

Spectra of explosive glowing of heavy metal azides at initiation by high-current electron beam

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Abstract. Glowing spectra of products resulted by heavy metal azides explosive decomposition initiated by high-current electron beam were measured and identified. Intensive emission lines related to atoms of alkali metals were observed in spectra of samples under study. These atoms enter explosives during their preparation. Emission lines of elements being part of a sample holder were also presented in spectra of explosion.

1. Introduction

Pulsed optical spectroscopy with the high time resolution is one of the promising and modern methods for studying of explosive decomposition of energetic materials (EM) [1–4]. Pulsed laser and electron beams are used as an energy source for explosion initiation in this method as they have several characteristics necessary for studying kinetics of explosive decomposition of condensed EM. The main of them are short duration of initiating pulse (~ 10 ns), high power density of pulse and possibility of its varying in a wide range of 10^5 – 10^9 W/cm² by focusing of energy flux on target surface. These characteristics accompanied by pulsed measurements of optical, mechanical and electric parameters of explosion with high time and dimensional resolution allow obtaining of new information related to initial stages and developing of energetic materials explosive decomposition process.

At present, a high time (~ 1 ns) [1, 2] and dimensional (~ 5 μ m) [5] resolutions are achieved. As for the spectral resolution, it is quite low and doesn't exceed ~ 5 – 20 nm in the majority of publications [1,2]. The cause is the low sensitivity of optical channel of photo-chronograph being used for registration of time-resolved spectra of explosive decomposition of energetic materials at the one pulse. Insufficient spectral resolution of the equipment doesn't allow to identify unambiguously products of explosive decomposition of EM. Therefore, the reliable information about formation dynamics and expansion velocity of atoms and molecules being produced at explosive decomposition of energetic materials cannot be obtained.

The presented work is aimed at measuring of emission spectra observed during explosive decomposition of heavy metal azides (HMA) in the spectral range of 200–980 nm with high spectral resolution sufficient for identification of explosion products.



2. Experiment

Experimental setup that was used for registration of spectra of explosive decomposition is depicted on figure 1. A pulsed nanosecond electron accelerator based on a pulsed high voltage generator GIN-600 connected to a vacuum diode was taken as a source of initiation. Average electron energy in a beam was ~ 250 keV, maximal current was 3 kA and pulse duration at FWHM amounted ~ 12 ns. The energy density of high-current electron beam (HCEB) was varied in the range of $0.1\text{--}1$ J/cm² by changing cathode-anode distance and using diaphragms.

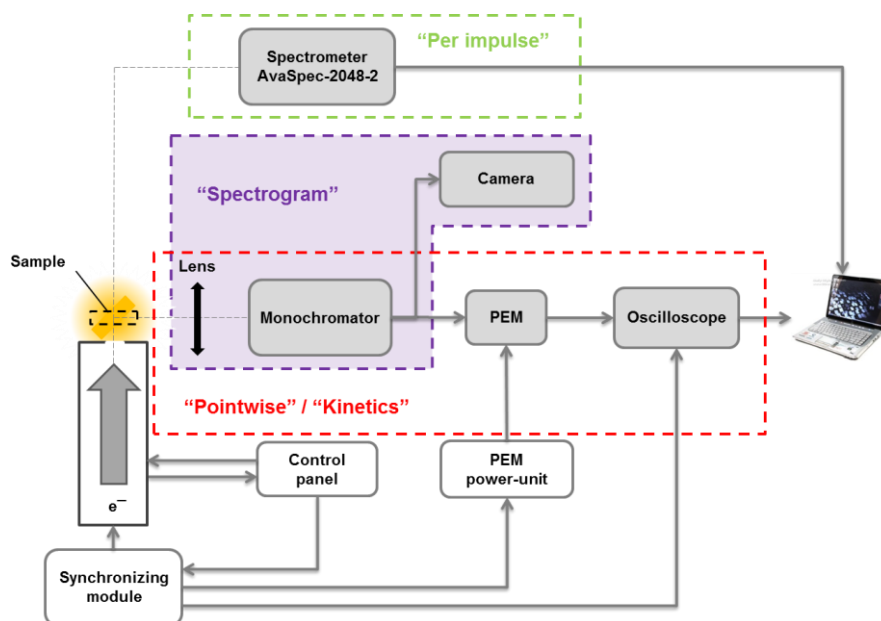


Figure 1. Scheme of experimental setup.

Two methods were used for registration of explosion spectrum. In the first one the image of explosion plasma from near-obstacle area was projected with a lens onto entrance slit of monochromator MDR-23 and photographed with digital camera SONY $\alpha 500$ mounted on monochromator instead of exit slit. Spectral resolution of the method amounted ~ 0.2 nm. Spectral range of measurements was 400–700 nm.

Time-integrated fragments of explosion spectrum ($\Delta\lambda \sim 25$ nm) were registered in spectral response range of camera SONY $\alpha 500$ per one excitation pulse. Atomic spectral lines registered in explosion plasma were identified using well-known atomic spectra of spectral lamps LSP-1. Those reference spectra were photographed along with explosion spectrum onto the same spectrogram.

In the second method integrated spectra of explosion were registered by means of fiber-optical spectrometer AvaSpec DUAL. Spectral range of measurements was 220–1100 nm, spectral resolution amounted ~ 1.5 nm.

Silver and thallium azides were chosen as subjects of research. Samples were pressed in the form of 250–300 μm thick tablets with diameter of 3 mm. Silver azide whiskers (threadlike monocrystals) with characteristic dimensions of $0.1\text{ mm} \times 0.05\text{ mm} \times 5\text{ mm}$ were also taken. Samples were placed and initiated in a vacuum chamber. Schema of samples' placement in experimental chamber are shown on figure 2.

Sample under study 1 was fixed on sample holder 2 and excited by electron beam through anode aperture 3 and 10 μm thick aluminum foil 4. Sample holders were prepared from different metals (aluminum, duraluminum, copper) and from M18 alloy. An obstacle 5 (20 mm \times 10 mm \times 2 mm aluminum plate) was placed at distance L from samples's surface. It was stopping the plasma jet formed during sample explosion. The purpose of using an obstacle was increasing of intensity of explosion products glowing and dimensional localization of plasma.

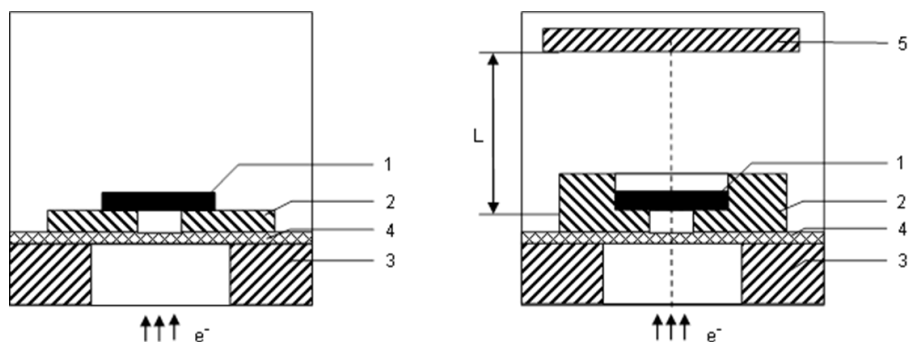


Figure 2. Schema of explosive initiation by electron beam that were used for measuring spectra of explosion decomposition products: 1 – sample, 2 – sample holder, 3 – anode, 4 – 10 μm thick aluminum foil, 5 – obstacle.

3. Results and discussion

Figures 3 and 4 depict spectrogram fragments of explosion plasma of AgN_3 and TlN_3 pressed samples obtained by means of digital camera SONY $\alpha 500$ in different spectral ranges.

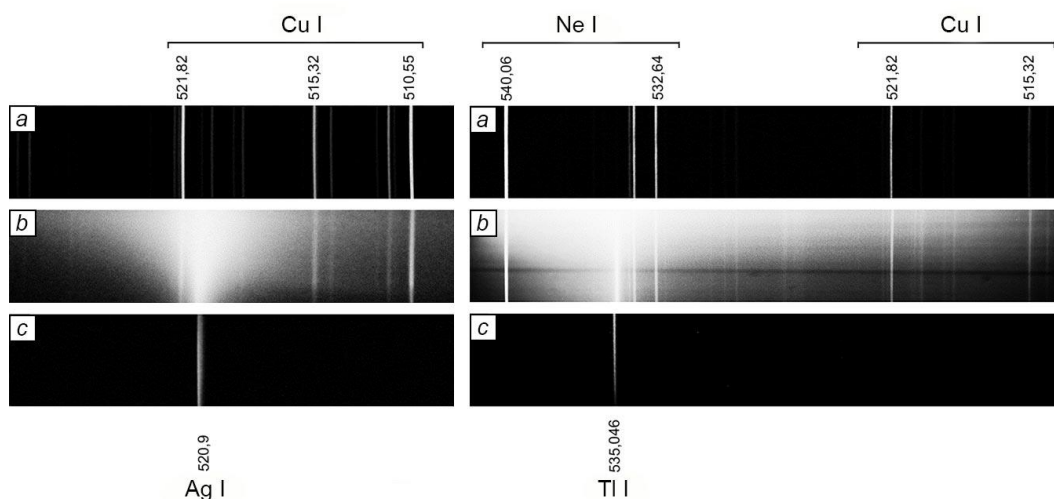


Figure 3. Explosion spectrograms of pressed AgN_3 (on the left) and TlN_3 (on the right) measured by means of optical spectrometer MDR-23 and digital camera in "green" spectral range: a – fragments of lamp LSP-1 (Cu) spectra, b – fragments of explosives samples explosion spectra, measured near obstacle on the background of LSP-1 (Cu) spectra, c – fragments of explosive samples explosion spectra at free expansion of explosive decomposition products.

It can be seen that two types of glowing can be observed in spectrum of explosion. These are line spectra of atoms being a part of explosive material and a continuous spectrum representing glowing of dense low-temperature plasma. Plasma pressure and temperature grow at the deceleration of explosion products on a solid obstacle and this leads to broadening of spectral lines of atoms being a part of explosive (figures 3 b, 4 b) It has been established that intensity ratio of continuous and line emission in spectra of explosion plasma depends on a mass of a sample and expansion conditions of explosive decomposition products (free expansion into vacuum or deceleration on solid obstacle). In case of low mass of the sample ($m \approx 5$ mg), the temperature and pressure in plasma decrease rapidly while the explosion products expand freely. This leads to violent intensity decrease of continuous spectrum. As a rule line spectra of explosion is observed in such conditions. With increasing of explosive mass ($m \approx 20$ mg) the continuous spectrum intensity and the volume occupied with dense plasma increase. The above is confirmed by spectrograms depicted in figures. For example, the spectra of TlN_3 and AgN_3 ($m \approx 5$ mg) explosion are line (figures 3 c and 4 c). At the explosion of HMA samples with mass more than 20 mg line emission of atoms is observed on the background of continuous spectrum (figures 3 b, 4 b).

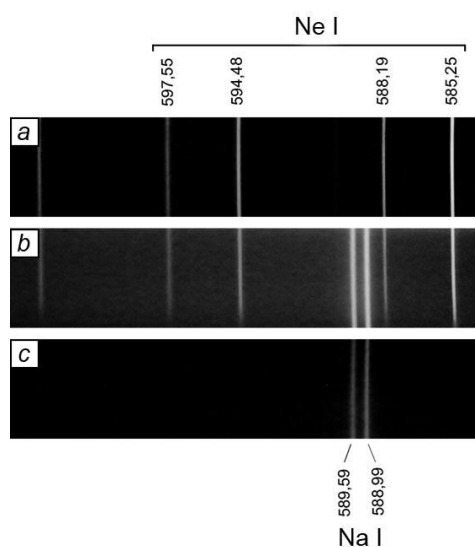


Figure 4. Spectrograms of pressed TiN_3 explosion measured by means of optical spectrometer MDR-23 and digital camera in "yellow-red" spectral range: a – fragment of lamp LSP-1 (Cu) spectra, b – fragment of explosives samples explosion spectra, measured in near obstacle on the background of LSP-1 spectra, c – fragment of explosive sample explosion spectra at free expansion of explosive decomposition products.

It can be seen that two types of glowing can be observed in spectrum of explosion. These are line spectra of atoms being a part of explosive material and a continuous spectrum representing glowing of dense low-temperature plasma. Plasma pressure and temperature grow at the deceleration of explosion products on a solid obstacle and this leads to broadening of spectral lines of atoms being a part of explosive (figures 3 b, 4 b). It has been established that intensity ratio of continuous and line emission in spectra of explosion plasma depends on a mass of a sample and expansion conditions of explosive decomposition products (free expansion into vacuum or deceleration on solid obstacle). In case of low mass of the sample ($m \approx 5$ mg), the temperature and pressure in plasma decrease rapidly while the explosion products expand freely. This leads to violent intensity decrease of continuous spectrum. As a rule line spectra of explosion is observed in such conditions. With increasing of explosive mass ($m \approx 20$ mg) the continuous spectrum intensity and the volume occupied with dense plasma increase. The above is confirmed by spectrograms depicted in figures. For example, the spectra of TiN_3 and AgN_3 ($m \approx 5$ mg) explosion are line (figures 3 c and 4 c). At the explosion of HMA samples with mass more than 20 mg line emission of atoms is observed on the background of continuous spectrum (figures 3 b, 4 b).

The boost of continuous spectrum intensity can be observed in case of plasma jet deceleration on solid obstacle. The cause of this intensity growth is additional plasma heating by shock wave, formed in near-obstacle region. In this case the continuous spectrum is observed only near the obstacle. On a distance from obstacle intensity of continuous spectrum decreases. And starting from some point the line spectrum of explosive decomposition products can be registered. FWHM of spectral lines decreases the farther explosion products are from the obstacle. Regularities noticed above are typical for explosion plasma as well as for spectra of plasmadynamic jets forming during the pulsed evaporation of metals by HCEB [6].

It has been established that the strongest lines appearing in the emission spectra of AgN_3 and TiN_3 samples are the lines of silver Ag I (520.91, 546.55, 547.16 nm) and thallium Tl I (535.05 nm) respectively. These lines are responsible for green color of plasma observed at explosion of these explosives in vacuum.

Two densely spaced ($\Delta\lambda = 0.6$ nm) intensive emission lines of sodium atoms have been found in the "orange" spectral range in explosion spectra of monocrystals and pressed powder compacts of AgN_3 and TiN_3 . These are Na I 588.99 and 589.59 nm (figure 4).

Emission spectra of explosive decomposition products of pressed samples of AgN_3 and TiN_3 measured by means of optical spectrometer AvaSpec DUAL are presented on figure 5.

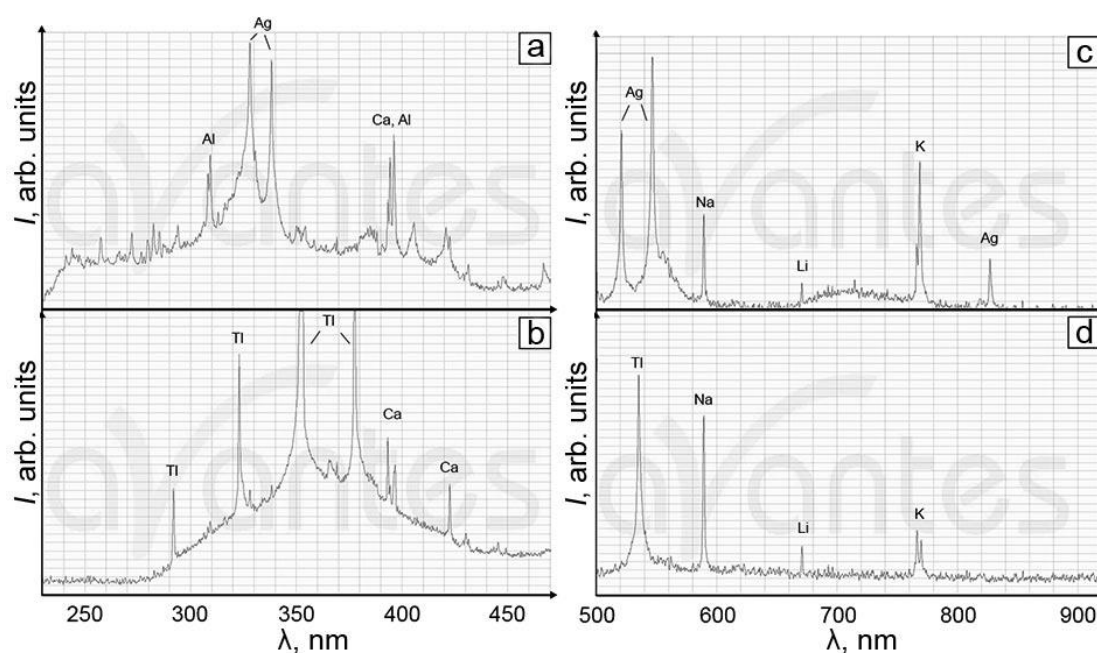


Figure 5. Explosion spectra of pressed samples of AgN_3 (a, c) and TlN_3 (b, d) measured in UV and visible spectral ranges by means of optical spectrometer AvaSpec DUAL.

The most intensive lines in spectra of explosive glowing of silver azide (figure 5 a, c) and thallium azide (figure 5 b, d) are the atom lines of metals being a part of HMA: Ag I (328.07, 338.29, 520.91, 546.55 and 547.16 nm) and Tl I (291.83, 322.98, 351.92, 352.94 and 535.05 nm). Intensive emission lines of alkali metal atoms have been found in "orange" and "red" spectral ranges of explosion spectra of AgN_3 and TlN_3 pressed samples and AgN_3 whiskers: Na I (588.99; 589.59 nm), K I (766.49, 769.89 nm) and Li I (670.78 nm).

Analysis of obtained experimental results demonstrates that alkali metals are pollution agents that enter explosives during the process of their producing. Appropriate spectral lines are always presented in explosion glowing spectra of HMA irrespective of the sample holder type. The presence of these elements in samples under study has been confirmed by measuring of impurity concentration by means of inductively coupled plasma method.

The role of sample holder played in forming of explosion spectrum has been established. In case of exploding of HMA samples placed on duralumin holder aluminum Al I (308.22, 309.27, 394.41, 396.15 nm) and calcium Ca I (393.37, 396.85, 422.67 nm) lines appear in explosive glowing spectra (figure 5). Atomic lines Al I 396.15 and Ca I 396.85 nm (as well as sodium lines Na I 588.99 and 589.59 nm) has been registered as one line due to insufficient spectral resolution of spectrometer AvaSpec DUAL. It is known that calcium is the main pollution agent of metals surface [7]. Therefore calcium lines do appear along with intensive aluminum lines in spectra of such surfaces. Atomic lines registered in explosion plasma of AgN_3 and TlN_3 samples are presented in table 1.

Table 1. The list of identified spectral lines registered in HMA explosion plasma.

Material	Identified line
AgN_3	Ag I (328.07, 338.29, 520.91, 546.55 + 547.16, 827.35)
	Na I (588.99 + 589.59)
	Li I (670.78)
	K I (766.49, 769.89)
	Al I (308.22, 309.27, 394.41, 396.15)
	Ca I (393.37, 396.85)

TiN ₃	Tl I	(291.83, 322.98, 351.92 + 352.94, 377.57, 535.05)
	Na I	(588.99 + 589.59)
	Li I	(670.78)
	K I	(766.49, 769.89)
	Ca I	(393.37, 396.85)

4. Conclusion

Emission spectra of products of HMA explosive decomposition are measured with high spectral resolution sufficient for their identification. It is found that there are several types of glowing can be found in explosion spectra of samples under examination: these are line spectrum of atoms being a part of explosive material and continuous spectrum representing glowing of dense low-temperature plasma. Line and continuous spectra intensity ratio depends on a mass of explosive and conditions of plasma jet expansion.

The most intensive lines in spectra of explosive glowing of AgN₃ and TiN₃ relate to atom lines of silver and thallium. And these lines are responsible for green color of explosion plasma. Intensive emission lines are observed in "orange" and "red" region of explosion spectra of HMA. These lines relate to alkali metals Na, Li and K which enter explosives during their preparation.

Information obtained in this work is of great interest to modeling process of explosive decomposition of initiation and brisant explosives under external energetic pulse action and to developing explosive-based light sources for atom and molecular spectroscopy of energetic and inert materials. The results show possibility of developing rapid and economical atomic emission method for determination of elemental composition of explosives as well as solid bodies of different types.

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