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Nature of Glowing Generated by Irradiation of Pentaerythrite Tetranitrate by an Electron Beam

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Results of studying the nature of glowing generated by pentaerythrite tetranitrate (PETN) excitation by an electron beam with a mean electron energy of ≈250 keV and a current-pulse duration of 15 nsec are presented. The pulse-averaged power density of the beam is varied within $10^6 \leqslant P \leqslant 10^{10}$ W/cm^2. For $10^6 \leqslant P \leqslant 10^8$ W/cm^2, the main type of glowing is demonstrated to be pulsed cathodoluminescence of PETN. In the pre-detonation mode ($P \approx 10^9$ W/cm^2), more inertial glowing is formed on the rear front of the luminescence peak, which is identified as the glowing of products of explosive transformation of PETN formed in the region of electron-beam travel. For $P \geqslant 5 \cdot 10^9$ W/cm^2, an additional glowing pulse is formed, which is associated with formation and spreading of a dense plasma emerging owing to detonation of the entire mass of the sample.

Key words: pentaerythrite tetranitrate, pulsed initiation, explosive glowing.

Korepanov et al. [1] were pioneers in initiating an explosion of pressed pentaerythrite tetranitrate (PETN) samples by a pulsed electron beam. They found one peak of explosive glowing (EG) with a base duration of ≈300 nsec after the induction period (≈100 msec) under conditions of unconfined spreading of the plasma. This glowing pulse was interpreted as the glowing of explosive decomposition of PETN. Similar experimental results on PETN single crystals were obtained, and the EG spectra in the wavelength range of 550 to 1000 nm were measured [2]. The studies showed that EG consists of two peaks whose spectra coincide and are continuous if the glowing is registered from the side of the irradiated PETN surface (single crystals and pressed samples) under conditions of unconfined spreading of explosion products. The first and second EG peaks with durations of 100 and 500 nsec and with a maximum near 850 nm were interpreted in [2] as PETN luminescence that arises in the course of the explosive decomposition reaction and proceeds in the solid phase until the sample becomes mechanically destroyed.

The objective of the present activities was to find the physical nature of glowing generated by PETN irradiation by a powerful electron beam and to determine the instant of the phase transition in the sample from the solid to the plasma state.

In contrast to [2], the present measurements made it possible to record not only the luminescence of the solid phase, but also the glowing of the products of explosive decomposition of PETN with a spatial resolution outside the solid-phase surface, as was described in [3].

The research object was powdered PETN in the form of pellets pressed at 10^9 Pa. The samples were excited in a vacuum chamber at a pressure of 10^{-2} Pa and temperature of 300 K. The irradiated PETN surface could be mounted at an angle of 90 or 45° to the electron beam. The geometry of EG excitation and registration ($\alpha = 45°$) allowed simultaneous registration (without spatial resolution) of all types of glowing initiated by the electron beam: both luminescence and emission of the plasma in the region adjacent to the sample surface. For optical transmission of explosive decomposition products to be measured, a probing beam of laser radiation parallel to the irradiated PETN surface at a prescribed distance L was initiated. The changes in

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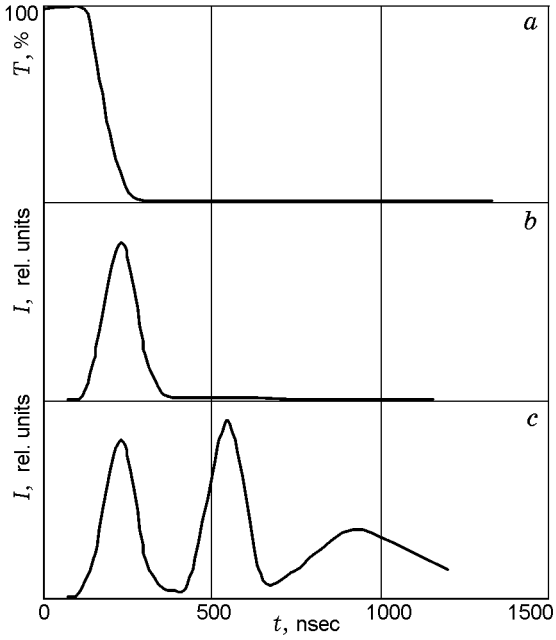

Fig. 1. Kinetics of transmission (a) and glowing (b and c) of the products of explosive decomposition of PETN (geometry of excitation and registration $\alpha = 90°$): free spreading of explosion products (a and b) and in the presence of two targets (c).

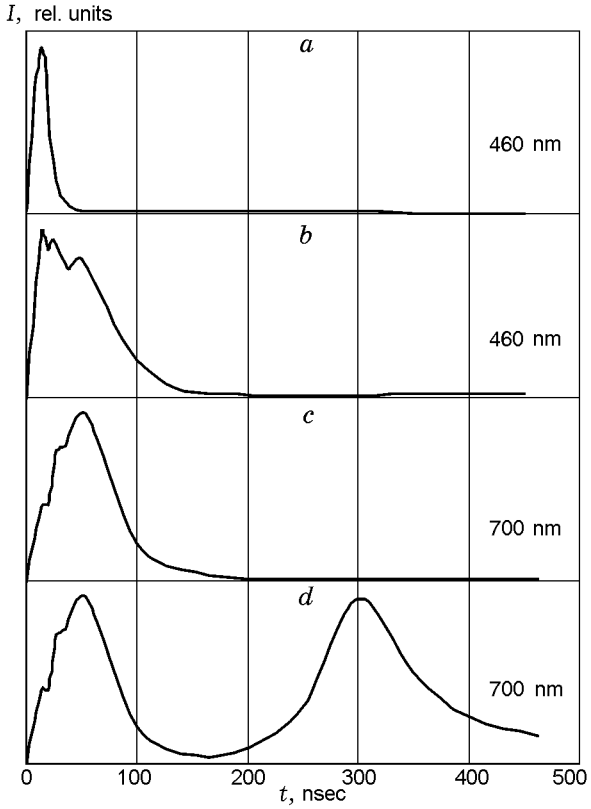

Fig. 2. Kinetics of glowing observed in the zone of PETN irradiation (geometry of excitation and registration $\alpha = 45°$): $10^6 < P < 10^8$ W/cm^2 (a), $P \approx 10^9$ W/cm^2 (b and c), and $P > 5{\cdot}10^9$ W/cm^2 (d).

the flux of probing radiation that passed through the plasma of the explosive decomposition plume were registered as functions of time after the sample excitation. The spreading velocity of explosion products was measured by placing targets on their paths.

The kinetics of optical transmission of explosion products in the zone at a distance $L = 0.2$ mm from the irradiated PETN surface is illustrated in Fig. 1a. The EG kinetics ($\lambda = 580$ nm) measured in the case of free spreading of explosion products and in the presence of two targets (geometry of excitation and registration $\alpha = 90°$) are shown in Figs. 1b and 1c, respectively. It follows from these oscillograms that the inertial EG peak and absorption are formed simultaneously with a delay of ≈120 nsec, which testifies that explosion products have already appeared by that time. Thus, the inertial EG peak (second EG peak in terminology of [2]) is caused by emission of the products of explosive decomposition of PETN rather than by luminescence.

To study the integral kinetics of glowing accompanying explosive decomposition of PETN, we used the geometry of excitation and registration $\alpha = 45°$. Figure 2 shows the kinetics of glowing of the irradiated PETN surface for different powers of the electron beam. If the power ranges within $10^6 < P < 10^8$ W/cm^2, the main type of glowing is the pulsed cathodoluminescence (PCL) of PETN (inertialess peak of glowing with a growth front of ≈13 nsec; Fig. 2a), which is evidenced by the spectral and kinetic characteristics of glowing and their coincidence with PETN PCL parameters measured in [1]. Figures 2b and 2c show the kinetics of glowing of the irradiated PETN surface recorded in the blue ($\lambda_1 = 460$ nm) and red ($\lambda_2 = 700$ nm) spectral ranges at $P \approx 10^9$ W/cm^2. At this power of the electron beam, the duration of the glowing pulse increases because additional (more inertial) glowing with a fine structure occurs on the rear front of PCL ($\lambda_1 = 460$ nm). Note that the PCL intensity decreases if EG is registered at a wavelength of 700 nm, which alters the registered shape of the pulse and shifts the position of the maximum in time (Fig. 2c). At $P > 5 \cdot 10^9$ W/cm^2, the shape of the first EG peak remains almost unchanged, and a second EG peak is formed with a delay of 100–150 nsec (Fig. 2d). The emergence of the second EG peak is accompanied by an intense flash observed in the entire volume of the vacuum chamber, an acoustic pulse, and mechanical disintegration of structural elements, which is indicative of PETN detonation.

The most difficult problem is to interpret the glowing that has a fine structure and appears at the rear front of PCL in the pre-detonation regime of irradiation.

A special study showed that glowing (in addition to luminescence) at a power density of the electron beam close to the threshold value for initiation of PETN detonation is observed in single crystals and pressed samples of NaCl, CaF_2, and CdS. This glowing is associated with emission of the plasma formed owing to cumulation of the electron-beam energy in microvolumes of the substance. The possibility of plasma formation in PETN irradiated by an electron beam with a power much smaller than the threshold value is indicated by gas-dynamic phenomena. It was found that ablation products formed after PETN excitation by an electron beam ($P \approx 10^7$ W/cm^2) leave the crater toward the electron beam with a velocity of ≈160 m/sec; as a result, the sample acquires momentum in the opposite direction ($v \approx 1.5$ m/sec and $m = 75$ mg). The low threshold of the emergence of gas-dynamic processes in PETN and inert dielectrics mentioned above allows us to conclude that the main role in substance gasification belongs to the electrical breakdown developed in the field of the injected volume charge of the beam. Electrodischarge processes developed at low electron-beam densities, however, are insufficient for providing plasma glowing intensity commensurable with PCL. At $P \geqslant 10^9$ W/cm^2, the electrodischarge processes become more intense, which results in chemical energy release and formation of the first EG peak. The shock wave formed thereby initiates detonation of the entire mass of the sample.

Thus, two consecutive explosions (the first one occurs in the zone of electron-beam travel with the glowing intensity maximum reached ≈50 nsec after the excitation pulse; the second one is the detonation explosion) form two EG peaks with a continuous spectrum, which are related to emission of the products of explosive transformation of PETN.

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