L}-\frac{S_b L}{D}\right)\sinh[T/L]\right]$$

wherein

$$C=(S_f S_b L/D \quad + \quad D/L)\sinh[T/L]+(S_f+S_b)\cosh[T/L].$$

R denotes the reflectivity at the frontside of the semiconductor sample, ϕ the incident photon flux, S_f and S_b the front and rear velocity of the surface recombination, z the penetration depth of the light, L the diffusion length of the minority charge carriers, D the diffusion constant of the minority charge carriers and T the thickness of the semiconductor sample.

Prior Art

Known methods based on the measurement of the surface photo voltage use the above first mentioned, simplified relationship.

With one of such methods the level of the generated surface photo voltage is kept constant. The principle of such a method is described in a publication by Goodman et al. „A metghod for the measurement of short minority carrier diffusion lengths in semiconductors“ in the Journal „J.Appl. Phys.“ Vol. 33, p.2750, 1961.

The photon flux and the surface photo voltage are measured with different wavelengths according to different photo energies. The photon flux is changed in such a way, that a constant surface photo voltage is obtained for each wavelength. The different photon fluxes obtained withdifferent photon energies are plotted against the reciprocal absorbtion coefficient. This graph is then linearily extrapolated and the point of intesection of the extrapolated graph with the abscissa is determined for the determination of the diffusion length of the minority charge carriers.

This is also described in the US 5,177,351 A as the state of the art.

In a different kind of such a method the photon flux is kept constant.

Such a method is already described as prior art in the US 5,663,657 A.

The US 5,025,145 A describes such a method, wherein first the induced photo voltage is measured for different photon fluxes to ensure a linear relationship between the surface photo voltage and the photon flux. Then the photo voltage is measured for a number of selected photon energies, i.e. wavelengths with light with a constant photon flux having a value in the linear range. The surface photo voltages obtained in such a way having monotonously increasing photon energies are plotted as a function versus the reciprocal values of the absorbtion coefficients according to the given photon energies. The diffusion length of the minority charge carriers is determined by extrapolation for determining the reciprocal absorbtion coefficient for a (modulated) surface photo voltage equal to zero.

Both methods are based on the above mentioned simplified model requiring a linear relationship between the photon flux required for a constant surface photo voltage or the surface photo voltage, respectively, on one hand and the penetration depth of the light. The use of such a model allows the determination of the frontside surface recombination and the diffusion length. The influence on the rear side of the semiconductor sample is normally ignored or the results are corrected in an again simple way using a factor depending on the thickness of the semiconductor sample.

As the optical excitation with different wavelengths is carried out sequentially, both methods are relatively slow. Furthermore, the „CMSPV"-method operating with constant surface photo voltage has the disadvantage that for each wavelength the photon flux hast to be newly adjusted in order to obtain the given photo voltage. Even if this is carried out by a seperate control circuit, this causes further slowdown. The speed of the measurement is of crucial importance, if the surface of a semiconductor sample needs to be scanned point by point for a plurality of points.

Furthermore the sequential measurements of the surface photo voltage for the different wavelengths cause systematic errors. The state of the surface is changed by the measurement itself. Thereby the accuracy of the method is limited. The velocity of the surface recombination even depends on the intensity of the optical excitation, i.e. on the photon flux incident on the surface of the semiconductor sample. As at least a portion of the surface states exhibit a relatively slow recombination, a hysteresis effect occurs. This violates the assumption of the simplified model that all data points for the different wavelengths are obtained under the same surface conditions.

The WO 00/02058 (=DE 198 31 216 A1) describes a method for determining the dependency of the surface photo voltage on the wavelength. Therein the wavelength is periodically changed over a wavelength range at a certain frequency. The surface photo voltage changing in accordance therewith is measured. From the obtained measured signal the components with a plurality of frequencies are determined by means of fourier transformation. These components are corrected with respect to the frequency response and phase response of the measurement set up. From the such determined components the surface photo voltage is determined by signal processing.

From the US 6,512,384 B1 a method for the determination of the diffusion length of minority charge carriers is known, wherein the surface photo voltage at each investigated position of the semiconductor sample measurements are carried out simultaneously for a plurality of wavelengths of the exciting light. In such known method the surface of the semiconductor sample is excited with a light beam composed of superimposed photon

fluxes with different wavelengths. From the measured surface photo voltage the components with the different modulation frequencies are filtered. Thereby the speed of the measurement is considerably increased.

This known method, however, does not avoit the errors caused by the dependency of the surface recombination on the intensity. As a modulation with different frequencies causes a variation of the entire photon flux between zero and the total amount of all photon fluxes of the superimposing wavelength light sources, the state of the surface also then considerably changes during the measuring process.

Disclosure of the invention

It is an object of the invention, to carry out the measurement at each point of a semiconductor sample with a method for the determination of the diffusion length of minority charge carriers or equivalent characteristics of a semiconductor sample quicker and more accurate.

More precisely it is an object of the invention to ensure essentially the same surface states for a method of such kind wherein the investigated point is excited with light of different wavelengths and wherein the surface photo voltages obtained for the different wavelengths are determined.

According to the invention this object is achieved with a method of the above mentioned kind with the method steps:

(a) simultaneously illuminating an area on the surface of a semiconductor sample with superimposed exciting light beams with a plurality of wavelengths,

(b) modulating the light beam of the different wavelengths with the same frequency, but different phases,

(c) selecting a modulation function and its phases in such a way, that the sum of the photon fluxes of all light beams at all times within a tolerance range, the tolerance range being considerably smaller than the sum of all photon fluxes,

(d) simultaneously phase-dependent measuring of the components of the surface photo voltage caused by the different light beams and

(e) determining the characteristic of the semiconductor sample from the relationships between the components and the respective wavelengths.

Based on this method a device for determining a characteristic of semiconductor sample, comprising: means for mounting a semiconductor sample forming a surface, a plurality of light sources with different wavelengths each of the light sources generating a light beam, means for superimposing such light beams for the generation of a combined light beam simultaneously comprising the wavelengths of all light sources and falling on an area of the surface of the semiconductor sample, modulating means for modulating the light sources with different modulating functions, means for measuring the surface photo voltage generated in the area of the surface and showing a signal distribution, and signal evaluation means for determining the signal distribution components of the surface photo voltage based on the various light beams with various wavelengths by means of the modulating functions of the various light sources, as shown in the US 6,512,384 B1, the invention provides modulation means operating with the same frequencies for all light sources, the modulation means operating with phase shifts among the different light sources and the modulation functions and its phases being selected in such a way that the sum of all photon fluxes lies within a tolerance range, which is considerably smaller than the sum of the photon fluxes.

With the method according to the invention and the device according to the invention the measurements are carried out simultaneously for all exciting wavelengths as in the US 6,512,384 B1, so that the measuring time is shortened. However, the difference between the components of the obtained signal distribution of the surface photo voltage based on the different wavelengths are distinguished not by their frequency which is used to

modulate the different wavelengths or light sources, but their modulation phase. The modulation frequency is the same for all wavelengths. Thereby it is possible to select the phases of the different modulations in such a way that the entire photon flux is approximately constant. Therefore the measurement is always carried out under the same conditions in this respect. The errors occuring due to variations of the photon flux for different modulation frequencies are avoided.

Further aspects of the invention are subject matter of the subclaims.

An embodiment of the invention is described below in greater detail with reference to the accompanying drawings.

Fig.1 is a block diagram and scematically shows a device for checking a semiconductor sample with modulated light of different wavelengths and for measuring the surface photo voltage.

Fig.2 scematically shows the set up of a device for illuminating the semiconductor sample with modulated light of different wavelengths and for measuring the surface photo voltage.

Fig.3 shows the distribution of the surface photo voltages generated with a device according to Fig. 2 by three light beams of different wavelengths modulated with different phases.

In Fig.1 numeral 10 denotes a computer for data processing and controlling. the computer 10 controls an illumination unit 12. The illumination unit 12 generates, as described below, three light beams with different wavelengths, which are modulated with the same frequency but with different phases. The light beams and their modulation are monitored by an excitation monitor 14. The excitation monitor provides the distribution of the photon fluxes of the three light beams. Such distributions are switched on the computer 10 for the data processing. A testing probe 16 measures the surface photo voltage generated by excitation with the light beams at one point of a semiconductor sample 18.

The distribution of this surface photo voltage is fed to the computer 10 via a data receiving unit 20. The semiconductor sample 18 is mounted on a sample table 22 which is moveable under the control of the computer 10 for scanning the surface of the semiconductor sample 18.

The set up is schematically shown in Fig. 2. The sample 18 is illuminated at a measuring point by a plurality of light sources. In Fig.2 three such light sources 24, 26, and 28 are shown. The light sources 24, 26 and 28 form the illumination unit 12 in Fig.1. The light sources 24, 26 and 28 are preferably laser diodes or luminescent diodes. The light sources emit light beams 30, 32, 34 with different wavelengths. The light beams 30, 32, 34 are each collimated by a collimating optics 36, 38 and 40, respectively, on end surfaces of fibers 42, 44 and 46, respectively. A fiber coupler 48 superimposes the light beams guided in the fibers 42, 44 and 46. The superimposing light beams are then guided through a fiber 50 to a measuring point 52 on the surface of the semiconductor sample 18.

The testing probe 16 measures the surface photo voltage at the measuring point 52 on the surface of teh semiconductor sample 18. Such testing probes are well known to the person skilled in the art and are, therefore, not described here in greater detail.

A modulator assembly 54 modulates the light emission of the light sources 24, 26 and 28 and, thereby, the photon flux of the light beam 30, 32 and 34, respectively. The modulation is carried out periodically with the same frequency for all light beams 30, 32 and 34. The modulation function, however, are phase shifted amongst each other. Fig.3 shows a preferred form of a modulation function and the respective distribution of the surface photo voltage generated thereby. The modulation functions essentially correspond to oneway-rectifyed sine functions, i.e. the positive half-waves of the sine function. The modulation functions are essentially zero between the positive half-waves. In Fig.3 numeral 56 denotes the modulation function or the corresponding surface photo voltage of the light source 24. Numeral 58 is the modulation function of the light source 26 and numeral 60 denotes the modulation function of the light source 28. The three modulation functions 56, 58 and 60 are phase-shifted by 120° relative to the frequency of the

modulation functions. For any number n of light sources the phase shifts preferably is $2\pi/n$. In Fig.3 numeral 62 denots the sum of the photon fluxes or surface photo voltages, respectively. It can be seen, that the photon flux of the superimposed light beams, i. e. the sum of the photon fluxes of all light beams, at all times lies within a tolerance range, which is considerably smaller than the sum of the photon fluxes. Thereby approximately constant illumination conditions for all wavelengths are obtained at the measuring point 52. By the selection of the modulation functions 56, 58, 60 a rest wave structure is obtained for the sum of the photon fluxes and the surface photo voltage SPV. This facilitates the attribution of the different components of the surface photo voltage to the individual light sources 24, 26, 28 and thereby to the different wavelengths.

The modulation functions are fed to a quick A/D-converter or a plural lock-in-circuit 70 by a modulator assembly 54 with lines 64, 66 and 68. The lock-in-circuit 70 receives the surface photo voltage from a voltage amplifier. The lock-in-circuit 70 forms a part of the data receiving unit 20 and provides signals at the computer 10 according to the different modulated light sources 24, 26 and 28 and the components of the surface photo voltage caused by the corresponding wavelengths of the exciting light.

A constant, non-modulated photon flux is guided to the measuring point 52 from a light source 74 and a fiber 76 or a bundle of fibers. This photon flux only provides a non-modulated component of the surface photo voltage. It does not generate a modulated signal with the modulation frequency and therefore does not disturb the result of the measurement. This non-modulated photon flux can be used to saturate surface states or traps for minority charge carriers over the entire thickness of the semiconductor sample 18.

A photo detector 78 receives light through a bundle 80 of fibers which is reflected at a measuring point 52 from the surface of the semiconductor sample 18. From the photon flux incident from the fiber 50 and the photon flux reflected on the surface of the semiconductor sample 18 the effective photon flux actually entering the semiconductor sample can be determined. The signal of the photodetector 78 is fed to the lock-in-circuit 70 through an amplifier.

A temperatur sensor 79 measures the temperature of the semiconductor sample 18. The signal of the temperatur sensor 79 is fed to the computer 10 or the lock-in-circuit 70, respectively, through an amplifier 81.

The described assembly operates as follows:

The exciting photon flux $\phi_{exc}(t)$ entering the semiconductor sample is

$$\Phi_{exc}(t) = \Phi_{bias} + \sum_{j=1}^{n} \Phi_j * M(t) * \exp(i\varphi_j) * T_{reflex}(\lambda_j)$$

wherein ϕ_{bias} is the photon flux of the background light, ϕ_j and φ_j representing the amplitude and the phase shift of the light beam at the wavelength j, M(t) is the modulation function used for modulating the light sources 24, 26, and 28 and $T_{reflex}(\lambda_j)$ the reflection correction for the j^{th} wavelength due to the reflection of the surface of the semiconductor sample 18. The letter i denotes the imaginary number.

The reflection correction $T_{reflex}(\lambda_j)$ is calculated from the simultaneously measured portion of the exciting light which is reflected from the surface of the semiconductor sample 18 into the bundle of fibers 80. At the end of the bundle of fibers 80 a photo detector with a large detection area detects the light. The electrical signal generated from the photo detector 78 is finally fed to the computer 10 through an amplifier 82. By suitable adjustment of the transmission function of the bundle 80, the characteristics of the photo detector 78 and the reflection of the optics of the SPV testing probe head before the automatized measuring process the actual reflected light at each measuring point 52 of the semiconductor sample 18 at each used wavelength can be determined and can be used to correct the photon flux. The exciting photon flux ϕ_{exc}, the photon flux penetrating the semiconductor sample, is computed from the incident photon flux ϕ_j for each wavelength.

The simultaneous measurement of the reflected light renders the assembly and the method independent from the theoretical photon flux corrections.

In a modified embodiment the light reflected at the surface of the semiconductor sample can be directly measured within the testing probe head by means of a suitable beam splitter in the form of a partial beam derived from the main beam.

The amplitudes and phases of the signals of surface photo voltages generated by exciting with n wavelengths are simultaneously measured with the testing probe 16 in connection with the data receiving unit 20 and fed to the computer 10 for further signal processing. the data receiving unit 20 is a quick analogue-digital-converter, which scans the signal of the surface photo voltage with a scanning rate which is higher than 2nf, wherein f is the modulation frequency. In order to improve the signal-to-noise ratio and to ensure that all components of the different wavelengths are exposed to the same scanning conditions, the signal is detected over a plurality of the modulation frequency and stored. After the detection of the data the signal distribution for extracting the diffusion length is processed. The signal distribution is smoothed by suitable means, for example a digital filter applied to the signal in the computer program, to reject noise components not belonging to the surface photo voltage. The signal can also be averaged zu a signal distribution, in such a way that finally a final signal distribution is obtained with a window of one modulation period, i.e. a window with a time interval of 1/f.

The computer 10 is fed with a signal representing the change of the surface photo voltage by excitation with the superimposed, modulated light beams 24, 26, 28:

$$\Delta V_{SPV}(t) = \sum_{j=1}^{n} \Phi_j * M(t) * \exp(i\varphi_j) * T_{reflect}(\lambda_j) * T_{SPV}(\lambda_j)$$

Therein M(t) is the signal distribution of the driver signal of the modulator assembly which is used to modulate the light source 24, 26 and 28, i.e the $j=1^{st}$, $j=2^{nd}$ and $j=3^{rd}$ light source, i.e. the above mentioned modulation function, φ_j denotes the phase shift of the j^{th} exciting beam 30, 32, 34, i.e. the $j=1^{st}$, $j=2^{nd}$ and $j=3^{rd}$ exciting beam, T_{reflex}

denotes the correction function taking into account the light reflected at the surface of the semiconductor sample 18 and T_{SPV} is the modification by which the effect caused by the surface photo voltage itself is taken into account. The transmission function $T_{reflex}(\lambda_j)$ resulting from the light reflected for each wavelength measured with the photo detector 78 as described above is a correction factor for the amplitude of the j^{th} excitation beam. In the embodiment of Fig.2 the distribution M(t) of the modulation function is provided by the modulator assembly 54 controlling the light sources according to such a synthetically derived function. The distribution M(t) also can be measured from the light emitted by the light sources 24, 26 and 28.

The effect of the surface photo voltage $T_{SPV}(\lambda_j)=A_{SPV}(\lambda_j)\exp(i\Psi_j)$ represents a change of the amplitude and the phase of each component with the corresponding wavelength. The relationship between the exciting photon flux and the change of the surface photo voltage caused thereby is given by a real "adjustment factor" A_{SPV} and a phase shift Ψ. The surface of the semiconductor sample operates in a similar way as a time function element with capacitor and resistor. The above equation can be written as:

$$\Delta V_{SPV}(t) = \sum_{j=1}^{n} \Phi_j * M(t) * \exp(i\varphi_j) * T_{reflex}(\lambda_j) * A_{SPV}(\lambda_j) * \exp(i\psi_j)$$

By adapting the amplitudes $A_{SPV}(\lambda_j)$ and the phase shifts $\exp(i\Psi_j)$ the signal distribution resulting from the superposition of the modulation frequencies with the corresponding photon fluxes of the different wavelengths can be adapted to the measured signal ΔV_{SPV} of the surface photon voltage. Practically the graphs 56, 58 and 60 ($\phi_j M(t)$) corrected with respect to the wavelength dependent reflectivity, are changed in amplitude and phase according to a certain algorithm until the sum of the obtained signal distribution coincides with the measured distribution of the modulation ΔV_{SPV} of the surface photon voltage. The graph 90 in Fig.3 shows the adaption to the thus obtained graph distribution. The graph 92 shows the measured distribution of the surface photon voltage.

The thus obtained values for the phase shift Ψ_j can be used to correct the amplitude of the surface photon voltage SPV with respect to the dependency of the modulation frequency. (Nakhmanson "Solid State Electronics" 1975, Vol 18, P.617).

The corrected values $A^*_{SPV}(\lambda_j)$ directly are the relationships between the photon fluxe and the amplitude of the surface photon voltage SPV for the j^{th} wavelength. Thereby the diffusion length L of the minority charge carriers can be determined for each measuring point directly from $A^*_{SPV}(\lambda_j)$.

Two computation methods can be applied:

The approximation for short diffusion lengths uses the above mentioned relationship

$$\Delta V_{SPV} \propto \Delta n = \Phi_{eff} \frac{1}{S + D/L} * \frac{1}{1 + z/L}$$

This relationship is valid, if the diffusion length is shorter than about half the thickness of the sample. If two wavelengths are assumed the values A_1 and A_2 represent the relationships $\Delta V_{SPV\text{-}1}/\phi_1$ and $\Delta V_{SPV\text{-}2}/\phi_2$. L can be derived therefrom using the above equation as

$$L = (\frac{A_2}{A_1} z_2 - z_1) / (1 - \frac{A_2}{A_1}),$$

wherein z_j are the penetration depths at the j^{th} wavelength.

As mentioned above this approximation for short wavelengths is only valid for a relative to the diffusion length large thickness of the semiconductor sample. However, today high quality semiconductor material has a diffusion length comparable with the thickness of the semiconductor sample or even larger than that. In such a case the effect of the rear surface recombination has to be taken into account by fitting the results into the above

mentioned more general equation. At first the signal ΔV_{SPV} is normalized to for example the signal occurring at the shortest wavelength λ_{min}. This normalization provides:

$$\Delta V_{SPV} norm(\lambda) = \frac{\Delta V_{SPV}(\lambda)}{\Delta V_{SPV}(\lambda_{\min})}$$

By such a normalization the above given prefactor C is eliminated. With the normalized signal (the adding of the term "norm" being omitted) results in:

$$\frac{\frac{\Delta V_{SPV}(\lambda)}{\Phi_{eff}(\lambda)}}{\frac{\Delta V_{SPV}(\lambda_1)}{\Phi_{eff}(\lambda_1)}} \propto \frac{L^2}{L^2 - z^2}\left[\left(z\frac{S_b}{D} - 1\right)\left(\cosh\left[T/L\right] - \exp\left[\frac{-T}{z}\right]\right) + \left(\frac{z}{L} - \frac{S_b L}{D}\right)\sinh\left[T/L\right]\right]$$

R is the reflectivity on the front side of the semiconductur sample 18, S_b is the velocity of the surface recombination on the rear side, z is the penetration depth of the light, L is the diffusion length of the minority charge carriers, D is the diffusion constant of the minority charge carrier and T is the thickness of the semiconductor sample 18.

If n values A_1, A_2,...A_n are used (i.e. $\Delta V_{SPV\text{-}1}/\phi_1$, $\Delta V_{SPV\text{-}2}/\phi_2$,... $\Delta V_{SPV\text{-}n}/\phi_n$), as they result from the measurement for the ratios $\Gamma_j = A_j/A_1$, i.e. for the values A_j normalized against A_1 it is obtained

$$\Gamma_j \propto \frac{L^2}{L^2 - z_j^2} * \left[\left(z_j\frac{S_b}{D} - 1\right)\left(\cosh\left[T/L\right] - \exp\left[-T/z_j\right]\right) + \left(\frac{z_j}{L} - \frac{S_b L}{D}\right)\sinh\left[T/L\right]\right].$$

If L and S_b are taken as free adaption parameters the diffusion length and the rear velocity of the surface recombination can be derived from the n-1 equations resulting from the above expression. This method is not dependent on any assumptions about the rear velocity of the surface recombination. As an additional parameter, i.e. S_b, is directly derived from the measurement at least three wavelengths are needed for this method.

Claims

1. Method for determining a characteristic of a semiconductor sample forming a surface with the steps:

   (a) simultaneously illuminating an area on the surface of a semiconductor sample with superimposed exciting light beams with a plurality of wavelengths,

   (b) modulating the light beam of the different wavelengths with the same frequency, but different phases,

   (c) selecting a modulation function and its phases in such a way, that the sum of the photon fluxes of all light beams at all times lies within a tolerance range, the tolerance range being considerably smaller than the sum of all photon fluxes,

   (d) simultaneously phase-dependent measuring of the components of the surface photo voltage caused by the different light beams and

   (e) determining the characteristic of the semiconductor sample from the relationships between the components and the respective wavelengths.

2. Method according to claim 1, **characterized in that** the characteristic to be determined is the diffusion length of minority charge carriers.

3. Method according to claim 2, **characterized in that** the determination of the diffusion length of the minority charge carriers is determined by fitting value pairs

of surface photo voltage ΔV_{SPV} and wavelengths λ or the penetration depth z of the light into the equation

$$\frac{\frac{\Delta V_{SPV}(\lambda)}{\Phi_{eff}(\lambda)}}{\frac{\Delta V_{SPV}(\lambda_1)}{\Phi_{eff}(\lambda_1)}} \propto \frac{L^2}{L^2 - z^2}\left[\left(z\frac{S_b}{D} - 1\right)\left(\cosh\left[T/L\right] - \exp\left[\frac{-T}{z}\right]\right) + \left(\frac{z}{L} - \frac{S_b L}{D}\right)\sinh\left[T/L\right]\right]$$

wherein S_b is the velocity of the rear surface recombination, L is the diffusion length of the minority charge carriers, D is the diffusion constant of the minority charge carriers and T is the thickness of the semiconductor sample.

4. Method according to any of claims 1 to 3, **characterized in that** the intensity distribution of the different light beams is measured and used for determining the respective compontents of the surface photo voltage.

5. Method according to any of claims 1 to 4, **characterized in that** additionally the photon flux reflected from the surface of the semiconductor sample is measured for the determination of the effective photon flux really penetrating the semiconductor.

6. Method according to any of claims 1 to 5, **characterized in that** the temperature of the semiconductor is measured for taking into account the dependence of the wavelength dependent penetration depth of the photon flux on the temperature.

7. Method according to any of claims 1 to 6, **characterized in that**

(a) the modulation of each light beam is carried out with a modulation function essentially corresponding to the positive half-waves of a sine function, and

(b) the modulation function of the different light beams are phase shifted by essentially $2\pi/n$ relative to the modulation frequency which is the same for all light beams, wherein n denotes the overall sum of the superimposed light beams.

8. Method according to any of claims 1 to 7, **characterized in that** the semiconductor is step-by-step moved relative to the superimposed light beams.

9. Device for determining a characteristic of a semiconductor sample, comprising:

(a) means (22) for mounting a semiconductor sample (18) forming a surface,

(b) a plurality of light sources (24, 26, 28) with different wavelengths each of the light sources generating a light beam (30, 32, 34),

(c) means (42, 44, 46, 48, 50) for superimposing such light beams for the generation of an combineded light beam simultaneously comprising the wavelengths of all light sources and falling on an area of the surface (52) of the semiconductor sample (18),

(d) modulating means (54) for modulating the light sources (24, 26, 28) with different modulating functions,

(e) means (16) for measuring the surface photo voltage generated in the area of the surface and showing a signal distribution, and

(f) signal evaluation means (70) for determining the signal distribution components of the surface photo voltage based on the various light beams (30, 32, 34) with various wavelengths by means of the modulating functions of the various light sources (24, 26, 28),

characterized in that

(g) modulation means (54) operating with the same frequencies for all light sources,

(h) the modulation means (54) operate with phaseshifts among the different light sources, and

(i) the modulation functions and its phases are selected in such a way that the sum of all photon fluxes lies within a tolerance range, which is considerably smaller than the sum of the photon fluxes.

10. Device according to claim 8, **characterized in that**

(a) modulation means are provided for modulating each of the light beams (24, 26, 28) is modulateable by modulating means with a modulation function (56, 58, 60) essentially corresponding to the positive half-waves of a sine function, and

(b) the modulation function (56, 58, 60) of the different light beams (30, 32, 34) are phase shifted by essentially $2\pi/n$ relative to the modulation frequency which is the same for all light beams (30, 32, 34), wherein n denotes the overall sum of the superimposing light beams (30, 32, 34).

11. Device according to claim 9 or 10, **characterized in that** the characteristic to be determined is the diffusion length of minority charge carriers.

12. Device according to any of claims 9 to 11, **characterized in that** the light sources (30, 32, 34) are laser diodes.

13. Device according to any of claims 9 to 11, **characterized in that** the light sources (30, 32, 34) are luminescence diodes.

14. Device according to claim 12 or 13, **characterized in that** the means for superimposing the ligth beams are provided with a fiber coupler (48) wherein the different light beams can be coupled through entrance side fibers (42, 44, 46) and which is connected to an exit side fiber (50) receiving the superimposed light beam

and guiding it to an illuminated area (54) on the surface of the semiconductor sample (18).

15. Device according to any of claims 9 to 14, **characterized by** means (78, 80) for measuring the portion of the light beam reflected at the surface of the semiconductor sample (18).