PHOTOCONDUCTIVITY OF P-TYPE SI SINGLE CRYSTALS WITH DIFFERENT TREATMENT

By

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Abstract

The spectral distribution and mechanism of photoconductivity of P-type Si single crystal with different surface treatments were measured using monochromatic square light pulses of different wavelengths and different chopping frequencies giving $\Delta E = 1.06$ e. v., independent on the surface treatment, while the photoconductivity $\Delta \sigma$ depends on the surface condition at short wavelength side. The average carrier life time τ is found to be in the order of magnitude of 10^{-6} sec. The dependence of τ upon the light intensity, excess illumination and wavelength λ is also studied.

Introduction

Si has a great practical importance due to it's applications in infrared, radar detectors and solar batteries. Therefore a great deal research work has been carried out on the physical properties of Si in the past few years. (1-5)

The aim of the present work is to study the effect of surface treatment of P-type Si single crystal's photoconductive properties.

The dark conductivity σ_o of any semiconductor can be expressed in the following relation

$$\sigma_o = e\,(n_o\mu_n + p_o\mu_n) \quad \ldots\ \ldots\ \ldots\ \ldots\ \ldots\ \ldots\ \ldots \quad (1)$$

where e is the electronic charge, n_o and p_o are the densities of free electrons and holes respectively and μ_n , μ_p are the electron and hole mobilities respectively. The excess non equilibrium carriers Δ n and

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Δ p produced by the absorption of optical radiation increases the conductivity by a value $\Delta\sigma$ called the photoconductivity, where :

$$\Delta\sigma = e(\Delta n \mu_n + \Delta p \mu_p) \quad \ldots\ \ldots\ \ldots\ \ldots\ \ldots \quad (2)$$

Considering the steady state conditions, the non equilibrium carriers are given by

$$\begin{matrix} \Delta n \\ st \end{matrix} = \beta K I \tau_n$$
$$\begin{matrix} \Delta p \\ st \end{matrix} = \beta K I \tau_p \quad \ldots\ \ldots\ \ldots\ \ldots\ \ldots\ \ldots\ \ldots \quad (3)$$

The steady state photoconductivity is given by

$$\Delta\sigma_{st} = e \beta K I (\mu_n \tau_n + \mu_h \tau_h) \quad \ldots\ \ldots\ \ldots\ \ldots\ \ldots \quad (4)$$

, where β is the quantum yield, K is the absorption coefficient, I is the intensity of light and τ is the life time of the charge carriers, (1-2-6-7) which is widely affected by the recombination and trapping processes in the semiconductor. These processes depend on the surface condition of the material due to polishing, etching or exposure to different kinds of gases.

According to Devore (8) analysis $\Delta\sigma_{st}$ (bulk) $>>\Delta\sigma_{st}$ (surf) and the ratio between the two values is directly proportional to the surface recombination velocity s, thus in the steady state

$$\frac{\Delta\sigma \text{ (bulk)}}{\Delta\sigma \text{ (surf)}} \alpha \ s \quad \ldots\ \ldots\ \ldots\ \ldots\ \ldots \quad (5)$$

The photoconductivity of Si was studied by Teal (4,9) giving a maximum photoconductivity at $\lambda_{1/2} = 1.05\ \mu$ corresponding to $\Delta E_g = 1.12$ e.v. Ivanof (10), Kontsevoi (11), Reshba (12), Bath (13) and Morten (14) studied the effect of surface conditions on the spectral distribution of the photoconductivity giving different values of S for different surface treatment of thin slabs of Si. The dependence of $\Delta\sigma$ of Si on the intensity I of illumination was investigated by Pettusevich (15), Talat and Yunovich (16) and Cutler (13). The life time τ was also determined by Hograth (17) giving a value of 80 x 10^{-6} sec for P-type Si. The activation energy of impurities was measured by Collins (18). The recombination and trapping of non equiliburim carriers in Si was studied by Mayres and Hornbeck (19).

Experimental Procedure

Thin specimens with rectangular cross section of P-type Si single crystal, oxidized or polished or etched with different etchants,

were used in the present work. For the purpose of contact we used silver paste, which gave a satisfactory ohmic contact with the material under investigation. The optical system and electrical circuit used for measurements is shown in fig. (1). The light source S is a band filament tungsten lamp (1000 w), cooled with compressed air. Light is focussed on the monochromator slit M, where it is chopped by a toothed disc C, rotated by a stable D.C. motor m to obtain systematic square light pulses of different frequencies (4000 - 6500 c/sec). The diaphragm D is used for the variation of light intensity. The monochromatic chopped light is then focussed on the specimen r, which is connected to a load resistance R (R = r) throught a D.C. supply V. The load resistance R is connected to an oscilloscope through an A.C. wide band amplifier A. The alternating voltage v received at amplifier, observed on the oscilloscope and measured by the millivalve voltmeter v is proportional to the photoconductivity $\Delta \sigma$, where

$$\frac{\Delta \sigma}{\sigma_0} = \frac{4 V}{V} \quad \ldots \ldots \ldots \ldots \ldots \ldots \quad (6)$$

Assuming $R_L = r$ and $\frac{\Delta \sigma}{\sigma_0} << 1$

This experimental arrangement is used for the determination of :

a- The spectral distribution of the steady state photoconductivity $\Delta \sigma$

b- The life time τ from the frequency dependence method ([7,20]).

c- The life time τ evaluated from the oscillograms ([7,20]).

Results and Discussion

Fig. (2) shows the spectral distribution of steady state photoconductivity at room temperature of oxidized P-type Si single crystal at different four intensities of ratio 1 : 2 : 4 : 8 for curves a, b, c and d respectively. Fig. (3) shows the same relation for P-type Si single crystal with various surface treatments at constant intensity. It is clear that all the curves in fig. (2) and (3) show a peak a λ = 1.04 giving $\lambda_{1/2}$ = 1.17 corresponding to optical activation energy Δ E = 1.06 e.v. in good agreement with values reported by other authors ([9,4]). Fig. (3) shows a steep fall at ahort wave length indicating that the photoconductivity for etched sample f is higher than that for polished sample a. This behaviour is due to surface recombination resulting from changing the surface condition which affects the

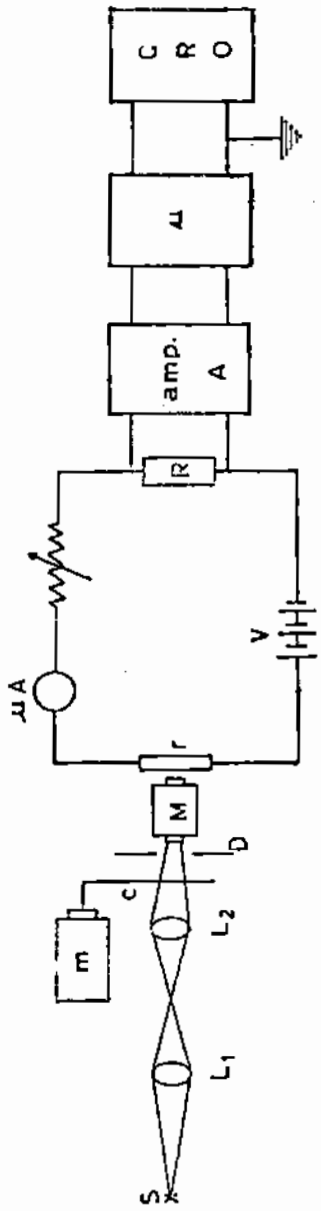


Fig. 1 — Digram of the arrangement employed for measuring the A. C. photoconductivity using modulated monochromatic light.

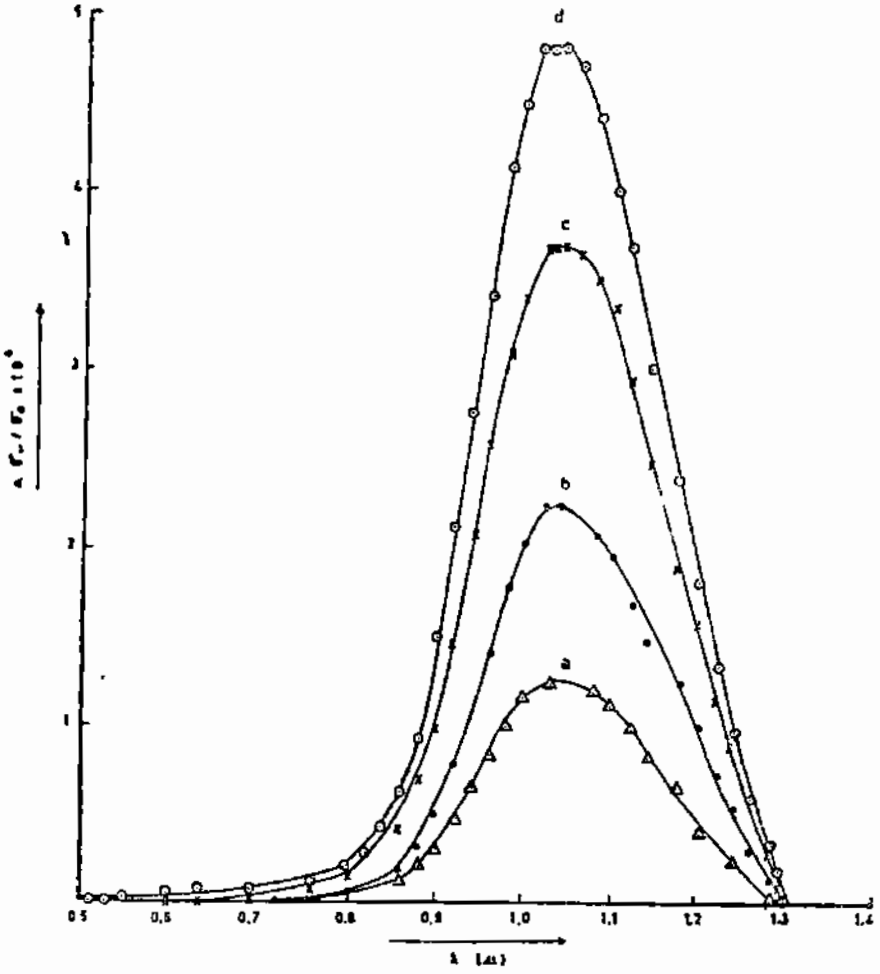


Fig. 2 — The spectral distribution of oxidized p. type silican at different intensitiesc.

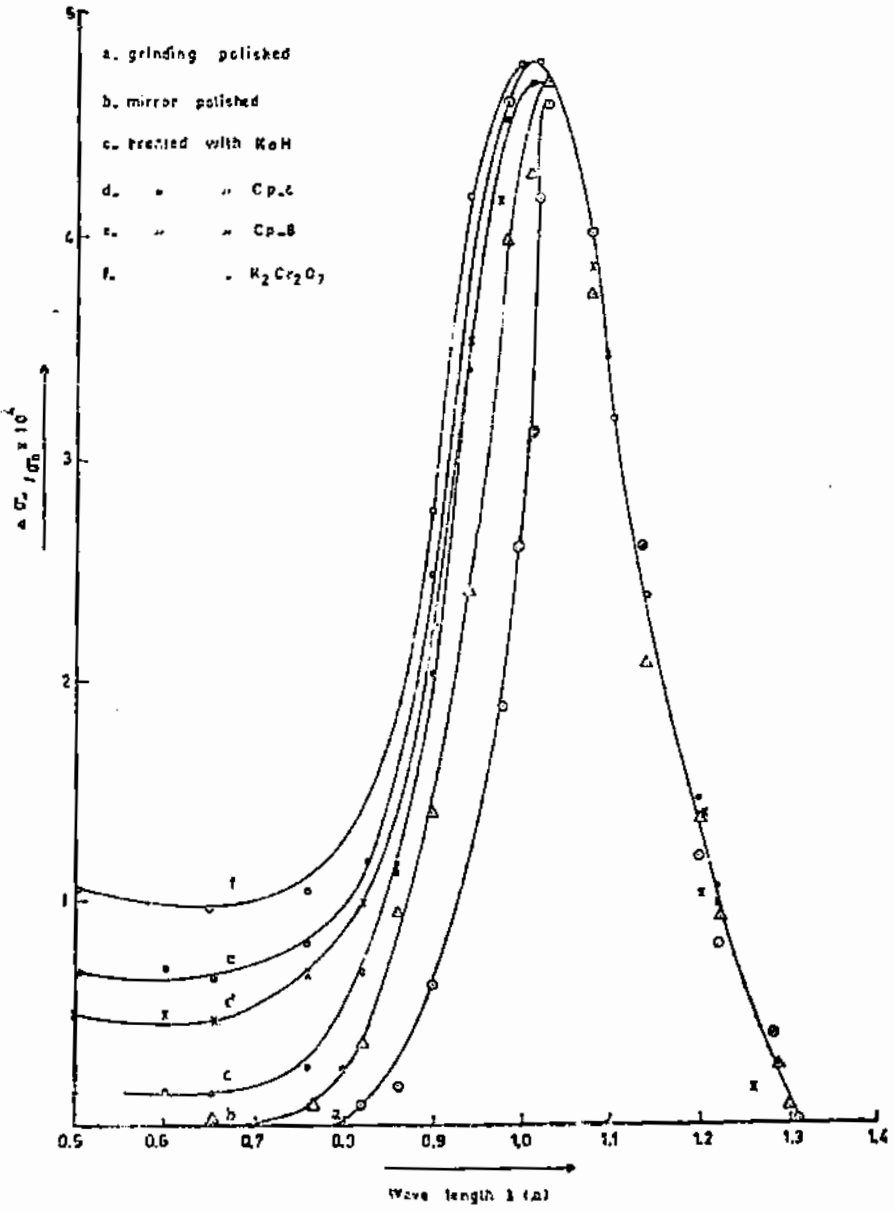
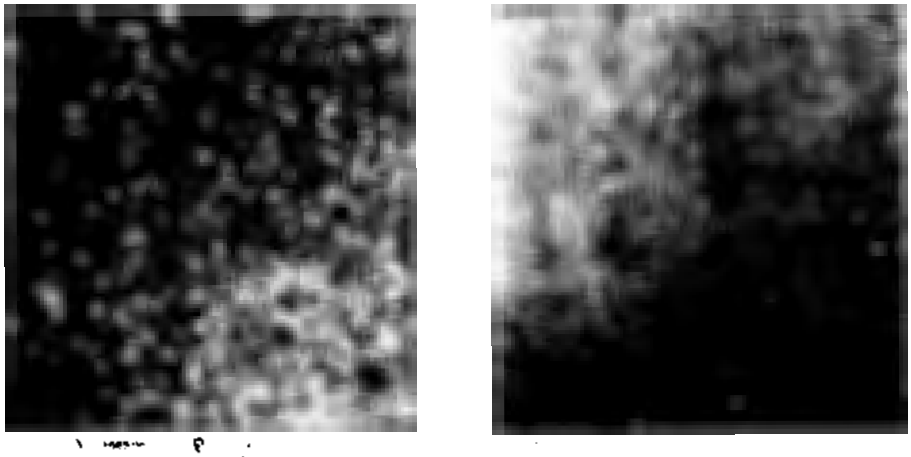


Fig. 3 — Spectral distribution of P-type silicon for various surface treatments.

number of defects acting as surface states recombination centres produced by mechanical or chemical treatments of the sample as shown in photographs a and f in fig (4), where the number of defects is large for sample a, while it is reduced for sample f due to etching. According to fig. (3) and equation (5) : S_f (polished) $> S_a$ (etched). This conclusion agrees with results of other authors. [10-15]

Fig. (5) shows the dependence of the photoconductivity singal on the illumination intensity I, showing that $\Delta\sigma \propto I$ at low intensities (linear recombination), while $\Delta\sigma \propto \sqrt{I}$ at high intensities (quadratic recombination) as verified in fig. (6).



(a) (f)

Fig. 4 — Photographs of polished and etched samples.

Fig. (7) represents the photoconductivity frequency dependence at $\lambda = 1.14$ at different intensities of ratio 1 : 2 : 4 : 8 : 16 for curves a, b, c, d and e respectively. From these curves the life time τ is calculated according to the following relation.

$$\frac{\Delta\sigma}{\Delta\sigma_{st}} = \text{tansh } \frac{1}{4f\tau} \quad \ldots \ldots \ldots \ldots \ldots \ldots (7)$$

giving $\tau = 68$, 61, 51, 42 and 37 μ sec. respectively. Values obtained are represented graphically against log I in fig. (8), indicating that τ decreases with increasing I. Such behaviour may be due to trapping process of carriers.

The relaxation oscillogram method was also used for the determination of τ . Fig. (9) shows the variation of $\Delta\sigma$ with time t during the decay evaluated from one of the obtained oscillograms giving a straght line as expected from the relation

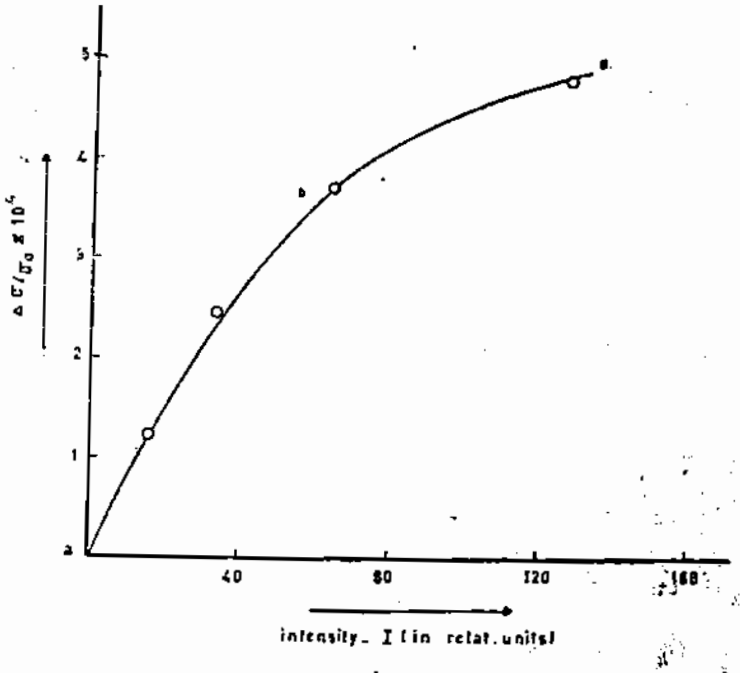


Fig. 5 — The dependence of $\frac{\Delta\sigma}{\sigma}$ on illumination intensity I.

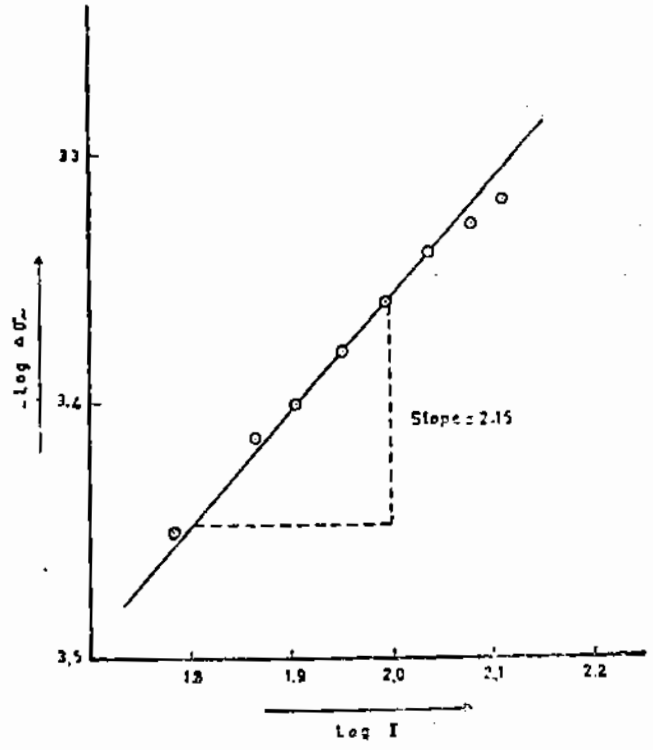


Fig. 6 — Verification of the quadratic relation

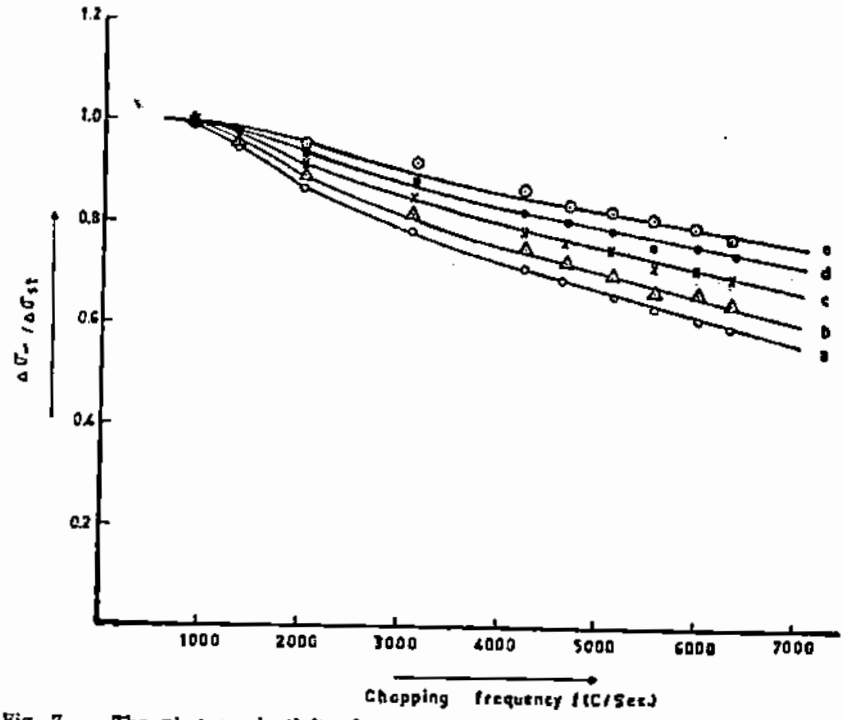


Fig. 7 — The photoconductivity frequency dependence at different modulated light intensities of oxidized p-type silicon.

$$\Delta \sigma = \Delta \sigma_{st} \, e^{-t/\tau} \qquad \ldots \ldots \ldots \ldots \ldots \qquad (8)$$

where τ is calculated from the slope. Values thus obtained are in the same order of magnitude as those obtained by frequency dependence method. Fig. (10) represents the relations $\Delta \sigma (\lambda)$ and $\tau (\lambda)$ showing that τ has a minimum at the position of λ peak $= 10.3 \mu$. This agrees with the theoretical point of view, where $\Delta \sigma \alpha \Delta n$ according to equation (2), $\Delta n \alpha I$ according to equation (3) and $I \alpha \frac{1}{\tau}$ according to fig. (8). Thus $\tau \alpha \frac{1}{\Delta \sigma}$

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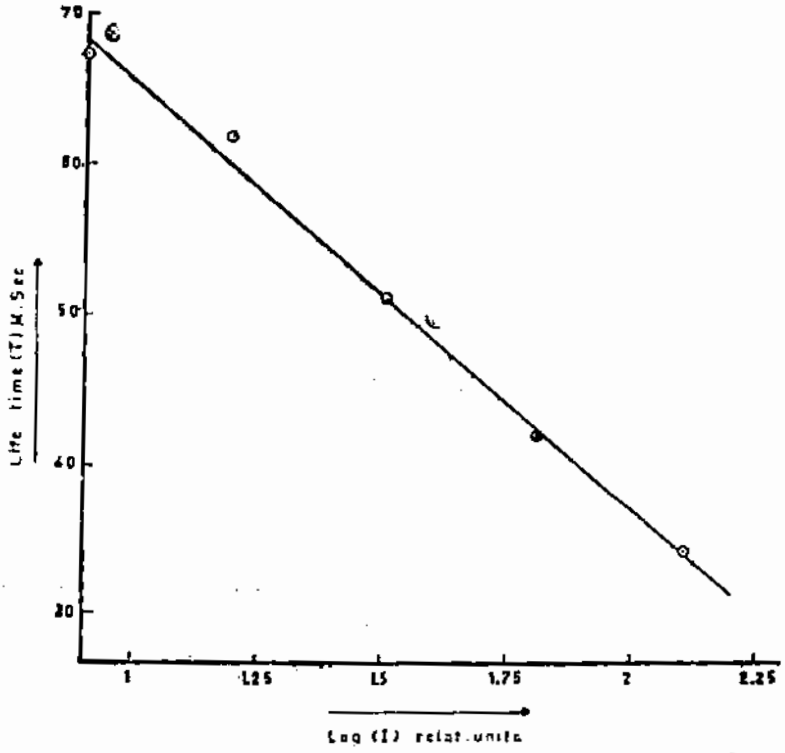

Fig. 8 — Lifetime dependence on the intensity of the modulated light for oxidized p-type silicon.

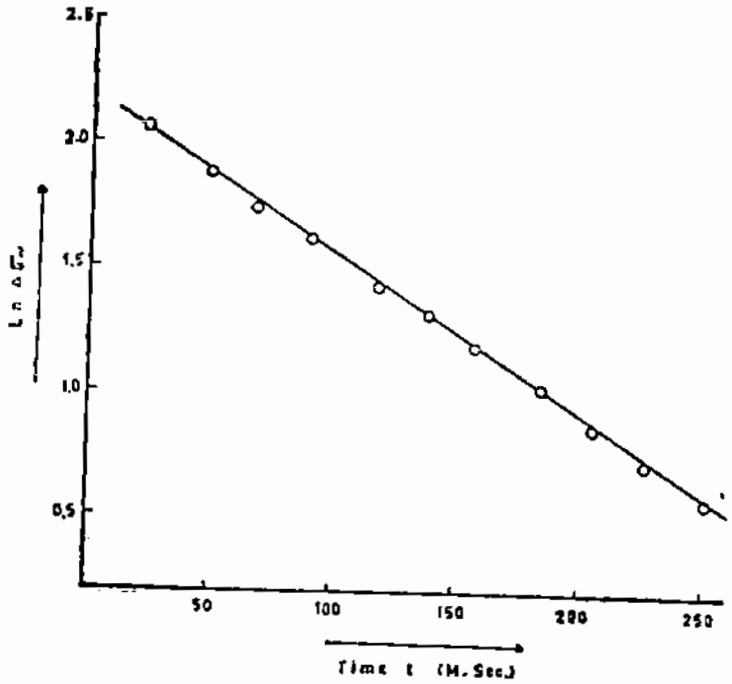

Fig. 9 — Decay of photoconductivity at I_1 ($\Delta\sigma$ in arbitrary units).

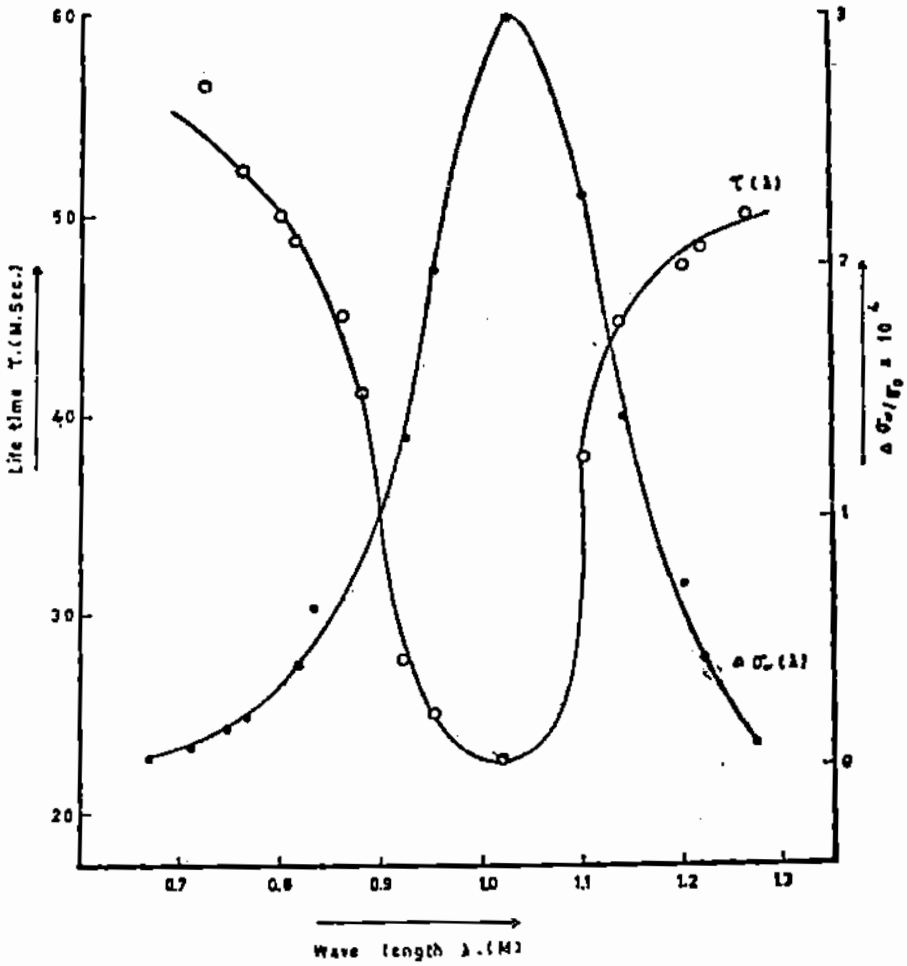

Fig. 10 — $\Delta\ \sigma\ (\lambda)$ and $\tau\ (\lambda)$ for oxidized p-type silicon.

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