Direct laser initiation of open secondary explosives

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Abstract. The goal of this paper is experimental study of the mechanism of initiation of secondary explosives (SE) by short laser pulse. Laser initiation of SE is much more difficult in comparison with initiation of primary explosives. Using of some special methods is typically requested to realize laser initiation of SE: using of porous SE, putting it in a closed envelope, and using some optically dense additives. In this paper we consider interaction of laser pulse with open surface of non-porous, optically uniform SE. Only pure chemical methods were used to control the light sensitivity of SE. Implementation of the method of laser initiation is reduced to the optimization of composition and molecular structure of the explosives, along with the optimization of the laser pulse (its duration, energy density and wavelength).

1. Introduction

The use of a laser pulse instead of electric pulse heating for initiation of explosives is considered as a promising alternative, which is insensitive to external electromagnetic influences. In addition, short laser pulses can significantly reduce and optimize the ignition-period of the explosion. Therefore, the laser radiation impact on energetic materials is in recent years the subject of comprehensive studies in many scientific centers (see, for example, reviews in publications [1–3]).

The use of a laser beam for excitation of solid explosives has several advantages over conventional electro-bit and percussion ways of initiation. These include: reduced sensitivity of the initiator assembly to the external electrical discharges; formation of the detonation front having required geometry and some others. The greatest interest and difficulties are associated with laser initiation of secondary explosives (SE) [4]. Typical solution of this problem uses the intermediate initiating explosives, as well as porous secondary explosives, which keeps undesirable sensitivity of the initiator-assembly to mechanical impacts at the level of priming explosives.

In contrast to priming explosives, the most sensitive to the laser pulse, several new energetic compounds were recently proposed, which are the transition metal complexes with energetic ligands (replaced by tetrazole). They combine low threshold under the action of thermal radiation, with moderate sensitivity to mechanical and thermal stress [5]. Initiation of explosion in these compounds under a short laser pulse (duration 20–30 ns ∼ 10⁻⁸ s) is delayed from 5 to 75 µs ∼ 10⁻⁵ s, indicating an essential role of photochemical processes in the mechanism of laser initiation [2].

The accumulated experimental data indicate that the magnitude of the threshold energy required for excitation of the explosion, depends to a greater extent on the chemical structure of the molecule and to a lesser extent on the heat release of the explosion, oxygen balance
and detonation rate, that are parameters traditionally used to characterize SE. Therefore, such energetic substances have been termed—photosensitive explosives.

According to the current views, the photosensitive explosives must have a relatively low level of self-absorption in the wavelength range of the laser radiation [5]. However, a number of energetic complexes having similar structures contain significant number of representatives, which have intense color due to selective light absorption in the visible spectrum [4, 6, 7]. According to [5], it makes them less attractive for the laser initiation problem. This question has not been studied in the literature that was the reason for submitted investigation.

2. Experiments

The study has been conducted for series of complex compounds: perchlorates of copper Cu(II), nickel Ni(II), and cobalt Co(III). As ligands were selected: ammonia (NH₃), hydrazine (H₂N-NH₂), substituted hydrazines: acethydrazide (H₃C-C(O)-NH-NH₂), semicarbozide (H₂N-C(O)-NH-NH₂), ethylenediamine (H₂N-CH₂-CH₂-NH₂), monoethanolamine (H₂N-CH₂-CH₂-OH), 4-amino-1,2,4-triazole (N₂C₂H₂)N-NH₂. The substances were synthesized by the method described in [6, 7]. Experimental samples were produced by the method of the deaf pressing of powders of individual energetic complexes. The relative density of the samples was 90–95% of the density of the single crystal. Used tablet had circular cross-section with diameter of 7 mm, and height \( h = 5–7 \) mm (see figure 1).

The light initiation of the explosives were carried out in experiments using solid-state pulsed lasers with a wavelength of 694 nm (the ruby laser) and 1063 nm (the neodymium laser). The pulses duration of the ruby laser was from 2 to 3 ms, and the pulses duration of neodymium laser was 20 ns. The laser beam has been directed normally to the sample surface. The diameters of the laser beams were: 3–4 mm in the case of ruby laser, and 1mm in the case of neodymium laser. The pumping of ruby laser was carried out up to a value of 2.35 kV. In addition to experiments with samples irradiation by the parallel laser beams, some experiments were conducted (in a similar settings), with the beams focused on the sample surface, and experiments with the samples irradiated by divergent beams. The results of the experiments are presented in table 1.

![Figure 1. Samples of tested synthesized explosives.](image)
Table 1. Light sensitivity of tested explosives.

| No. | Energetic material | Ruby laser beam | Neodymium laser beam |
|-----|--------------------|----------------|---------------------|
| 1   | Bis-(Ethylenediamine)Cu(II) perchlorate (hydrate, or semihydrate) | In focus | Rejection | Parallel beam | Combustion |
| 1a  | Composition of 50 % Bis-(Ethylenediamine)Cu(II) + 50 % ammonium perchlorate | In focus | Rejection | Parallel beam | Combustion |
| 2   | Tris-(Ethylenediamine)Nickel(II) perchlorate (semihydrate) | In focus | Rejection | Parallel beam | Rejection |
| 3   | Bis-(acethyldrazide)-Cu(II) perchlorate | In focus | Explosion | Parallel beam | Explosion |
| 4   | Tris-(symicarbazide)Nickel(II) perchlorate | In focus Parallel beam | Explosion | Parallel beam | Explosion |
| 7   | Hexaammine-Cobalt(III) perchlorate | In focus | Rejection | Parallel beam | Rejection |
| 8   | Perchlorate of hydrazine Nickel(II) | In focus | Explosion | Parallel beam | Explosion |

3. Discussion of experimental results and conclusion

Analysis of experimental data shows that compounds containing in their structure one-deputizing hydrazines (primary), steadily detonate from the laser beam under tested conditions. Compounds containing 4-amino-1,2,4-triazole (CN12H2-N-NH2 such ability does not possess.

A comparison of the light sensitivity with the sensitivity to impact and with the critical diameters of the energetic complexes [4] led the authors to conclusion that the most sensitive among the investigated series are complex compounds containing in their structure of substituted hydrazines. As the explanations were given information about the structural formula of the compound containing the weak link of metal-complex agents with a fragment of hydrazine. This is consistent with the data [4], according to which tetrazen, the molecule of which contains a secondary hydrazide fragment (CN4H-N=NH-C(=N H)-NH2H2O) (but does not contain metal) does not possess the sensitivity to a laser beam of 1.5 J/cm2). Similar patterns were revealed in our experiments on laser initiation.

Thus, the sensitivity only occurs in the energetic complex compounds of transition metals containing as a ligand the hydrazine fragments.
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