The Threshold Phenomena in Pentaerythritol Tetranitrate, Initiated by Powerful Electron Beam

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Abstract – Powerful electron beams of nanosecond duration in combination with optical pulse spectrometry are widly used for studying processes in solids and monitoring the properties of various solids including explosives. At present much of experimental data has been gained about the physical and chemical processes in initiating explosives. Such investigations for the secondary explosives have been reported recently. Here we report the experimental results of the physical and chemical processes developed in brisant explosives – PETN when influenced by a powerful electron beam of nanosecond duration with a power density in the range from 10^6 to 10^{10} W/cm^2. The research results of the PETN detonation velocity, the space-time parametres of plasma glow and absorption developed near the PETN surface during its explosive decomposition are presented. Cratering and the gas-dynemic phenomena are investigated. The explosive glow kinetics is shown to reflect the process of the dense plasma formation and expansion as a result of two consecutive explosions: in a zone limited by the run of an electron beam and detonation of other PETN weight. It is presumed that the basic process that leads to electron beam energy cumulation and PETN "hot spots" formation is supposed to be the electric breakdown developed in electric field of the injected volume charge beam. The possibility of PETN shock-wave initiation is proved.

1. Introduction

The initiation of PETN pressed samples explosion by electron beams of nanosecond duration has been presented in the research for the first time. The threshold power density sufficient for detonation was determined; the explosive glow kinetics was measured. It has been set that after the induction period of 100 ns duration when plasma expanded freely, a peak of the glow with the half-height of 120 ns duration was observed. This glow pulse is interpreted as the glow of the PETN explosive decomposition products. Later, the authors of research [2] repeated these experiments with PETN monocrystals and also measured the explosive glow spectra. The investigation researches showed, when the glow measured from the zone of an electron beam influence under conditions of the free explosive decomposition products expansion, the glow consists of two components their spectra are being coincident and continuous. The first and second of the explosive glow peaks with a continuous spectrum maximum near 850 nm, are [2] interpreted by the authors as PETN luminescence arising during the explosive decomposition and proceeding in a solid phase until the sample mechanical destruction pre-detonation luminescence [3]). As the spectrum and kinetic characteristics of the glow of the PETN explosive decomposition are similar to the explosive decomposition heavy metal azides characteristics the authors assume that the initial stage of the PETN explosive decomposition develops in chain.

The [2] results interpretation arises some doubts. Firstly, there is no plasma glow explosion at its free expansion on the explosive glow oscillogram and it appears only when there is an obstacle. Secondly, the reason of the glow second peak formation and the intensity reduction of the first one is not clear. It is natural when the glow from the PETN irradiation zone is measured there is an additional glow peak. The physical processes that result in this glow peak (at high power of an electron beam) can vary: pulse cathodoluminescent, erosive plasma glow in the sample micro zones caused by the energy cumulation of an electron beam and, finally, the glow of chemical decomposition products formed in the electron beam run zone.

The aim of the research is to determine the physical nature of the first and second glow peaks observed at the initial stage of the PETN explosive decomposition and the moment of sample phase transition into plasma condition.

2. Technique experiment

The electron beam with the effective electron energy of ~ 250 eV, the half-height duration of ~15 ns and power density P changing in the range of 10^6 –10^{10} W/cm^2 was used to study the pre-detonation phenomena and PETN detonation. The powdered PETN in the form of pellets 0,3 – 2 mm thick and diameter of ~ 2 mm, received under pressure of 10^9 Pa was studied. The PETN samples were excited by an electron beam in the vacuum chamber at pressure 10^{-2} Pa and temperature 300 K. The probing schemes of the glow and absorption as those presented in [4] were used to study the dynamics formation and expansion of its explosive decomposition products. The irradiated PETN surface could be set at 90^0 or 45^0 to an electron beam and optical axis of the measuring scheme. The measuring scheme (α=45^0) allowed

(without spatial resolution) to measure all kinds of the glow initiated by an electron beam both in a solid (luminescence) and in the region adjacent to its surface (plasma). The image of the sample (with 2.5 magnification) and the adjacent region of plasma expansion was projected by a lens onto the exit slit of an MDR-23 monochromator. The probing laser beam (He-Ne – laser, л=632.8 nm) is directed in parallel to the PETN irradiated surface at distance L to measure optical transmission of the explosive decomposition products. The change of a probing radiation flux having passed through the plasma of the explosive decomposition plume after the sample was excited. The obstacles set at different distances from the rear side (to the beam) of the sample surface were used to determine the velocity of expansion of the explosion products. These measurement schemes allowed to consistently measure the glow kinetics or optical transmission of the PETN explosive decomposition kinetics with the help of photo detector PEM-118. The signal from the photo detector (luminescence or transmission) was recorded by the oscillograph Tektronix TDS 2022. An explosive glow and transmission could be registered from any zone of the sample or the region of plasma plume expansion. The sizes of these zones were determined by the monochromator slit width and the diameter of diaphragm S which was set in front of entrance slit of MDR-23.

3. Results and discussion

The kinetics of optical explosion products transmission obtained from the adjacent zone to the PETN irradiated surface (L = 0,2 mm) is presented in Fig.1a. The explosive glow kinetics (λ =580 nm), measured at free expansion of the explosive decomposition products and at with two obstacles are presented in Fig. 1, b, c respectively. The time basic origin corresponds to the excitation moment of the sample influenced by the electron beam. The oscillogram presented in Fig. 1a shows that scattering of probing radiation by the explosive decomposition products delays ($t_з = t_{ind} + t_{pe}$), where t_{ind} – the induction period; t_{pe} – time of plasma plume expansion up to the probing region. It is evident, that the delay is ~ 120 ns at L=0,2 mm. The scheme where the sample was set at 45^0 to the way of electron beam was used to obtain the complete kinetic curve of the glow going with the explosive decomposition. The glow kinetics from the PETN irradiated surface at the different electron beam power are presented in Fig. 2, a, b, c. It was found, when power changes in the range of $10^6 < P < 10^8$ W/cm^2, PETN pulse cathodoluminescent (PCL) is the main glow type which is proved by spectrum and kinetics characteristics of the glow measured and coincidence with PETN PCL parameters having been measured at P ~10^6 W/cm^2. The glow kinetics was observed from the PETN irradiated region at P ~ 10^9 W/cm^2 (pre-detonation mode). It can be seen that at the rise-up portion being unchanged (τ_f ~ 12 ns) the increasing of glow pulse duration and the thin structure at the descending part occurs. The form of the first explosive glow pulse practically does not change at P > $5 \cdot 10^9$ W/cm^2 (the detonation irradiation mode) and after the delay (t_{ind} – the induction period) the second explosive glow peak is formed, its amplitude and kinetic characteristics being determined by the sample sizes. The formation of the second explosive glow peak is followed as a rule by the intensive glow flash which can be seen in all the volume of the vacuum chamber, by the sound pulse and mechanical destruction of the constructional elements which are near the sample, that is to be evident of PETN detonation. Practically synchronously with this peak of dissipation of probing radiation by explosive decomposition products testifies that the sample chemical decomposition is completed up to this moment. Thus, the second explosive glow peak is not related to luminescence and is connected with the glow of the PETN explosive decomposition products. The interpretation of the glow with its thin structure and appearing at the descending part of cathodoluminescence of pre-detonation irradiation mode is the most complicated. Specific researches showed that the additional glow to luminescence at electron beam power density being close to the threshold detonation to initiate PETN, is observed in dielectrics and semiconductors of various compounds (not energy materials), it is connected with plasma glow originating in the electron beam cummulation energy zones in the sample being irradiated. There are two physical reasons that can lead to electron beam energy localization in the target being irradiated and can increase cubic density rating of energy release by (1–2) order. The first reason is the electric breakdown developing in dielectrics and high-resistant semiconductors in the region of the electron beam injected volumetric charge [4], the second – spatial heterogeneity of the electron beam, e.g. beam filamentation at self-focusing in the vacuum diode. It is necessary to note, that the electric breakdown in ionic crystals and semiconductors of the group A_2V_6 starts to develop at rather low power density (P>$5 \cdot 10^6$ W/cm^2) and it is the basic physical process responsible not only for the plasma formation in dielectrics but also for the samples destruction. As PETN is dielectric, it can be assumed, that the electric breakdown is also developed in PETN by an electron beam. There are a number of stages: beam cummulation energy, plasma formation, shock-wave and gas-dynemic phenomena and destruction.

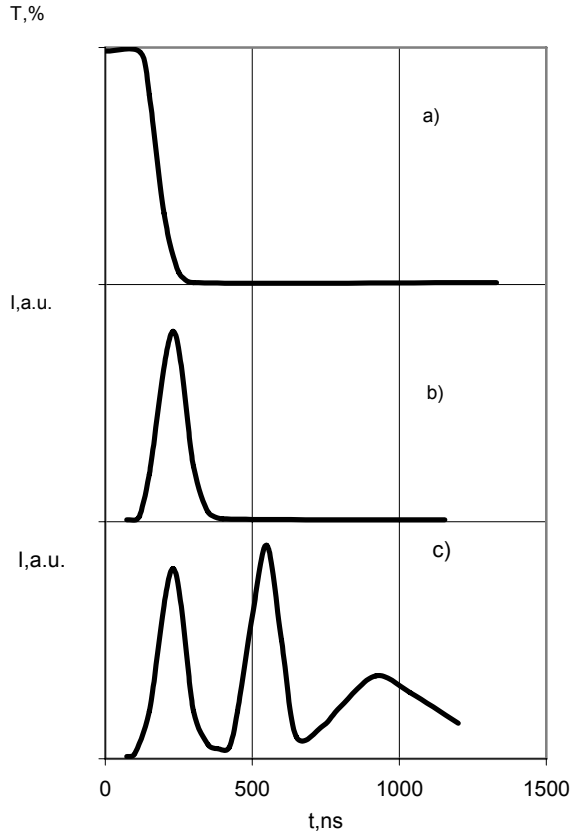

Fig. 1. Kinetics of transmission (a) and glow (b, c) of the PETN explosive decomposition products when the detonation by the electron beam is initiated: a, b – at free explosive products expansion; c – with two obstacles

The possibility of PETN electrical discharge phenomena development while being irradiated by electron beam with the power less than the threshold detonation is possible because of gas-dynamic phenomena being observed in parallel with cratering process. When studying the process of the PETN pressed pellets destruction there was found one distinctive feature – the micro particles dispersal emitting out of the crater at long distances, their electrization and adhesion to windows of the experimental chamber. It was assumed that the low destruction threshold and large kinetic micro particles energies the result of the sample gasification due to electric breakdown development and, in addition, due to the course of chemical reaction decomposition, in zones adjacent to "hot spots" i.e. the channels of electric breakdown. The following measurement scheme was used to research gas-dynamic phenomena. The sample with the parameters: Ø = 6 mm, h = 1,5 mm, where Ø –pellet diameter, h – thickness; and weight m = 75 mg, was attached to a thin filament above the electron beam collimator and was excited by the beam with energy density ~ 0,5 J/cm^2.

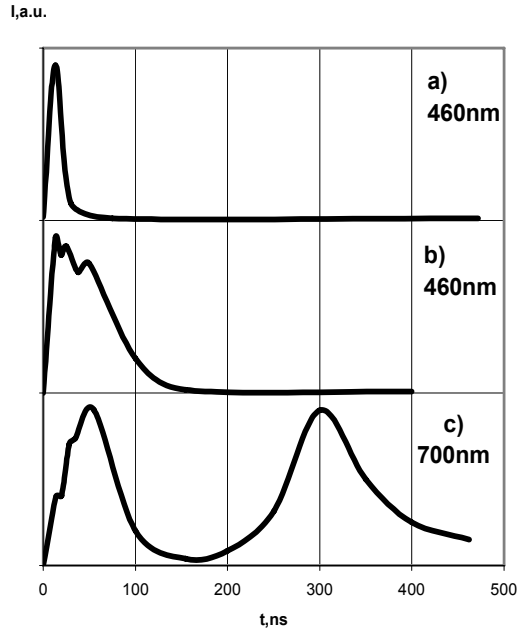

Fig. 2. Glow kinetics observed from the PETN irradiation zone at various power of the electron beam: a – (10^6<P<10^8) W/cm^2; b – (P ~ 10^9) W/cm^2; c – (P>$5\cdot10^9\cdot$W/cm^2)

At the moment of excitation pulse products of ablation were emitted towards the electron beam therefore the sample got pulse in the opposite direction – along the electron beam movement. The He-Ne laser beam was directed in parallel with corresponding surfaces to measure the velocity of the sample and micro particles emitting from the crater. The change of laser radiation flux after the sample excitation was measured in series. The intensity change oscillograme of the probing radiation going in parallel to the rear side of PETN pellet surface allows to determine the velocity of the PETN pellet movement: V = 1.5 m/c, and then the kinetic energy can be calculated: W = 56 · 10^{-6} J (0,37% from the beam energy). It has been found experimentally that the velocity of the substance emitted from the crater, makes 160–200 n/c. To find out how the parameters of solid influence its gas-dynamic properties, the gas-dynamics of materials of various kinds was studied and the glow kinetic characteristics of plasma caused by the thermal explosion of the samples. It was found out that sublimation temperature is the determinant parameter for metals. The permeability of solids to gases (the possibility of the chemical decomposition products emission from the irradiated region onto the solid's surface) is the additional factor for dielectrics (monocrystals, polymers). Rather low threshold of gas-dynamic initiation processes in various dielectrics allows to assume that the electric breakdown is basic for the substance gasification when irradiated by

electron beam. In PETN electrical discharge processes are supposed to initiate process of substance chemical decomposition near the electric breakdown channels. At large electron beam powers the chemical reaction spreads on all the region of the electronic beam deceleration. The shock wave that follows, initiates the detonation of other PETN weight. Two consecutive explosions make two explosive glow peaks with a continuous radiation spectrum. In the paper the velocity of PETN detonation was measured as follows. Samples of a cylindrical form were made of PETN powder with the dispersion 6000 cm^2/g which was put in preliminary drilled holes in metal plates, the sizes of holes are: Ø = 1,8 mm, h = (0,5 – 9) mm where it was condensed. The time period in which the detonation wave initiated by electron beam passes the distance equal to the charge length, was measured by optical method (according to the glow of explosive decomposition products). The base (the charge length) is being changed the delay time of detonation wave yield onto the rear side (relatively to the electron beam) of the plate surface was measured and the velocity of detonation wave was calculated. The maximum speed made 8200 m/s.

4. Conclusion

From the above-stated we can consider the obtained results. The electron beam power density being changed in the range of $10^6 < P < 10^8$ W/cm^2 the pulse cathodoluminescence is the basic kind of the glow initiated by the electron beam in PETN. Electrical discharges processes start to develop in the electron beam run zone at $P > (5 – 8)\cdot10^6$ W/cm^2 which leads to the cumulation of energy release and gasification of high explosives. The micro plasma glow intensity is still insufficient for registration at the background of intensive cathodoluminescence of the sample. The power increase of the initiating pulse leads to the raise of the charges released energy and the number of hot spots, being the centers of the origin of chemical decomposition reaction. The expansion of the chemical reaction zone on all the solid volume excited by electron beam takes place at $P\ 10^9$ W/cm^2. The chemical reaction originated in the region of electron beam run (micro explosion of the PETN volume limited by beam deceleration zone) leads to the generation of an intensive shock wave which initiates the detonation of all the weight of the sample.

References

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