

High Sensitivity Technique in Contactless Measurement of Silicon Wafer Carrier Lifetimes.

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Abstract

This paper presents semiconductor carrier lifetime contactless measurement technique to increase the measurement sensitivity by using a slot line characterized by very narrow slot waveguide and a consideration of a conventional figure of merit to evaluate the sensitivity in the measurement techniques.

Contactless measurement techniques of minority carrier lifetimes in semiconductors are expected to be an effective tool especially to evaluate a degree of crystalline perfection of silicon wafers. The principles of the main techniques are based on the photo-conductive decay method using microwaves¹⁻⁷). It is usually difficult to measure the carrier lifetimes of the silicon wafer having low resistivity and a short lifetime by such techniques. Because, carriers excited by a illumination light are so few compared with the ones in thermal equilibrium that the signal output induced by the change of the photo-conductance is negligible. In order to realize the lifetime measurement of such wafers, it is needed to increase sensitivity in the measurement techniques. Some techniques to increase the sensitivity have been proposed^{4,6}). However, it can not be yet said that sufficient sensitivity for a practical use in the measurement for such wafers has been obtained.

This paper presents a technique to increase the sensitivity by using a slot line characterized by very narrow slot waveguide and a consideration of a conventional figure of merit to evaluate the measurement sensitivity in the measurement techniques. The signal output voltage ΔV_0 involving the information of the lifetime has been given⁶) in the contactless techniques using reflected microwaves, as in eq. (1). The sensitivity may be estimated conventionally from the magnitude of ΔV_0 .

$$\Delta V_0 = K_d \left(K_r K_c V_i \frac{\Delta G}{G} \right)^\beta R_L \quad (1)$$

Where, K_d and β are the detectivity and the index in a detection characteristics ($i_0 = K_d v^\beta$) of a detection diode⁶), respectively, and K_r : the coefficient introduced from the property of the reflection coefficient⁶), K_c : coupling coefficient between the the wafer specimen and electric field leaked from the detection unit, V_i : the incident microwave line voltage, R_L : the resistance of the detection diode, G : the equivalent conductance of the specimen in thermal equilibrium and ΔG : the equivalent conductance-change due to the excess carriers generated by the illumination of the pulse light to satisfy approximately steady-state injection. In

order to increase the sensitivity, here, we try to increase K_c which is drastically depends on the detection unit. It has been reported that the high sensitivity is obtained from the convergence of the electric field based on parallel resonance of strip-lines (slot line, coplanar line, micro stripline)⁶⁾. If the field converges by further narrowing the slot-width, the higher sensitivity might be expected. So, a preliminary experiment to check the expectation was done. Figure 1 shows two dimensional distributions of the electric field measured along and perpendicularly across the slot. As seen in Fig. 1(b), the field converges as the slot width narrows, so that the field intensity becomes strong as seen in Fig. 1(a). Figure 2 shows the slot-width dependences of the relative sensitivity measured for two kinds of silicon wafers. From the results, it can be recognized that the sensitivity becomes high as the slot width narrows, as expected.

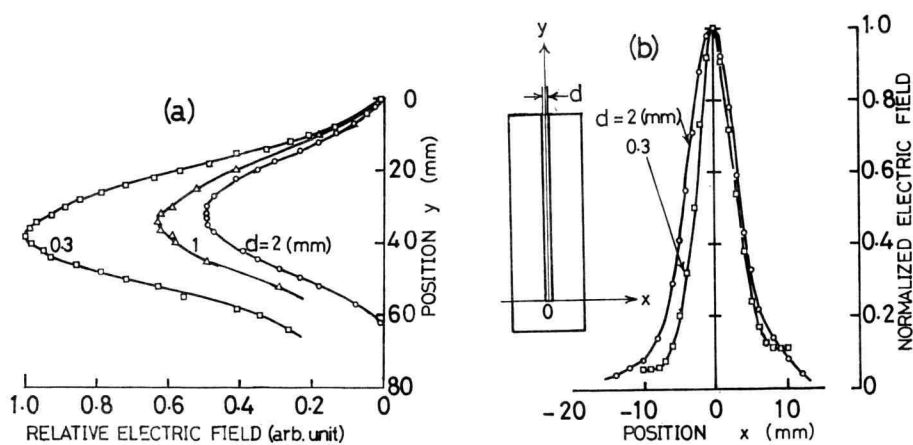


Fig. 1 Electric field intensity distribution along y direction (a) and x direction (b).

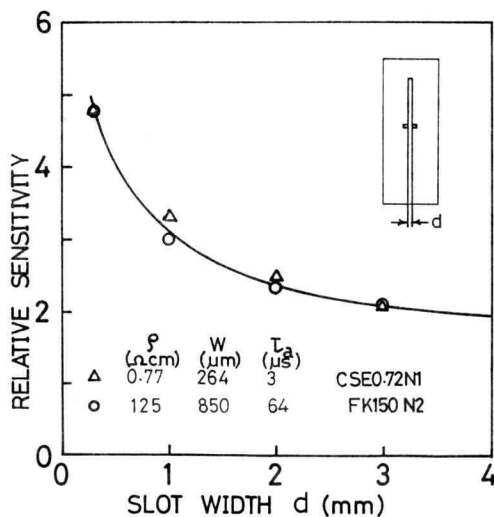


Fig. 2 Slot-width dependences of the sensitivity. w: specimen thickness

$\Delta G/G$ in eq. (1) is related to the characterizations of the illumination light and the wafer specimen, as in eq. (2), to simplify, by introducing the factor K_s to express the ratio the space shaped by the carriers generated to the ones in which the electric field penetrates.

$$\frac{\Delta G}{G} = K_s \frac{\Delta \sigma}{\sigma} = K_s \frac{e(\Delta n \mu_n + \Delta p \mu_p)}{\sigma} = K_s \frac{(1-r)\eta I_L}{h\nu} \frac{e(\mu_n + \mu_p)}{V} \rho \tau_a \quad (2)$$

where, η : an effective quantum efficiency of the light, I_L : light intensity, $h\nu$: photon energy, r : a reflection coefficient of the light on the specimen surface, e : an electron charge,

Table 1. List of the silicon specimens. The size of the specimens was formed to be 1 cm square. w: specimen thickness

	Specimen name	ρ (Ωcm)	τ_a (μs)	w (μm)
☆	CSE0.005N1	0.0027	8.0	226
▲	CSE0.72N1	0.77	3.0	264
●	CSE0.9N1	0.92	3.5	254
○	CK2P1	4.1	4.5	406
■	CK12P1	14	7.0	350
⊙	CSE19P1	19	0.93	188
⊖	CK30P1	39	12	394
△	FK40P1	40	1.6	250
□	FT50P1	52	2.5	243

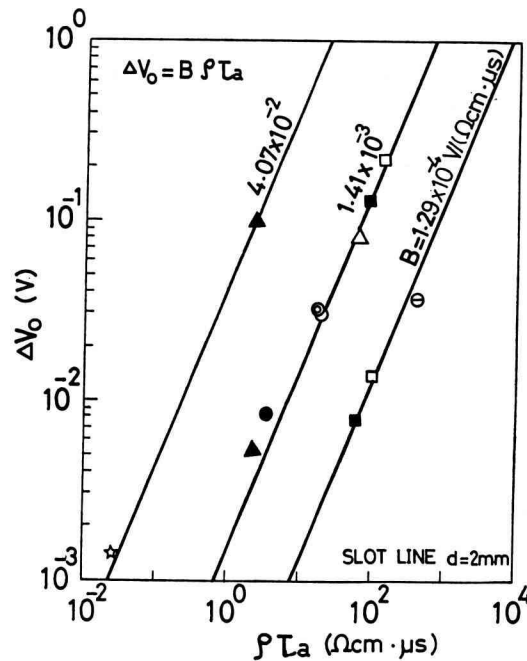


Fig. 3 ΔV_0 versus $\rho \tau_a$

μ_n, μ_p : mobility of electron and hole, respectively, V : the effective volume* of the carriers generated, ρ : resistivity of the specimen and τ_a : a carrier lifetime. Equation (1) is also written as in relation $\Delta V_0 = B\rho\tau_a$ by replacing by B the other terms excepted the term concerned with the specimen itself. ΔV_0 and τ_a were measured⁶⁾ for various specimens of silicon wafers as listed in Table 1 by using the slot line with 2 mm slot-width under $V_1 = 2.59$ V, $R_L = 1$ k Ω , $\beta = 1$ (linear detection) and those resistivities were measured by four-probes method. Figure 3 shows ΔV_0 plotted against $\rho\tau_a$. These data can be seen to fall on the straight lines with the constant gradient B . This means that the above relation is reasonable. ΔV_0 may increase in proportional to the light intensity. The data plotted in the vicinity of the line $B = 1.41 \times 10^{-3}$ V/($\Omega\text{cm}\mu\text{s}$) show the experimental data in the case of 11 times of I_L in $B = 1.29 \times 10^{-4}$. The data fall on the line with $B = 1.41 \times 10^{-3}$ estimated from the multiple of I_L . Furthermore, the data in $B = 4.07 \times 10^{-2}$ show the ones

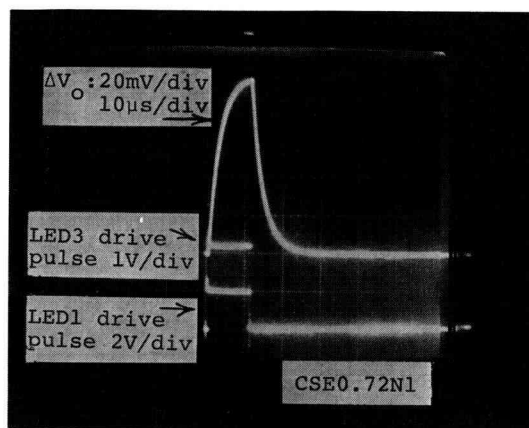


Fig. 4 An example of the output signal waveform observed.

in I_L multiplied by 7.9 times by use of four LED's and V_i multiplied by 3.7 times by the increase of oscillation output power. Those data also fall on the line estimated from the multiples. Thus, due to the reasonability of the relation, the magnitude of B or $\rho\tau_a$ can be considered conveniently as the figure of merits of the sensitivity. The maximum B obtained in this arrangement is 4.07×10^{-2} V/($\Omega\text{cm}\mu\text{s}$), as evidenced by the output voltage waveform as shown in Fig. 4 observed for the data (\blacktriangle) in the inset of Fig. 3. In accordance with the another figure of merit, the $\rho\tau_a = 0.1$ $\Omega\text{cm}\mu\text{s}$ was obtained under $\Delta V_0 = 5$ mV.

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* The depth of penetration of the light for the wavelength ($\sim 950\text{nm}$) used conventionally is $50\mu\text{m}$, so it is considered that the volume scarcely depends on the wafer thickness for the conventional thicknesses ($> 200\mu\text{m}$).

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