Explosive radiation sources for analytical spectroscopy

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Abstract. The possibility of using the explosion energy of condensed explosives in solids analytical spectroscopy was investigated. For the atomization and excitation emission spectra of solids (BaCl₂ and SrCl₂) pressed powders of furazanotetrazinedioxide (FTDO, C₂N₄O₂) were used. Initiation of the explosion was induced by the influence of high-current electron beam. The impurity atoms that are the part of FTDO, as well as atoms and molecules formed by the evaporation of BaCl₂ and SrCl₂ were identified in the spectra of explosion plasma.

1. Introduction
At present, the atomic spectrum analysis is used in various fields of natural science and the production; it allows you to quickly and accurately identify the substance composition. The transfer of the solid substance into the gaseous state can be achieved by exposure to directed concentrated high-power energy flux (DCHPEF) which includes laser radiation and high-current electron beams [1-3]. At such influence, instantaneous vaporization of any substance and simultaneous delivery of all elements, included in the sample, into analytical plasma torch, regardless of their volatility is achieved. In this aspect, explosive radiation sources (ERS) based on the detonation of condensed explosives (explosives) are of interest. High specific energy content of explosives (~5 kJ/g) and a small discharge time allows obtaining high levels of specific heat power and ensure the heating of any material up to tens of thousands degrees. In this case, all substances transfer into the plasma state and emit powerful optical radiation. The possibility of obtaining long-lived plasma formations with full output optical radiation at the level of a few percent of chemical explosives stored energy was showed in [4-5].

With regard to the possibility of ERS application in substance analytical spectroscopy, such studies, to our knowledge, have not been carried out. The purpose of this work is to explore the possibility of using the explosive radiation sources based on the detonation of condensed explosive in atomic and molecular spectroscopy.

2. Experiment
For study objects salts of BaCl₂ and SrCl₂ were selected, which were placed on the explosives surface. 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 amounted to ~ 12 ns. The scheme of the experimental setup is shown in figure 1 and figure 2.
Sample 1 was placed on the surface of explosive 2, which was placed on aluminum foil 3 with thickness of 10 μm, and then an initiation by an electron beam through the hole in the anode 4 was made. Two methods were used for recording the explosion spectrum. In the first one, the image of explosion plasma was projected with a lens onto the entrance slit of monochromator MDR-23 and photographed with digital camera SONY α500 mounted on monochromator instead of the exit slit. Spectral resolution of the method amounted to ~0.2 nm. The spectral range of measurements was 400–700 nm.

Figure 1. The scheme of explosive initiation by electron beam that were used for measuring spectra of explosion decomposition products: 1–sample, 2–explosives, 3–aluminum foil 10 μm thick, 4 – anod.

Time-integrated fragments of explosion spectrum (Δλ~25 nm) were recorded in spectral response range of camera SONY α500 per one excitation pulse. Atomic spectral lines recorded 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, the integrated spectra of explosion were recorded by means of fiber-optical spectrometer AvaSpec 2048-2. The spectral range of measurements was 220–1100 nm, spectral resolution amounted to ~1.5 nm.

3. Results and discussion
Preliminary, the explosion plasma spectra of "clean" FTDO samples were studied. Figure 3 shows the explosion atomic emission spectra. It can be seen against the background of low-intensity continuous spectrum four lines are distinguished belonging to: sodium (588.9 nm and 589.5 nm), lithium (670.7 nm), and potassium (769.8 nm and 766.4 nm). Sodium doublet line is recorded as one line due to lack of the spectrometer's resolution ability. According to studies [10], alkali metal lines (Na, Li, K) found in the FTDO explosion plasma indicate occurrence of impurities in the samples during manufacture.

![Figure 3](image1.png)

**Figure 3.** Explosion emission spectrum of pure FTDO disposed on an aluminum substrate at initiating by electron beam.

![Figure 4](image2.png)

**Figure 4.** FTDO explosion luminescence spectra with the BaCl₂ addition.

FTDO explosion glow spectrum with the addition of barium chloride is shown in figure 4. The figure shows that the explosive emission spectrum contains additional molecular and atomic lines: Ba (553.55 nm), BaCl (513.8 nm and 524.5 nm), CaCl (620.9 nm). Detailed identification of the obtained spectrum is shown in table 1. The spectra of the explosive emission of barium chloride with a high spectral resolution (0.15 nm) were recorded using a digital camera through a monochromator MDR-23 (figure 5). To identify the molecular spectra literature data were used [11-13].
Figure 6 shows the spectrum of FTDO explosive emission with the addition of strontium chloride. Identification of the obtained spectrum is shown in Table 2. It can be seen that the impurity atoms of the FTDO are present in the explosion spectrum, as spectrum of SrCl molecules formed during explosive evaporation.

The data obtained in the experiments demonstrate the possibility of using explosives as a source of spectra excitation in atomic emission spectrometry and molecular spectral analysis. The main advantage of the explosives use in the spectral analysis is the ability to identify elemental composition of explosives, and other condensed materials. Alkali metal impurities recording in the FTDO emission spectrum shows the high sensitivity of the developed method.
Table 1. Explanation of the main FTDO explosion emission spectral lines adding BaCl$_2$ and SrCl$_2$.

| № | Identified line | Identified line |
|---|-----------------|-----------------|
| 1 | BaCl 513,8 [11] | Na 589,593[11]  |
| 2 | BaCl 524,05 [11]| CaCl 593,4[11] |
| 3 | BaCl 532,08 [13]| -               |
| 4 | Ba553,55 [11]  | SrO606,84 [12] |
| 5 | Na 589,593[11] | SrCl 623,9[13] |
| 6 | CaCl620,1[11]  | SrCl 635,8[13] |
| 7 | K 766,491[11]  | SrOH 646[13]   |
| 8 | K 769,989[11]  | SrOH 659[13]   |
| 9 | -               | -               |
| 10| SrOH 682[13]   |                 |
| 11| SrI 684,77[11]|                 |
| 12| K 766,491[11]  |                 |
| 13| K 769,989 [11] |                 |

4. Conclusion
The data obtained in the experiments demonstrate the possibility of using explosives as a source of spectra excitation in atomic emission spectrometry and molecular spectral analysis. The main advantage of the explosives use in the spectral analysis is the ability to identify elemental composition of explosives, and other condensed materials. Alkali metal impurities recording in the FTDO emission spectrum shows the high sensitivity of the developed method.

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