The nature of glow arising in PETN monocrystals' explosion initiated by a pulsed electron beam

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Abstract. The explosive decomposition of pentaerythritol tetranitrate monocrystals under the influence of a high-current electron beam (0.25 MeV, 20 ns, 15 J/cm2) was researched with the approach of high temporal resolution optic spectroscopy. We measured kinetics and emission spectra in real time scale. The thermal nature of the explosive glow was proven with the method of spectral pyrometry. The estimated temperature of the explosion is $T \approx 3000$ K..

1. Introduction

Pentaerythritol tetranitrate (PETN) is a secondary explosive that has extensive practical applications. There are numerous experimental studies where its decomposition under different initiation stimulus was researched [1-3]. One of the most fertile approaches applied in the field of explosives' decomposition research is pulse radiolysis. [4-6]. This method is believed to be highly informative as it is able to give insight into the nature of intermediate species and make it possible to estimate the temperature if it is high enough. In the present paper the kinetics of PETN monocrystals explosion initiated by pulse electron beam is studied with high temporal resolution optic spectroscopy. This way we determined the nature of glow arising during the decomposition.

2. Experimental methods and results

A pulsed electron accelerator GIN-600 was used as a source of high-current electron beam. The effective energy of an electron in the beam was 250 keV, the pulse duration was 20 ns, and the current density was up to 3 kA/cm^2.

The PETN monocrystal samples having thickness 1.5 – 2 mm and width 3 – 4 mm were installed on a copper crystal holder in a vacuum chamber of the accelerator. The distance between anode and the sample was 3 mm. The crystal surface made the angle of 45° with the beam direction and the axis of optic measurement system. The anode was made of a steel plate with a round central hole having diameter 2 mm, which was used as a discharge outlet of the vacuum diode. The distance between the steel cathode with diameter 2 mm and the anode was 3 mm. In the conditions described the incident

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energy density of the high-current electron beam influencing the sample was 15 J/cm^2. The experiments were performed at the temperature 300 K and pressure 0.01 torr.

The kinetic and spectral dependencies of the glow arising during the PETN explosion were measured with a spectral streak-camera as it is described in [7]. The main parts of the apparatus were a polychromator used for decomposition of the glow into spectral components and a streak-camera working in the mode of linear timebase deflection. The image from the output screen of the streak-camera was read by a PCC-device and was transmitted to a computer where it was processed. The apparatus makes it possible to measure the spectral dependencies of the glow stimulated by a single pulse influence on the sample in the range 350 – 700 nm in the timebase deflection mode. The temporal resolution of the apparatus was 10 nm, the spatial resolution was 10 ns. The spectral response of apparatus was measured in the preliminary experiment where the spectral dependence of the correction coefficient k(λ) was determined with the standard incandescent lamp TRSh 2850-3000 which color temperature is known.

The kinetics of the glow at the wavelength λ = 590 nm obtained from the processed spectral-temporal image is shown on the fig. 1. The temporal dependence has two peaks. The first one observed in the nanosecond range is concerned on the sample's glow during the high-current electron beam influence, while the second one in the microsecond range is linked to the sample's decomposition.

The spectral dependence of the glow observed at the moment of the second intensity maximum (1 μs) is presented on the fig. 2. One observes a continuous spectrum with the intensity increasing in the red spectral range. The spectral lines of the excited nitrogen molecules [8] formed as a result of the decomposition are seen on the background of continuous spectrum.
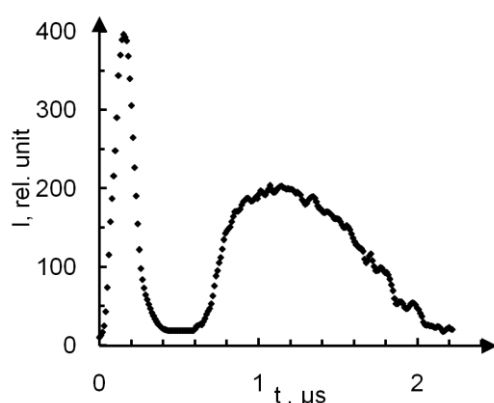

Fig. 1. The kinetics of PETN glow stimulated by the high-current electron beam pulse with energy density 15 J/cm^2 measured at the wavelength λ = 590 nm.
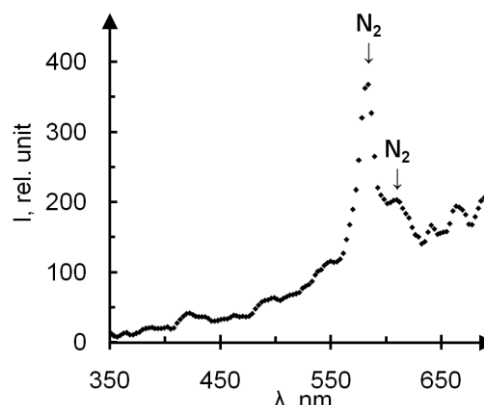
Fig. 2. The spectral dependence of the PETN monocrystal glow at 1 μs after the influence of high-current electron beam pulse.

3. Discussion

The nature of the glow arising during the high-current electron beam influence on the sample corresponding to the first peak on the temporal dependence (fig. 1) was studied thoroughly and interpreted in [4,5]. The nature of the glow observed on the stage of chemical decomposition corresponding to the second peak on the glow kinetics (fig. 1) has not got a proper understanding in [4,5]. It was suggested that the glow is linked to the NO$_3$-radicals luminescence, though the arguments for were unsound. Moreover, it was not determined whether the nature of the glow is the luminescent or thermal. The luminescent point of view stated in [4,5] was based on the fact that the spectral dependence in the range 600 – 1000 nm (λ$_{max}$ = 840 nm) could not be fitted with the Plank's equation.

However, the possible spectral dependence of the emissivity factor, which distorts the thermal spectral dependencies of real objects comparing to the Plank's one, was not taken into account.

In the present paper the spectral dependencies were measured in the range 350 – 700 nm, so we used the approach of spectral pyrometry utilizing the Wien's coordinates for the results processing. This approach is as follows. The spectral dependence of the real object thermal emission is described by the Plank's equation with the emissivity factor ε:

$$I = \varepsilon C_1 \lambda^{-5}/[\exp(C_2/\lambda T) - 1] \tag{1}$$

where $C_1 = 37418$ W·μm^4/cm^2; $C_2 = 14388$ μm·K.

The problem arising when one tries to find out whether the spectrum of an object is thermal or not is concerned on the emissivity factor ε. The emissivity factor could be a smooth function of the wavelength in the case of so called gray body or may vary significantly with the wavelength. This obstacle could be overcome when one carries out the measurements in the Wien's range:

$$C_2/\lambda T \gg 1 \tag{2}$$

In this case the equation (1) simplifies:

$$\ln(\lambda^5 I) - \ln(\varepsilon C_1) = -C_2/(\lambda T) \tag{3}$$

One is able to elucidate the thermal nature of the glow with plotting the function $\ln(\lambda^5 I)$ against $x = C_2/\lambda$ and checking whether the curve is linear. This way the distorting influence of the ε is eliminated. The temperature of the sample could be estimated as the slope of the linear curve.

The fig. 3 shows the spectrum of the PETN monocrystal glow at the stage of the chemical decomposition in the Wien's coordinates. The dependence is almost linear, so it proves the thermal nature of the glow. The temperature corresponding to the slope is $T = 3030$ K.
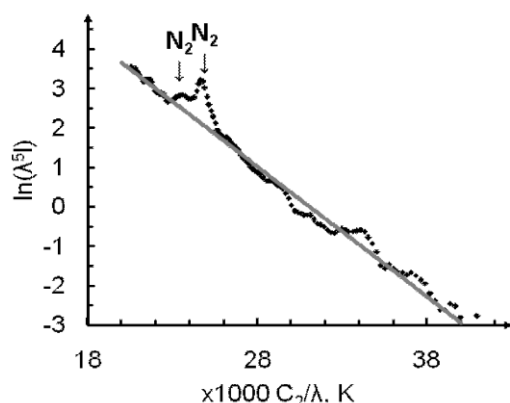

Fig. 3. The spectral dependence of the PETN monocrystal measured after 1 μs after the high-current electron pulse influence plotted in the Wien's coordinates.

4. Conclusion

The spectral-temporal dependencies of the glow arising during the explosion of PETN stimulated by the high-current electron pulse were measured. The spectral dependencies at the stage of chemical decomposition were processed in the Wien's coordinates and the thermal nature of the glow was determined. It could be considered as an argument for the thermal nature of the reaction acceleration at this stage.

Acknowledgments

5. References

[1] Dreger Z A, Gruzdkov Yu A et al. 2002 *J. Phys. Chem.* B **106** (2) 247

[2] Tarzhanov V I, Zinchenko A D Sdobnov V I et al 1996 *Combust. Expl. Shock waves* **32** 454

[3] Korepanov V I, Lisitsyn V M, Oleshko V I et al. 2003 *Tech. Phys. Letters* **29** 669

[4] Aduev B P, Belokurov G M, Grechin S S, Tupitsin E V 2004 *Tech. Phys. Letters* **30** 774

[5] Aduev B P, Belokurov G M, Grechin S S, Shvayko V N 2007 *Rus. Phys. J.* **50** 99

[6] Aluker E D, Aduev B P, Krechetov A G, Mitrofanov A Yu, Zakharov Yu A 2006 *Early stages of explosive decomposition of energetic materials* (Focus on Combustion Research) Ed. S Z Jiang (New York: Nova Publishers) chapter 2 pp 55 – 88.

[7] Shvayko V N, Krechetov A G, Aduev B P et al. 2005 *Tech. Phys.* **50** 732

[8] Pierce R and Gaydon A 1949 *Identification of molecular spectra* (London: Chapman and Hall, 1950) 240 p.

[9] Magunov A N 2009 *Instruments and Experimental Techniques*. **52** 451