INTRODUCTION

Thermoluminescence (TL) appears when a solid sample (usually an insulator or semiconductor) is heated after being irradiated at a low temperature $T_0$. Part of the energy absorbed by the sample in course of irradiation may be released during heating. Thermoluminescence has found important application in dating and dosimetry. The rigorous theory of thermoluminescence is very complicated. The most popular model of thermoluminescence (TL) is the three parameter model suggested by Halperin and Braner\(^1\) and later developed by Chen et al\(^2\). In three-parameter model, TL is described by the parameters namely activation energy ($E$), order of kinetics ($b$) and frequency factor ($s$). There are a number of methods for the determination of activation energy ($E$), such as peak shape, initial rise, various heating rates method etc. Out of these methods peak shape method probably is the simplest because in peak shape method activation energy ($E$) can be determined by knowing only two or three characteristic temperatures of the peak. In this paper we present a review of the peak shape method for the determination of activation energy of a TL peak.

The geometrical shape of a TL-glow peak plays an important role in TL applications. It is an important and convenient method for calculating the trapping parameters of distinct energy levels within the crystal. This method is based on measurements of a few points on the glow peak as shown in Fig. 1.

**Fig 1.** An isolated glow-peak and the temperature parameters

**ABSTRACT**

In this paper different varieties of peak shape method for the determination of activation energy ($E$) in Thermoluminescence have been reviewed.

**Key words:** Thermoluminescence, Peak shape method, Activation energy PACS NO.: 78.60 Kn.
One can define from the figure the following parameters:

- $T_m$ = temperature at maximum intensity
- $T_1, T_2$ = temperatures on either side of $T_m$, corresponding to half-intensity
- $\tau = T_m - T_1$, half width at lower temperature side
- $\delta = T_2 - T_m$, half width at higher temperature side
- $\omega = T_2 - T_1$, the total width
- $\mu = \frac{\delta}{\omega}$, so-called geometrical shape factor or symmetry factor

Grossweiner was the first to use the shape of glow peak to calculate the trap depth and the frequency factor. His method is based on $T_1$.

Using first order kinetics one can write,

$$I_a = I(T) = n_0 \exp(-E/kT) \exp\left[-\frac{T}{kT_m} \int \exp(-E/kT) dT\right] \quad (1)$$

And

$$I_a(T/2) = I(T) - n_0 \exp(-E/kT_1) \exp\left[-\frac{T}{kT_m} \int \exp(-E/kT) dT\right] \quad (2)$$

Their ratio is

$$\frac{1}{2} = \exp\left[-\frac{E}{k} \left(\frac{1}{T_1} - \frac{1}{T_m}\right)\right] \exp\left[\frac{T_m}{kT} \int \exp(-E/kT) dT\right] \quad (3)$$

The integrals in the brackets can be resolved by asymptotic expansion. By dropping terms after the first in series, expression (3) changes in the following:

$$\frac{1}{2} = \exp\left[-\frac{E}{k} \left(\frac{1}{T_1} - \frac{1}{T_m}\right)\right] \exp\left[\frac{T_m}{kT} \int \exp(-E/kT) dT\right]$$

Doing logarithm and rearranging and then applying the maximum conditions one obtains

$$\frac{E}{k} \left(\frac{1}{T_1} - \frac{1}{T_2}\right) - 0.693 = 1 - \left(\frac{T_1}{T_m}\right)^2 \exp\left(-\frac{E}{kT_1} + \frac{E}{kT_m}\right)$$

For $\frac{E}{kT_1}$ larger than 20, the exponential of the last expression becomes equal to 0.184.

Furthermore, the term $\left(\frac{T_1}{T_m}\right)^2$ can be neglected because it affects $E$ by less than 2% if $s/\beta$ is larger than $10^7$. With these approximations, the final form becomes

$$E = 1.51k \frac{T_m T_1}{T_m - T_1} \quad (4)$$

Dussel and Bube showed that Grossweiner's method for determination of $E$ was out by about 7% and gave some other similar formulas for $E$ using $T_m$, $T_2$ and $\delta$ or $\omega$ instead of $\tau$.

Lushchik also proposed a method based on the glow peak shape for both first order and second order kinetics. Introducing the parameter $\delta = T_1 - T_m$, a glow peak can be approximated to a triangle as shown in Fig. 2.

![Fig. 2: Approximation of a glow-peak in a triangle](image-url)
In this case with a good approximation one has
\[ n_M = \frac{1}{\beta} \int_{t_M}^{t_0} I(t) dt \]
\[ \equiv \frac{1}{\beta} \text{Area} \Delta ABC = \frac{I_M 2\delta}{2\beta} = \frac{I_M \delta}{\beta} \]  \ ...(5)

where \( n_M \) is the carrier concentration at the maximum. At maximum point,
\[ I_M = n_M \beta E \exp \left( -\frac{E}{kT_n} \right) \]  \ ...(6)

Using condition at maximum i.e.
\[ \frac{\delta E}{kT_n} = \exp \left( -\frac{E}{kT_n} \right) \] equation (6) becomes
\[ I_M = n_M \frac{\beta E}{kT_n^2} \]  \[ E = \frac{2kT_n^2}{\delta} \]  \ ...(7)

In a similar way for second order kinetics, Lushchik used the solution for \( n \), replaced \( n \) with \( n_M \), and the intensity at the maximum. Thus activation energy for second order kinetics is
\[ E = \frac{2kT_n^2}{\delta} \]  \ ...(8)

Chen modified the 2 previous equations for a better accuracy in the \( E \) value. The frequency factor for the first order process is obtained by the following equation:
\[ s = 0.976 \left( \frac{\beta}{\delta} \right) \exp \left( 0.976 \frac{T_M}{\delta} \right) \]

Halperin and Brainer gave a different approach by using both \( T_1 \) and \( T_2 \). They considered the luminescence emission as mainly due to (a) raise of electron to an excited state within the forbidden energy gap below the CB and recombination with holes by the tunneling process (model A) and (b) recombination of electrons with holes via CB (model B). Both the models are depicted in Fig. 3.

Fig. 3: The energy band models showing the two recombination process
In the first process the value of $\Delta M$ is found to be

$$ E = H_1 \frac{k T_M^2}{\delta} $$

...(9)

where

$$ H_1 = \frac{\mu_M}{\rho + \mu_M} - 1 + \frac{B}{A \mu_M + B} $$

with the approximation $\mu_M = \frac{m_M}{m_0} = \frac{\delta}{\omega}$

Here $\rho = \frac{n_0}{m_0}$; $n_0$ and $m_0$ being the concentration of electron and holes at time

$A$ = probability of recombination

$B = \frac{s}{m_0}$, $s$ being the frequency factor

In the second process, it is given by

$$ E = \frac{H_1 k T_M^2}{\delta} (1 - \Delta_M) $$

with $\Delta_M = \frac{k T_M^2}{E}$

...(10)

has different value for first order and second order according to the following expressions:

$$ H_{21} = 1.72 \frac{\mu_M}{1 - \mu_M} (1 - 1.58 \Delta_M) $$

for first order

...(10a)

$$ H_{22} = 2 \frac{\mu_M}{1 - \mu_M} (1 - 2 \Delta_M) $$

for second order

...(10b)

Halperin and Braner also gave a very easy way to decide the type of kinetics involved in the process.

$$ \mu_M \geq \frac{1 + \Delta_M}{e} $$

for second order

Equation (9) can be changed by introducing $\tau = \alpha - \delta$. It is very useful because if it is very easy to eliminate any interfering glow peak appearing at the low temperature side, it is impossible to eliminate shouldering peaks at high temperature side of the observed peak. Therefore equation (9) becomes

$$ E = \frac{1.72}{\tau} k T_M^2 (1 - 2.58 \Delta_M) $$; first order

$$ E = \frac{2}{\tau} k T_M^2 (1 - 3 \Delta_M) $$; second order

The equations of Halperin and Braner require iterative process to find $\tau$ owing to the presence of $\Delta_M$. To overcome this difficulty a new approximated method was proposed by Chen.

Keming, following Bemski and Lax, introduced the possibility of temperature dependent frequency factor $s = \sigma T^\gamma$ where $-2 \leq \gamma \leq 2$. For all values of $\gamma$, Keming gave the following formula for first order peaks:

$$ \frac{k T_M^\gamma}{E} = (1.2 \gamma - 0.54) \omega + 0.0055 - \left[ \frac{1}{2} (\gamma - 0.75) \right]^2 $$

from which $E$ can be calculated. In this formula, the formula is reported to hold true for $0.75 < \gamma < 0.9$ and

$$ 10 < \frac{k T_M^\gamma}{E} $$

Chen summarised all the pre-existing methods and gave a detailed methodology for deriving the coefficients for the first and second order kinetics. He derived expressions for evaluating $E$ using numerical approximations. Chen method is useful for a broad range of energies ranging between 0.1 eV to 2.0 eV and pre-exponential factor between $10^{15}$ sec$^{-1}$ and $10^{13}$ sec$^{-1}$. It does not make any use of iterative procedure.
Furthermore, the procedure does not use any knowledge of the kinetics order which is found using directly symmetry factor $\mu$ from the peak shape. He used total half-width peak method to find $E_\omega$, high temperature side half peak to find $E_a$ and low temperature side half peak to find $E_\tau$.

He started from the first order equation, giving TL intensity as a function of the temperature,

$$I(T) = n_a s \exp\left(-\frac{E}{k T}\right) \exp\left[-\frac{s}{\beta} \int \exp\left(-\frac{E}{k T}\right) dT\right]$$

At $T_{MT}$, the expression of $I$ is obtained. The integral on the R.H.S can be approximated by means of an asymptotic expansion and a reasonable approximation is accepted. Using the assumption of Lushchik$^5$ that the area of the second half of the peak is equal to that of a triangle having the same height and half-width, he reached to the expression of activation energy for first order kinetics as

$$E_a = 2k T_a (1.25 \frac{T_M}{\alpha} - 1)$$
$$E_\omega = 0.97 \frac{k T_a}{\delta}$$
$$E_\tau = 1.53 \left(\frac{k T_a}{\tau}\right) - 1.5Q(2k T_a)$$

$s = \frac{2.673}{\alpha} \frac{T_M}{\omega}$

For second order kinetics the activation energy forms are

$$E_\omega = 2k T_M (1.756 \frac{T_M}{\alpha} - 1)$$
$$E_\delta = 0.853 \frac{2k T_M^2}{\delta}$$
$$E_\tau = 1.813 \left(\frac{k T_M^2}{\tau}\right) - 4k T_M$$

In the literature, there are plenty of reported cases of non-integer values of $b$, the order of kinetics. Chen$^7$ gave a method of calculating the activation for non-integer values of $b$ (GO). He started from the general order equation proposed by May and Patridge:

$$I(T) = n_a s \exp\left(-\frac{E}{k T}\right) \left[1 + \frac{s(b-1)}{\beta} \int \exp\left(-\frac{E}{k T}\right) dT\right]^{b-1}$$

The equation was rearranged using condition at the maximum and then solved numerically by approximating the integral by a certain number of terms of the asymptotic series and using the iterative Newton-Raphson method.

The Chen’s method consists of finding the temperature at the maximum $T_M$, by computer calculations. He used $0.7 \leq b \leq 2.5$ with $s \leq 0.1$, $1 \leq E \leq 1.6$, and $\beta = 0.5$. Once the value of $b$ is found, the intensity can be found by inserting the temperature at the maximum, in the previous equation and using again asymptotic series. The values of $T_1$, $T_2$, the low and half temperature intensity, can be calculated by solving numerically the equation

$$I(T) = \frac{T_M}{2}$$

Using the asymptotic series for the integral approximation, Chen found

$$T_1 = 0.95 T_M$$
$$T_2 = 1.05 T_M$$

After that the geometrical parameters of the peak i.e. $\delta$, $\tau$, $\alpha$, $\mu$, are found.

Interpolating and extrapolating the constants appearing in the equations for the 1$^{st}$ and 2$^{nd}$ order, Chen gave a general expression which summarises all the previously given expressions. The equations can be summed up as

$$E_\alpha = C_\alpha \left(\frac{k T_M^2}{\alpha}\right) + B_\alpha (2k T_M)$$
Where $\alpha$ is $\tau$, $\delta$ or $\omega$.

The values of $C_\alpha$ and $D_\alpha$ are summarised as below:

$C'_\alpha = 1.51 + 3(\mu - 0.42); B'_\alpha = 1.58 + 4.2(\mu - 0.42)$

$C''_\alpha = 0.976 + 7.3(\mu - 0.42); B''_\alpha = 0$

$C'_\omega = 2.52 + 10(\mu - 0.42); B'_\omega = 1$

With $\mu_g = 0.42$ for 1st order
And $\mu_g = 0.52$ for 2nd order.

Chen found that the order of kinetics $b$ is a monotonic function of shape factor $\mu_g = \delta/\omega$. Chen calculated $\mu_g$ (ranging from 0.36 to 0.55) for various values of ranging from 0.7 to 2.5 and presented a graphical relation between $b$ and $\mu_g$ (Fig. 4). This provided a simple method by which can be determined from a measured value of $\mu_g$.

According to Balarin, the previous expressions allow to determine the activation energy values accurately to within 0.5%. The experimental inaccuracy in the determination of $\omega$ then becomes dominant and limiting.

Balarin also proposed a graph which gives the kinetic order as a function of $\gamma = (\delta/\tau)$ (Fig. 5).

![Figure 4: The plot of kinetic order $b$ as a function of geometrical factor $\mu_g = \delta/\omega$](image)

![Figure 5: The plot of kinetic order $b$ as a function of geometrical factor $\gamma = \delta/\tau$](image)

Christodoulides developed some expressions for the determination of the activation energy, $E_a$, of a first order peak using the widths or half-widths of the peaks. These widths correspond to temperatures at which the signal level is $1/4$, $1/2$ or $3/4$ of the peak height, on both sides of the peak temperature at the maximum $T_M$. Fig. 6 shows the various temperatures previously defined.

![Figure 6: A glow peak and the various temperatures used in Christodoulides method](image)
The expressions are valid in the region of values 10 and 100. Using the 1st order kinetic equation giving the variation of height intensity with temperature, and inserting it in the equation of the maximum, for a constant heating rate, one gets the following expressions in terms of the variable $\varepsilon = \frac{E}{kT_M}$ and its value at the peak maximum $\varepsilon_M = \frac{E}{kT_M}$.

$$I = n_0s \exp\left\{-\varepsilon - \varepsilon_M^2 \exp(\varepsilon_M) \int_{\varepsilon_M}^{\infty} \frac{\exp(-\varepsilon)}{\varepsilon^2} d\varepsilon\right\}$$

The integral can be expressed in terms of the second exponential integral

$$E_2(\varepsilon) = \int_{\varepsilon}^{\infty} \frac{\exp(-t)}{t^2} dt = \varepsilon \int_{\varepsilon}^{\infty} \frac{\exp(-z)}{z^2} dz$$

So the former equation becomes

$$I = n_0s \exp\left\{-\varepsilon - \varepsilon_M^2 \exp(\varepsilon_M) \frac{E_2(\varepsilon)}{\varepsilon}\right\}$$

which has a maximum value, for $\varepsilon = \varepsilon_M$, equal to

$$I_M = n_0s \exp\left\{-\varepsilon_M - \varepsilon_M \exp(\varepsilon_M) \frac{E_2(\varepsilon_M)}{\varepsilon_M}\right\}$$

And finally,

$$I = I_M \exp\left\{-\left(\varepsilon - \varepsilon_M - \varepsilon_M \exp(\varepsilon_M) \frac{E_2(\varepsilon_M)}{\varepsilon_M}\right)\right\}$$

which gives the signal output $I$ as a function of $\varepsilon$ for a TL peak of given $I_M$ and $\varepsilon_M$.

For a given value of $E_M$, the ratio $I/I_M$ depends only on $\varepsilon_M$. An iteration procedure is needed to solve the above equation because one must be sure about the convergence of the procedure itself. This is done using as a starting value of

$$\varepsilon = \frac{E}{kT_M}$$

For $T < T_M$ i.e. $\varepsilon > \varepsilon_M$ and $\varepsilon > \varepsilon_M$, two different expressions of are obtained. In those expressions, a rational approximation may be used for the transcendental function.

Such an expression is,

$$\exp(\varepsilon)E_2(\varepsilon) = \frac{0.99997\varepsilon + 3.03962}{\varepsilon^2 + 5.026373\varepsilon + 4.19106} + \Delta(\varepsilon)$$

Where

$$|\Delta(\varepsilon)| \leq 10^{-7} \text{ for } \varepsilon \geq 10.$$ 

Simple linear relations can then be searched for connecting pairs of the quantities $(\varepsilon, \varepsilon_M, \varepsilon, \varepsilon_M, \varepsilon_M, \varepsilon, \varepsilon_M, \varepsilon_M, \varepsilon, \varepsilon_M, \varepsilon, \varepsilon_M)$ and $(\varepsilon_2, \varepsilon_2)$. Similar expressions are also given which allows to know the width of a peak whose $E$ and $T_M$ are known.

Mazumdar et al.13 (1988) extended the work of Christodoulides on peak shape method following general order kinetics. To construct a new set of expressions, they involved temperatures where intensity is 1/2, 2/3 and 4/5 of the maximum. The authors claim that the selection of these points is based on the fact that the upper half of the peak, in general, is expected to be free from interference satellite peaks.

They also started from the well-known GO equation and calculated

$$\varepsilon^+ (\varepsilon, \text{for } T < T_M) \text{ and } \varepsilon^- (\varepsilon, \text{for } T > T_M)$$

(10) and (11). However, their expressions are not valid for $b=1$. For a given value of the ratio $I/I_M$, the corresponding values of and are then determined using the same iteration procedure followed by Christodoulides, taking as the starting value of $\varepsilon$.

Now if $i$ and $j$ denotes the intensity ratios, the expression for the activation energy can be written as

$$B_{ij}(T_i, T_j) = \frac{T_i T_j}{C(T_i - T_j)^2} - \frac{T_j}{D}$$

where $T_i$ and $T_j$ are the temperatures at a given ratio at the falling and the rising side respectively of the peak. The values of the coefficients $C$ and $D$ are listed by Mazumdar et al., (1988).
With prior knowledge of \( b \), a new set of expressions for GO kinetics was presented by Gartia et al\(^1\). The mathematical procedure is similar to that given by Mazumdar et al\(^2\). Using equations for \( b=1 \) [Christodoulides\(^3\)] and [Mazumdar et al\(^4\)], applying iterative method, it is possible to write the following expression for activation energy:

\[
E = \frac{C_k T_M^2}{T_z - T_p} + D k T_M
\]

where \( T_z - T_p = \tau, \delta \) or \( \omega \).

The coefficients \( C \) and \( D \) are found using the method of least square for different order of kinetics \( b \) in the range from 0.7 to 2.5 and for \( x=1/2, 2/3 \) and 4/5. For a particular value of \( x \) the coefficients result to be dependent on and then can be expressed as a quadratic function of \( b \) itself. So that the previous equations can be rewritten as

\[
E = \left( \frac{C_o + C_1 b + C_2 b^2}{T_z - T_p} \right) + \left( D_o + D_1 b + D_2 b^2 \right) k T_M
\]

The authors claim the validity and the superiority of their method in comparison to those of Chen. Indeed the \( E \) values obtained by using expressions for \( x=1/2 \) are more accurate than those of Chen. Furthermore, it is pointed out that \( E_x, E_z \) and \( E_w \) are in excellent agreement among themselves, whereas Chen’s value for \( E_x \) and \( E_w \) yield poor results.

After the Chen’s work\(^7\), the graphical picture of the dependence of symmetry factor \( \mu_g \) on \( b \) has been utilized to determine easily the order of kinetics. The order of kinetics still remains a topic of controversy and a matter of debate. For a given value of \( \mu_g \), is not unique. It is dependent on and. For a given value of \( b \), \( \mu_g \), and for extreme values of \( E \) and \( s \), the maximum deviation in \( \mu_g \) can be as high as 7%. Therefore without an a priori knowledge of \( E \) and \( s \), absolute determination of \( b \) from the value of \( \mu_g \) is not possible. The treatment given by Gartia et al allows to find a general expression for \( \mu_g \), considering any position selected on the glow peak, in terms of the variable \( u = E/kT \) and its value at peak \( \mu_g = E/kT_M \).

Recently study of Kitis and Pagonis\(^\_
\)led to new insights as to the meaning of the coefficients used in Chen’s original equation. Although Chen’s GO kinetics expression (in fact approximations) proved to be very accurate in practice, it did not have any theoretical basis before. Moreover, in the final expression of \( E \), the characteristic parameter \( b \) was absent. Kitis and Pagonis theoretical foundation to the peak shape method coefficients as a function of \( b \). They deduced the equations:

\[
E_w = \frac{C_o b T_M^2}{a} - 2k T_M
\]

\[
E_z = C_x b \frac{k T_M^2}{\delta}
\]

\[
E_z = C_y b \left( \frac{T_M^2}{\delta} - \frac{b^{1/2} - 1}{b^{1/2} + 1} \right) 2k T_M
\]

\[ C_o, C_x, C_y \] are respective triangle assumption pseudo-constants which was evaluated by simulation. The numerical simulation of synthetic glow-peaks was performed by using very broad regions of the trapping parameters (\( E \) ranging from 0.7 eV to 2 eV, \( s \) ranging from \( 10^7 \) sec\(^{-1} \) and \( 10^{20} \) sec\(^{-1} \), \( b \) ranging from 1.1 to 2) in order to cover as many practical cases as possible. Fig. 7 shows the behavior of the pseudo-constants \( C_o, C_x \) and \( C_y \) as a function of the symmetry factor.

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![Fig. 7: The triangle assumption pseudo-constants as a function of symmetry factor](image-url)
The correctness of their equation was ensured by getting output activation energy values coinciding with the input ones. The errors of the peak shape method were studied in detail. They also described the error evaluation procedure, which allows one to gain all the benefits of the peak shape method when they are applied to experimental results. A scope for further improvement of the accuracy of the evaluation of the activation energy is there.

Due to the lack of physical basis of the most widely used GO model, Mixed order kinetics model was developed by Chen et al. using a set of three differential equations formerly used by Halperin and Braner. Yossian and Horowitz (1997) have successfully applied MO kinetics both to the synthetic glow-peaks and to isolated peak 5 in TLD-100 following post-irradiation annealing at 165°C and commented that MO kinetics is a viable alternative to GO kinetics in the intermediate range (1 < b < 2). Chen et al. have shown the variation of μ with α = \( \frac{n}{n + c} \), where c is the concentration of trapped electrons or holes not taking part in the TL process in the temperature range considered due to their being in deep traps or in low probability recombination centers by choosing a certain value of \( u_M \). They also reported that the shape of MO TL peak depends strongly on α (0 ≤ α ≤ 1) and a very weak function of \( u_M \). They presented a graphical picture (Fig.8) of the variation of \( \mu_g \) with α. From that one can estimate the value of α of an experimental TL peak by knowing the value of \( \mu_g \).

Singh et al. (1997) took into account the dependence of \( \mu_g \) on α in obtaining the value of α from \( \mu_g \) vs α curve by taking average of \( \mu_g \) for different values of \( u_M \) (20 ≤ \( u_M \) ≤ 40). They presented a set of peak shape formula involving α for determination of activation energy unlike those of Chen (1969). They evaluated

\[
E_1 = \frac{C_1 kT_M^2}{(T_M - T_x^-)} + D_1 kT_M \\
E_2 = \frac{C_2 kT_M^2}{(T_M - T_x^+)} + D_2 kT_M \\
E_3 = \frac{C_3 kT_M^2}{(T_M - T_x^+)} + D_3 kT_M
\]

\( T_x^- \) and \( T_x^+ \) are the temperatures on the rising side (\( T_x^- < T_M \)) and falling side (\( T_x^+ > T_M \)) of TL peaks at fractional intensity.

The coefficients \( C_j \) and \( D_j \) (j = 1 → 3) for a particular value of x depends on α. Using method of non-linear regression they expressed \( C_j \) and \( D_j \) as quadratic function of α as

\[
C_j = C_{j0} + C_{j1} \alpha + C_{j2} \alpha^2
\]
The coefficients \( C_{jk} \) and \( D_{jk} \) for \( x = 0.2, 0.5, 0.8 \) are tabulated by Singh et al. (1998).

Singh et al.,\(^{18}\) introduced filling factor \( f = \frac{n_0}{N} \), \( n_0 \) being the initial concentration of trapped electrons and \( N \) being the concentration of the electron trap site) in the MO equations.

Sunta et al.,\(^{19}\) (2002) tested the capability of MO and GO kinetics to fit synthetic glow-peak derived from various phenomenological models such as one-trap-one-recombination center model (OTOR), non-interactive multi-trap system (NMTS) and interactive multi-trap system (IMTS). They found that the MO kinetics model fits the NTMS and IMTS glow-peaks much more successfully than the GO kinetics. On the other hand, the MO fits poorly the TL peaks produced by the OTOR model. They attributed this result to the fact that the OTOR model is too simple and physically unrealistic.

Kisis et al.,\(^{20}\) (2008) obtained new peak shape methods for evaluating the activation energy based on MO. They deduced the expression of the pseudo constants \( C_\alpha, C_\beta \) and \( C_\gamma \) as a function of \( \alpha \). Consequently, activation energies are:

\[
\begin{align*}
E_\alpha &= C_\alpha \cdot \frac{1}{\mu_g} \cdot \frac{F_m + \alpha \cdot kT_A^2}{\omega} \\
E_\beta &= C_\beta \cdot \frac{F_m + \alpha \cdot kT_A^2}{\delta} \\
E_\gamma &= C_\gamma \cdot \frac{1 - \mu'_g}{\mu_g} \cdot \frac{F_m + \alpha \cdot kT_A^2}{\tau}
\end{align*}
\]

where

\[
F_a = \frac{\tau}{\tau} = \int \frac{n(t) dt}{T_A}
\]

The numerical simulation of synthetic glow peak was performed by using very broad regions of the trapping parameters \( 0.7 \leq E \leq 2 \text{eV}, 10^{11} \text{sec}^{-1} \leq \alpha \leq 10^{12} \text{sec}^{-1}, 0.01 \leq \alpha \leq 0.99 \)

Sunta et al.,\(^{21}\) has found some limitations of GO peak-fitting and peak-shape methods for determining the activation energy of the TL glow peaks in the cases in which retrapping probability is much higher than the recombination probability.
and the traps are filled up to near saturation level. Right values can be obtained when the trap occupancy is reduced by using small doses or by post-irradiation partial bleaching. They recommended that this method of activation energy determination should be applied only at doses well below the saturation dose.

In the present paper we have reviewed different variants of peak shape (PS) method. Normally the peak shape method is suitable for single and isolated glow peaks but the availability of peak shape expressions for arbitrary intensity ratios such as 1/4, 2/3 or 4/5 makes possible investigators to use the peak shape formulas even if one side (rising or falling) of the peak is clean as reported by Garzia et al.,22.

REFERENCES