DEPENDENCE OF THE EXCITATION OF GLOW CURVES ON THE ABSORPTION COEFFICIENT

R. CHEN, M. ISRAELI and N. KRISTIANPOLLER
Department of Physics and Astronomy, Tel-Aviv University, Tel-Aviv, Israel

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Excitation of glow curves in crystals in regions of relatively high absorption has been investigated theoretically. The dependence of the number of trapped carriers on the absorption coefficient is described. Experimental data of glow intensity versus wavelength are thus explained.

The excitation spectrum of the thermoluminescence (TL) glow curve in crystals near an absorption edge was usually found to consist of a sharp peak on the long wavelength tail of the absorption edge [1]. A similar effect was found in the excitation spectrum of photoconductivity [2]. The qualitative explanation of this effect is that at the long wavelength side, where the absorption coefficient is smaller, the excitation spectrum resembles the absorption dependence on wavelength. At shorter wavelengths, however, the absorption is much stronger and thus most of the incident light is absorbed in a thin layer. The traps in this layer are excited to saturation at relatively low doses whereas the probability of exciting deeper portions of the sample decreases for increasing absorption coefficient. The effective volume of the crystal is thus reduced for high absorption coefficients and so is the resulting glow intensity. One should expect, therefore, the appearance of an excitation peak between these two extreme regions, namely, at the range of intermediate absorption coefficient. A related effect of 'inverse peaks' [3] of absorption and photoconductivity has been explained qualitatively in a similar way. It should also be mentioned here that the dependence of glow excitation on the absorption coefficient was mentioned by Hoogenstraaten [4].

At present, we introduce a simple model giving the dependence of glow intensity on the absorption coefficient. The dependence of the glow on the width of the sample and on the dose of the exciting light will also be discussed briefly.

Let us take a sample of width L cm having two parallel surfaces of area 1 cm^2. One of the surfaces is illuminated uniformly by a monochromatic radiation for which the absorption coefficient is μ. The intensity at a depth x is by Beer's law $I = I_0 \exp(-\mu x)$ where I_0 is the incident light intensity and I the transmitted intensity. The concentration of carriers (n) created at this depth x is proportional to the number of absorbed photons; therefore,

$$n = -\mathrm{d}I/\mathrm{d}x = I_0 \mu \exp(-\mu x), \quad (1)$$

where the proportionality factor is set to be unity.

We shall assume that $n(x)$ does not depend on time for excitation with a constant photon flux. This situation occurs after a short period of time in the case where the number of carriers captured in traps of interest is small compared with the number decaying through other recombination processes. This assumption is valid for most experimental cases. It may be wrong only for the rare cases where the absorption changes substantially during the excitation of the sample. Suppose that the concentration of traps which, if filled by carriers, would contribute to the measured glow is M. Letting $m(x, t)$ be the concentration of trapped carriers at a depth x after excitation time t and assuming that the generated carriers may be trapped only in close vicinity to where they were excited, we get the following equation for the time dependence of $m(x, t)$

$$\partial m/\partial t = \alpha n(M - m) \quad (2)$$

where α is the proportionality constant. Solving eq. (2) and assuming that $m(x, 0) = 0$ and inserting n from eq. (1) we have

$$m(x, t) = M[1 - \exp\{-\alpha t I_0 \mu \exp(-\mu x)\}] . \quad (3)$$

$I_0 t$ is the incident radiation dose and will be de-

noted by D. The total population M_t can be found by integration over x from 0 to L,

$$M_t = \int_0^L m(x,t)\,dx$$

$$= M \int_0^L [1 - \exp\{-\alpha D \mu \exp(-\mu x)\}]\,dx\,. \qquad (4)$$

Since the maximum glow intensity is practically proportional to the population M_t, the behavior of M_t represents the behavior of the glow intensity. From eq. (4) one can see that M_t is zero both for $\mu = 0$, the case of zero absorption, and $\mu = \infty$, the case where the effective volume is zero. From eq. (4) it is also obvious that $M_t = 0$ for $D = 0$ and that $M_t = ML$ for $D = \infty$, as might be expected. For low doses ($\alpha D \mu \exp(-\mu x) \ll 1$) eq. (4) reduces to $M_t = M\sigma\mu D\{1 - \exp(-\mu L)\}$ which reveals a linear dependence on the dose, as is usually found with low doses.

By change of variables we find from eq. (4)

$$M_t/ML = 1 - (1/\mu L) \int_{\alpha D \mu \exp(-\mu L)}^{\alpha D \mu} \{\exp(-y)/y\}\,dy\,, \qquad (5)$$

the exponential integral on the right-hand side can be evaluated numerically for any value of αD, μ and L. Some care has to be taken in choosing the appropriate numerical methods for various boundaries of the integral. Fig. 1 shows the dependence of M_t/ML on μ as calculated numerically from eq. (5). The curves (a) to (e) were found for different values of the exciting dose, varying by a multiplication factor of $\sqrt{10}$. The maximum of the curve shifts toward lower values of μ for higher doses. Further calculations show that, for a larger width L, the maxima appear at smaller μ's although the values of μ_L are larger. The dependence of M_t/ML on the dose for a given sample and given exciting light (namely, given μ) can be seen by examining the values of the intersection of each curve in fig. 1 with a vertical line at the desired μ.

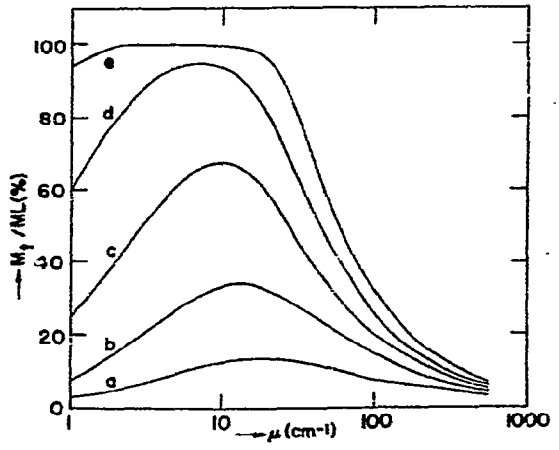

Fig. 1. Dependence of M_t/ML on μ for $L = 0.1$ cm. The doses change from (a) to (e) by factors of $\sqrt{10}$.

Finally, the dependence of M_t/ML on the wavelength rather than on the absorption coefficient can be found by combining the present results with given experimental or theoretical functions $\mu = \mu(\lambda)$, where λ is the wavelength. A possible theoretical [5] dependence is given by $\mu \propto (h\nu - E_g)^k$ where E_g is the band gap energy, $h\nu$ the energy of the photon and k has the values of $\frac{1}{2}$, $\frac{3}{2}$, 2 or 3. Another empirically known function is [5] $\mu \propto \exp[(h\nu - E_g)/kT]$. It is obvious that the steeper the function $\mu = \mu(\lambda)$, the narrower the peak of $M_t = M_t(\lambda)$ which represents the excitation spectrum.

The phenomenon of inverse peaks of absorption and glow excitation, namely, that minima of the excitation spectrum appear at the same wavelengths as the maxima of the absorption and vice versa is explained as follows. For values of μ higher than that for maximum excitation, an increase in μ results in a decrease in glow intensity. Results of this nature have been found in our laboratory for the excitation of TL in KBr crystals in the range 1200-1800 Å.

The excitation of TL in alkali-halides by UV irradiation into the exciton and perturbed exciton states has also recently been investigated both experimentally and theoretically in our group by Kristianpoller and Israeli [6] who discuss the creation of point defects by UV light rather than the filling of existing traps. This work is related to a previous one of Parker [7], who studied the excition induced F-center growth by UV light and its relation to the absorption coefficient.

REFERENCES

[1] A. Halperin and J. Nahum, J. Phys. Chem. Solids 18 (1961) 297.
[2] A. F. Ioffe, Physics of semiconductors (Academic Press, New York, 1960) p. 77.
[3] J. Kommandeur and W. G. Schneider, J. Chem. Phys. 28 (1958) 582.
[4] W. Hoogenstraaten, Philips Res. Repts. 13 (1958) 515.
[5] E. J. Johnson, in: Semiconductors and semimetals, Vol. 3, eds. R. K. Willardson and A. C. Beer (Academic Press, New York, 1967) Ch. 6.
[6] N. Kristianpoller and M. Israeli, Phys. Rev., to be published.
[7] J. H. Parker, Phys. Rev. 124 (1961) 703.