# About Power Thresholds, Criteria, Kinetics and Mechanisms of Ignition of Explosives by Laser Pulses and Pulsed Electron Beams

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**Abstract – Authors of this work carry out the analysis of applicability frameworks of various ignition criteria for modelling representatives of initiating explosives, secondary explosives and pyrotechnic mixed structures. It is established, that ignition criterion is energy of a pulse which value corresponds 50 % of ignition probability at short time of influences and the small sizes of a beam on a surface of substance, and in case a large sizes of beam – density of energy. In the field of long time the ignition criterion is power or density of power accordingly.**

It is necessary to understand values of energy $W_{05}$ as power thresholds of ignition (PTI), density of energy $H_{05}$, capacities $I_{05}$ and density of capacity $q_{05}$, corresponding to 50% of a level on a probability curve of initiation. Which of these parameters is most informative depends that is criterion of ignition in different experimental situation.

PTI is complex function of many parameters (duration of an influencing pulse $\tau_p$, characteristic relaxation time of external excitation $t_r$, diameter of a beam $d_n$, refraction $n_0$, absorption $\mu$ and dispersion $\beta$ coefficients of explosives, density of substance, dispersivity of explosive powders, pressure of molding and mass molding of explosive powders) and this circumstance is the reason of strongly difference in value of thresholds of various authors in experiences. In turn, criteria of ignition are determined by ratio between space-time parameters of an external influencing pulse and space-time scales of relaxation, which are typical for investigated sample in concrete conditions of experience. Some results of study of PTI at condition dependence on extended influence are presented in Fig. 1.

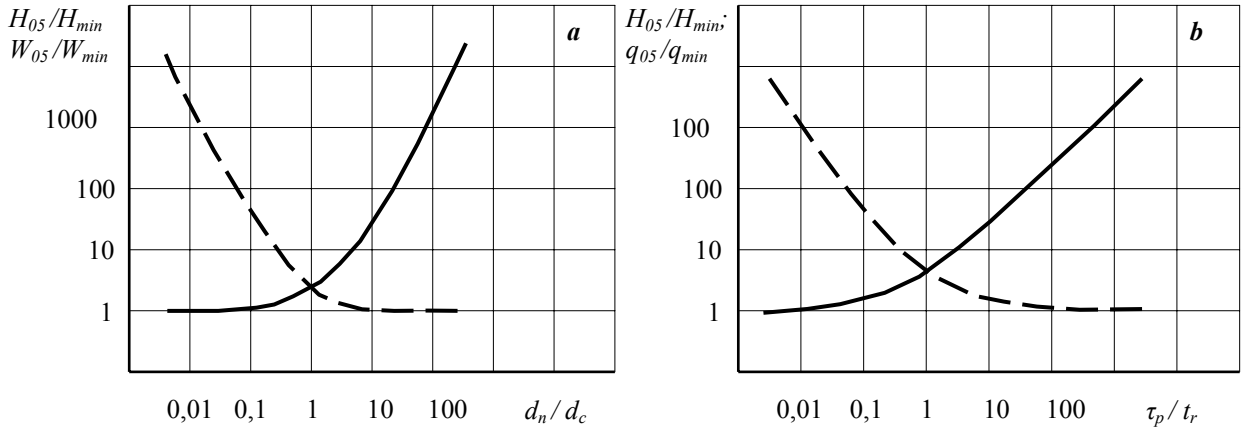


Fig. 1. Typical dependences of sensitivity of explosives versus diameter of laser beam (***a***) and duration of an influencing pulse (***b***).
Values of $d_c$ have: ~1 mm for highly compacted powders of PETN and heavy metal azides (powders, macrocrystals); ~0,1 mm for weakly compacted mixed ammonium perchlorate and superdispersed powder of aluminium.
Values of $t_r$ have: ~$10^{-7}$s for heavy metal azides; ~$10^{-3}$s for PETN; ~$10^{-2}$s for ammonium perchlorate + Al

Authors of the given work carry out the analysis of applicability frameworks of various criteria of ignition for modeling representatives of initiating of explosives, secondary explosives and pyrotechnic structures. It is established, that criterion of ignition is energy of a pulse at short time $\tau_p$ ($\tau_p < t_r$) and the small sizes of beam on surface of explosives (the size of excited area less than characteristic size of ignition – $d_c$) or density of energy at great values of $d_n$ ($d_n > d_c$). The criterion of ignition of explosives is capacity or density of capacity accordingly in the field of long duration ($\tau_p > t_r$).

It is suggested to insert additional parameter for more detail understanding of the nature of ignition – threshold cubic density of energy $\omega_{05}$ (cubic density of capacity $i_{05}$), which characterize the minimal size

absorbed energy (capacity) in unit of volume of substance result in ignition or explosive decomposition of substance.

The definition of $\omega_{05}$ for macrocrystals and powders with known optical characteristics is possible from a ratio:

$$\omega_{05} = F_0 H_{05} \mu,$$

where $F_0$ – coefficient of increase of illuminance in volume of environment [1]; $\mu$ – absorption coefficient of elementary volume. The threshold cubic density of energy for explosive powders with unknown distribution of illuminance into environment volume can be found from expression:

$$\omega_{05} = H_{05} (1-\rho_0) / (\alpha \tau_p + 1 / (\kappa *) 2) 1/2,$$

where $k * = \mu * + \beta *$ – the average absorption coefficient of diffusing environment ($\mu * + \beta *$ – the average coefficients of absorption and dispersion).

The approached estimations of threshold cubic density of energy for crystals and compacted (or volumetric compressed) powders of modelling explosives are resulted. The value of $\omega_{05}$ for heavy metal azides irradiated by short ($\tau_p \sim 10^{-8}$ s) pulses at various ways of excitation have amounted to (Table 1):

- $(10^{-3}$-$10^{0})$ J/cm$^3$ – under the action of a pulsed Nd-laser (energy of quantum – 1,17 eV, area of a transparency) on macrocrystals and the compacted powders of lead and silver azides;
- $10^{1}$ J/cm$^3$ – under the action of a pulsed electron beam (energy of electron – 300 keV) on macrocrystals and powders of lead and silver azides;
- $10^{3}$ J/cm$^3$ – under the action of a pulsed $CO_2$ – laser (energy of quantum – 0,117 eV, area of fundamental absorption) on powders of lead azide;
- $(10^{4}$–$10^{5})$ J/cm$^3$ – under the action of a pulsed excimer laser (energy of quantum – 4 eV, area of fundamental absorption) on macrocrystals and the compacted powders of lead and silver azides.

The analysis of the data results in the conclusion that sensitivity of explosives (estimated on parameter $\omega_{05}$) to various ways of initiation does not correlate with their ability to generation of electron-hole pairs. On the contrary, the threshold cubic density of energy is higher where high concentration of electron-hole pairs is created. So action the excimer laser and an electron beam results to immense concentration (up to $10^{21}$ cm$^3$) of charge carriers, however values of $\omega_{05}$ for these ways of excitation are high. At the same time sensitivity of heavy metal azides under the action of the Nd-laser does not result in direct to creation of electron-hole pairs (width of the forbidden zone in heavy metal azide ~ 3,5 eV). However, sensitivity of heavy metal azide under the influence of the Nd-laser is higher than 8 orders in comparison with sensitivity under the action of the excimer laser.

The opportunity of use of the suggested parameter of $\omega_{05}$ for identification of the nature and mechanisms of initiating of explosives is discussed. It is underlined, that such approach sharply limits opportunities of modelling representations from positions of the chain nature (model of chain duplication of zoned carriers of a charge – electrons and holes [2]).

The important information about nature of explosive decomposition under pulse of external influence can be received from the analysis of kinetic

Table 1. Thresholds of ignition of heavy metal azide (compacted powders, macrocrystals) at short pulse irradiation; $\tau_p \sim 25$ns.

| **Action** | **Type** | **$\mu$; $\mu$*, cm$^{-1}$** | **$h$, cm** | **$H_{05}$, J/cm$^2$** | **$\omega_{05}$, J/cm$^3$** | **Notice** |
|---|---|---|---|---|---|---|
| $CO_2$ – laser ($\lambda_0$ = 10,6 μm; $h\nu_0$ = 0,1 eV) | $Pb(N_3)_2$, powder | ~$10^3$ | $10^{-3}$ | < 5** | $10^3$ | Absence of electron-hole *(n-e)* pairs; heating |
| Nd-laser ($\lambda_0$ = 1,06 μm; $h\nu_0$ = 1,17 eV) | $AgN_3$, crystal<br>$PbN_6$, powder<br>$AgN_3$, powder | ~$10^{-2}$<br>$10^{-2}$;<br>10* | ~ 100<br>~ $10^{-2}$<br>$5\cdot10^{-3}$ | 0,1<br>$5\cdot10^{-3}$<br>$5\cdot10^{-3}$ | $10^{-3}$<br>0,1; 0,5<br>1,0 | Low concentration of *n-e* pairs (~$10^{12}$-$10^{14}$cm$^{-3}$); absence of heating of volume |
| Electron beam | $AgN_3$, crystal<br>$PbN_6$, powder | 320 | ≈ $10^{-2}$<br>~ $10^{-2}$ | 0,1<br>0,1 | 10 | High concentration of *n-e* pairs (~$10^{19}$-$10^{20}$cm$^{-3}$); absence of heating |
| Nitrogen laser ($h\nu_0$ = 3 eV)<br>Excimer laser ($h\nu_0$ = 4 eV) | $PbN_6$, powder<br>$AgN_3$, crystal, powder | $10^4$<br>$10^5$<br>$10^5$ | ≈ $10^{-4}$<br>≈ $10^{-5}$<br>≈ $10^{-5}$ | 0,1-<u>10</u><br><u>1,5</u><br>0,1-<u>5**</u> | $10^3$-<u>$10^5$</u><br>$10^4$-<u>$5\cdot10^5$</u> | Extremely high concentration of *n-e* pairs (≥$3\cdot10^{22}$cm$^{-3}$); strong heating of volume |

Here the sign * – means the average value on layer of diffusely scattering medium; ** – not published data; the underlined values – thresholds from an open surface of explosives.

characteristics of ignition and especially during initial stages of process. Synchronous multi-parameter measurements of kinetics with the high time resolution in this connection are of interest.

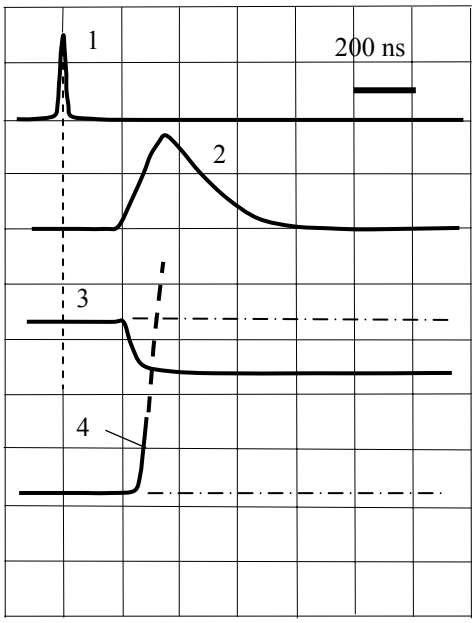


Fig. 2. There are typical oscillograms of explosive decomposition of lead azide at laser initiation. 1 – laser pulse; 2 flash of a luminescence; 3 – moment of scattering of sample; 4 – occurrence moment of a detonation pulse

In this paper the results of experimental observation of kinetics with the nanosecond time resolution for power material family at excitation by a laser pulse and pulse of electron beam in a wide range of levels of influence and a time interval including the induction period, fast explosive decomposition and scattering of explosion products are presented. Kinetics of an explosive luminescence and an acoustic pulse, dynamics of scattering of products, movements of front of a burning wave and occurrence of electric conductivity in volume of a sample was synchronously observed. Speeds of scattering of decomposition products, speed of burning front and speed of a compression wave are determined. Some of the explosive decomposition kinetics is represented in Fig. 2–4. The following basic laws of process are marked (Fig. 2).

At laser excitation ($\tau_p$ = 20 ns) after the termination of influence the induction period is always observed which duration at threshold influences amounts to 200 ns and decreases in case of increase in a level of external excitation. The short scintillation (duration of 100–200 ns, curve 2 in Fig. 2) arises after termination of the induction period, simultaneously with the advent of one begins scattering products decomposition (curve 3 in Fig. 2) and formation of the acoustic response. The termination of an

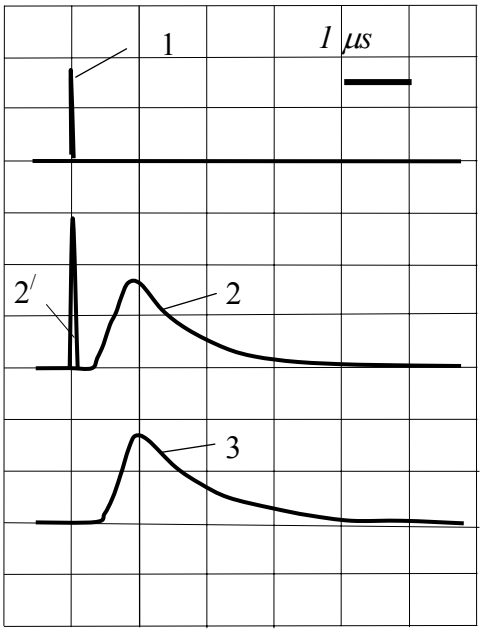


Fig. 3. There are kinetics of explosive luminescence silver azides at electron beam initiation. 1 – moment of an irradiation of a sample (reference pulse); 2/, 2 – cathodoluminescence pulse and explosive luminescence from an open surface; 3 – the surface of a sample is closed by a metal film.

explosive luminescence testifies to full decomposition of explosives in the field of influence. It is specified, that the explosive scintillation and explosive conductivity conditioned by low-temperature plasma, i.e. have thermal nature. It is shown, that any preexplosive phenomena, including described in [3], are absent at laser pulse excitation of power-producing materials.

The same kinetic laws are observed at ignition of explosives by electron beam with duration about 25 ns, as under laser excitation. The one peak of an explosive luminescence (curve 2, 3 in Fig. 3) is observed at ignition of initiating explosives, and two characteristic peaks (Fig. 4, *a*) of thermal nature – at ignition of secondary explosives. At ignition of explosives by electron beam the distinctive feature is occurrence of scintillation in the moment of an irradiation of a sample both at threshold levels and at levels of influence is significant smaller threshold size (curve 2/, Fig.3). Spectra and time characteristics of this kind of scintillation are investigated. The luminescent nature of this kind of scintillation is shown.

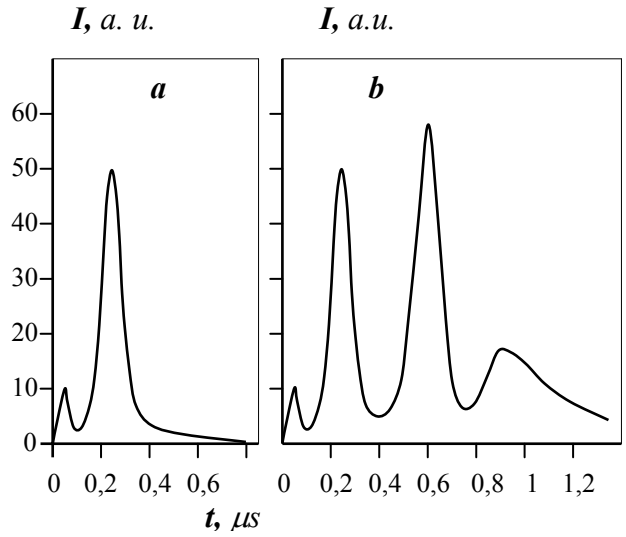


Fig. 4. There are kinetics of an explosive luminescence of PETN at electron beam initiation. *a* – at free scattering products of explosion (plasma); *b* – at presence of two barrier established on distance of 2 mm and 4 mm

The opportunity of the description of the obtained results from positions of thermal micro-focal models of initiating explosives [4–7] is considered. The model assumes localization of energy of an external pulse at various ways of influence, and the mechanism of localization can be various. So beam energy is located in the volume limited in the size of a beam and depth of light penetration at an irradiation by excimer or $CO_2$ – laser beam. The localization of beam energy is possible on optical micro-imperfections, distributed in volume of the transparent environment at irradiation by Nd-laser, and the processes of redistribution of beam energy at influence by an electron beam are possible after its absorption. Such situation (despite of huge distinctions in values $\omega_{05}$) into threshold levels of influence at all considered ways of pulse excitation makes possible creation of the thermal microcenters in volume of explosives in the size from $10^{-3}$ up to $10^{-5}$ cm (so-called "hot points"). The specific heat content of thermal microcenters is approximately equal and achieves values about $10^4$ J/cm$^3$ in a range of $\omega_{05}$=$10^{-3}$–$10^5$ J/cm$^3$.

For the benefit of such conclusion can testify the basic criteria of ignition if relaxation parameter $t_r$ to give sense of characteristic time of a thermal relaxation. In this case at $\tau_{and} < t_{rel}$ the temperature of the point can achieve values $10^3$–$10^4$ K, that provides fast development of decomposition process. This conclusion proves to be true the established thermal nature of an explosive luminescence and short time experimentally observed of induction period.

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