IMPROVED FLYING SPOT METHOD FOR DETERMINATION OF SURFACE RECOMBINATION VELOCITY IN SEMICONDUCTORS*

By J. GYULAI, L. MICHAILOVITS and EVE RAUSCHER

Research Group for Luminescence and Semiconductors of the Hungarian Academy of Sciences, Szeged

(Received May 15, 1967)

Based on the exact solution of the small-signal continuity equation, a nomogram is presented for the determination of surface recombination velocity in semiconductors when carriers are produced by a moving steady line source (Flying Spot Method). Through some examples the use of the nomogram is illustrated.

Earlier attempts [1, 2] to adapt the Flying Spot Method (FSM)[1] for measuring surface recombination velocity (SRV) s made use of formulae derived by series expansions of the corresponding solution of the continuity equation. To avoid limitations involved, an exact solution is presented, furthermore, based on this solution, a nomogram enabling a simpler though more exact determination of SRV has been constructed.

Let an infinite line-source at $X_s = x_s/L$, $Z_s = z_s/L$ (*i. e.* parallel to the $Y = y/L$ axis), $L = (D_0\tau)^{\frac{1}{2}}$, move in the direction $X = x/L$ along the surface of a semiconducting half-space ($Z = z/L \geqq 0$) with the uniform velocity c. As known [4], the solution of the dimensionless small signal differential equation of added carries for an instantaneous line source, otherwise corresponding to the above geometry, including SRV, can be given as follows (in form of the Green's function of the problem)

$$G(X, Z; X_s Z_s) = (4\pi U)^{-1} \exp[-U - (X - X_s)^2/4U]\{\exp[-(Z - Z_s)^2/4U] + \\ + \exp[-(Z + Z_s)/4U] - 2S \int_0^\infty \exp[-S\zeta - (Z + Z_s + \zeta)^2/4U]\, d\zeta\}, \tag{1}$$

where $U = t/\tau$, the reduced time and $S = s(\tau/D_0)^{\frac{1}{2}} \equiv s\beta$. For surface generation ($Z_s = 0$) and having a detector in $X = Z = 0$, the solution for the case of a steady, moving line source can be calculated on the base of (1), as the source of this kind can be considered as an infinite sequence of instantaneous sources, at different places in different moments. Thus all the carriers resulting from these elementary generations, which reach the detector during time U, exert a superposed effect, and the individual delays because of the moving source can be taken into account by

* This work was partly supported by the factory TUNGSRAM, Budapest.

[1] FSM for the determination of ambipolar diffusivity D_0 and bulk lifetime τ was elaborated by ADAM [3].

a suitable retardation of G, *i. e.*

$$G^*(0,0;U) = \int_{-\infty}^{c\beta U} G(0,0;U - X_s/c\beta; X_s, 0)\,dX_s = \int_{0}^{\infty} G(0,0;\xi;(U-\xi)c\beta, 0)\,d\xi, \qquad (2)$$

where $c\beta$ is the dimensionless velocity of the source. To avoid scale factors, it was preferable to calculate the slope of the $\log G^*(0, 0; U)$ *versus* U curve (*e. g.* behind the source):

$$L_3(U) \equiv |d(\log G^*(0, 0; U))/dU| = (c^2\beta^2/2)[1 - U\mathrm{I}_2(U)/\mathrm{I}_1(U)],$$

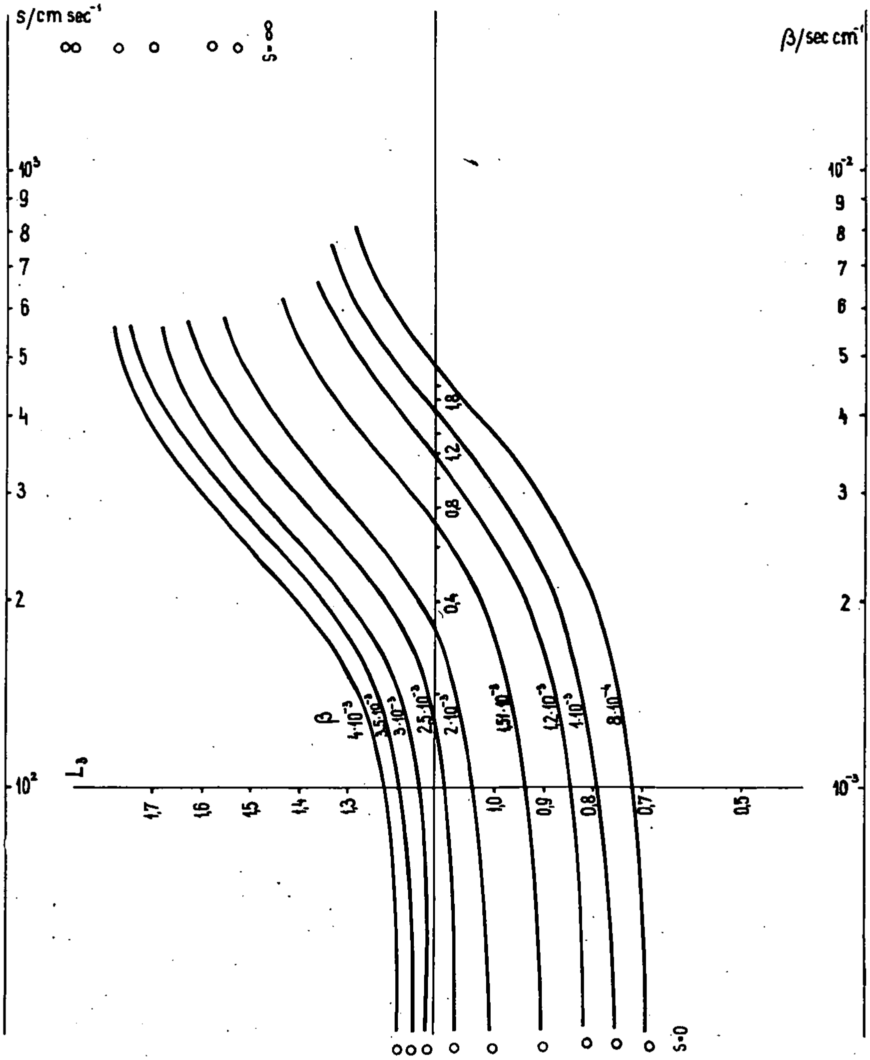

Fig. 1

where

$$\mathrm{I}_i(U) = \int_0^\infty \xi^{-i} \exp[-(1+c^2\beta^2/4)\xi - c^2\beta^2 U^2/4\xi] \times$$
$$\times \{1 - \pi^{\frac{1}{2}} S\xi^{\frac{1}{2}} \exp(S^2\xi)[1 - \Phi(S\xi^{\frac{1}{2}})]\}\, d\xi, \qquad (i=1,2),$$

$\Phi(x)$ being the error function. ($\mathrm{I}_i(U)$ can be exactly calculated for $S=0$ or $S=\infty$.)

The calculation of the integrals, for the case of $U=1{,}5$ and $c=600$ cm sec^{-1} and for several values of β and S enabled us to construct a nomogram (Fig. 1.)

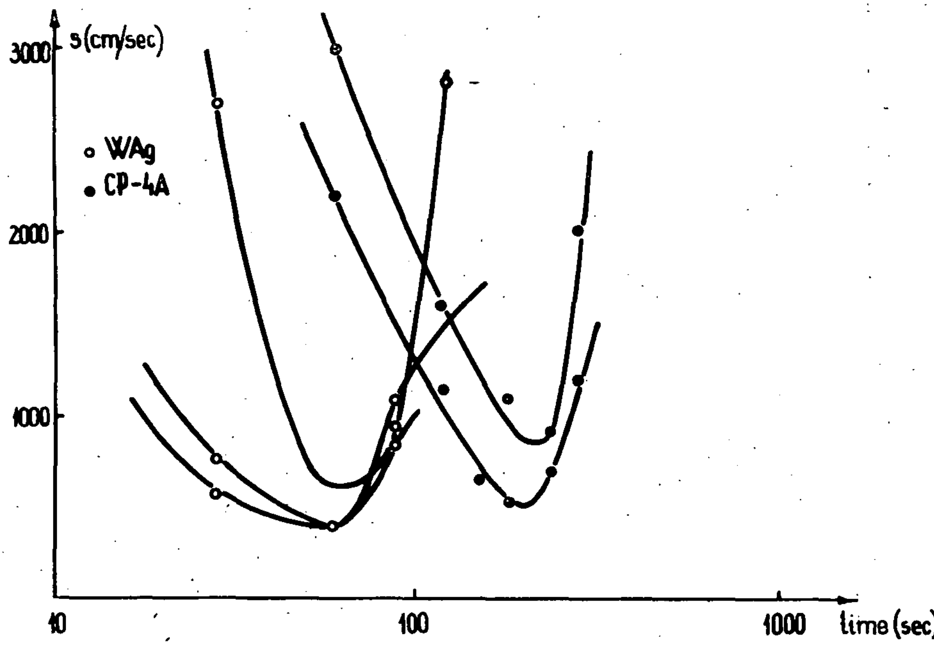

Fig. 2

rendering possible the determination of SRV provided β is known. For this purpose, first the slope $L_3(1, 5)$ of logarithmic plot of photoresponse *versus* U curves is to be measured (using the values of τ and D_0 previously determined *e. g.* with the original method of ADAM, using the same experimental curve). In the nomogram this value of $L_3(1, 5)$ is to be found on the appropriate curve corresponding to β, and is to be projected onto the medial axis (P_1). The actual value of β on the β-axis gives P_2. Then the intersection of a straight line through P_1 and P_2 with the s-axis gives directly the SRV in units of cm sec^{-1}.

As examples of application, we present two experimental curves for n-Ge (high ohmic), measured with the above method for determining an optimum of etch time in CP 4A and WAg, and the effect on SRV of successive treatments in different etchants (Figs. 2 and 3). In these cases the etch process was interrupted

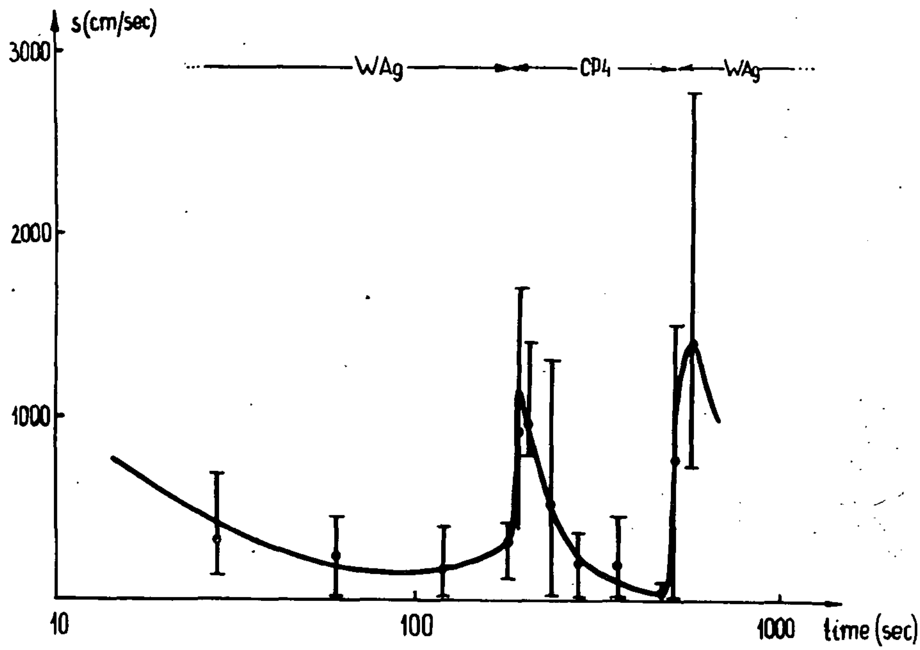

Fig. 3

from time to time and measurements were performed having the surface rinsed and dried. It is interesting to mention that the treatment with a second etchant produces first a rise in CRV, which is probably connected with a surface nearer to intrinsic.

* * *

The authors are indebted to Prof. A. Budó, the director of the Research Group for his steady interest during the course of the work.

References

[1] *О. В. Сорокин*, ЖТФ, **26**, 2473 (1956).
[2] *J. Gyulai*, Acta Phys. Hung., **12**, 167 (1960).
[3] *G. Adam*, Z. Naturforschg., **9a**, 617 (1954).
[4] *W. van Roosbroeck*, J. Appl. Phys., **26**, 380 (1955).

СОВЕРШЕНСТВОВАНИЕ МЕТОДА ДВИЖУЩЕГО СВЕТОВОГО ПУЧКА ДЛЯ ИЗМЕРЕНИЕ СКОРОСТЬ ПОВЕРХНОСТНОЙ РЕКОМБИНАЦИИ В ПОЛУПРОВОДНИКАХ

Й. Гьюлаи, Л. Михаилович и Е. Раушер

Номограмм был конструирован на основе точного решения уравнения непрерывности в случае возбуждения движущим световым пучком. Применение номограмма показано в нескольких примерах для образцов германии.