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Sensitization of PETN to laser radiation by opaque film coating

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ABSTRACT

Laser ignitability of a two-component system constituted of a copper (II) oxide layer and a PETN (pentaerythritol tetranitrate) tablet was studied. An ytterbium fiber laser with 1070 nm wavelength, 20 ms pulse duration and 3.6 kW/cm^2 power density was used. The threshold of launching of exothermic reaction as a function of the light absorbing coating layer thickness was studied. It has been found that the exothermic reaction zone formation does not always lead to the initiation of the entire sample. An analytical model describing the initiation of the exothermic decomposition reaction in the surface layer of the sample was developed. The effectiveness of the initiation of the explosion decreases with the increase in the thickness of the absorbing layer.

1. Introduction

Laser initiation of energetic materials opens up very interesting prospects for the development of blasting technology, especially in terms of safety This causes a rising tide of works devoted to the study of this branch of explosion physics and technology. [1–6]

The key problem of laser initiation of energetic materials is their transparency to laser radiation. Commonly this problem is solved by the introduction of intensively absorbing particles into the material. The effectiveness of this approach is shown [7–10]. However, several studies [11,12] note the ineffectiveness of this approach for the energetic material sensitization to laser radiation. The influence of a particle size on the effectiveness of energetic materials laser initiation is discussed in [13]. This effect can explain the difference in the effectiveness of light absorbing additives. Alternative schemes of a light absorbing fragment configuration were also discussed. It is shown that the opaque thin film on the energetic material surface heated by laser radiation can serve as a more effective instrument of the initiation of the explosive reaction in the adjacent layer of the energetic material than the absorbing laser light particle introduced in the energetic material bulk [13].

The study is aimed on the experimental implementation of the system described above, as well as simulation of the ignition process of the energetic material under the experimental conditions.

Initiation of energetic materials due to laser light action on an opaque film (foil) adjacent to the energetic material was implemented in [12,14,15]. However, the stimuli leading to an explosion of the sample are commonly considered as ignition by plasma or shock wave generated by the blasted metal film. A similar problem of modeling laser initiation of an explosive in a steel shell (units of mm thickness) with high power laser pulses was solved in [4,16]. This approach requires the use of a high power laser light flux. This fact can impede the application of this approach using optical fiber to transmit laser radiation due to the excess of its optical damage threshold. In this study, the heating of the energetic material layer adjacent to the thin “hot plate” is considered to be the stimulus of an explosive decomposition reaction of energetic material. It is possible to use a compact ytterbium fiber laser as a source of laser radiation.

The authors hope that the demonstrated results will allow us to formulate new effective approaches to the implementation of energetic materials laser initiation, and will be useful to describe the processes occurring under the laser irradiation on the energetic material charge in a thin opaque shell. It is also worth noting the fact that the proposed scheme can be considered as the only thermochemical process [13]. The hypothesis of the possibility of a photochemical initiation mechanism due to the laser radiation interaction directly with the energetic material is formulated in [17]. Some contribution of this mechanism to the development

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of the reaction of explosive decomposition in energetic materials containing light absorbing additives can be assumed. Thus, we can suppose a superposition of several mechanisms of laser initiation of polycrystalline samples containing absorbing inclusions. It can be an obstacle to the development of analytical models for the correct description of thermal initiation of energetic materials by laser radiation. In this study, the energetic material is shielded from the laser radiation by the opaque thin film.

2. Experimental details

PETN was used as a test energetic material, and copper oxide powder was used as a light absorbing coating material. Copper oxide was selected because of its good thermal conductivity, high absorption coefficient and relatively high decomposition temperature. Copper oxide powder consisted mainly of monoclinic phase. The phase composition was determined by the diffractometer DR-02 RADIAN, with a wavelength $\lambda = 1.541874$ Å.

Tablets with 3 mm diameter and 1 mm thick pressed into a stainless steel shell and consisting of a thin layer of copper oxide and layer of PETN were used as a test sample. PETN was made by nitrating of pentaerythritol with concentrated nitric acid at a temperature not higher than 293 K, and further purified by recrystallization from acetone. To prepare PETN micropowder (Fig. 1), 5 g of PETN were dissolved in 100 ml of high purity acetone then a solution was slowly added with vigorous stirring to the mixture of 1500 ml of distilled water and 100 ml of acetone. Precipitated PETN powder was filtered and dried in the air at room temperature. Copper oxide powder had a grain size of about 1 micron (Fig. 1).

The sample preparation was divided into two stages. At the first step, copper oxide weighed portion was pressed at 1 GPa. Thereafter the PETN was refilled and the tablet further was pressed at 200 MPa. The copper oxide layer was an opaque black film covering the entire top surface of the tablet. Press tool is shown on Fig. 2a.

A copper oxide pressed tablet weighing 200 mg and 25 mm in diameter was prepared. The extinction index of the tablet at the wavelength of 1070 nm was measured by a Shimadzu UV-3600 spectrophotometer. Its value is about 1750 cm^{-1}. The reflection coefficient of the similar 400 mg copper oxide tablet ($R_2 = 0.52$) was determined using Shimadzu UV-3600 spectrophotometer with a UV-VIS-NIR integrating sphere attachment ISR-3100.

A fiber laser YLS-150/1500-QCW (λ = 1070 nm) with IPG P30-001460 collimator with an average pulse power of up to 1.5 kW was used as the source of the initiating radiation. Each series were subjected to a laser initiation by rectangular pulse of 20 ms duration with 36 kW/cm^2 power density. The experimental setup scheme is shown in Fig. 2b. The incident laser pulse power on the surface of the sample was determined using the pyroelectric head PE50BF-DIF-C (Ophir Photonics). The laser beam profile was estimated using a set of diaphragms. An average power density within the sample diameter (3 mm) was accounted for the calculation and interpretation of results (Fig. 2c). The scatter of the initiating pulse power does not exceed 1%.

The exposition necessary for the initiation of the sample was calculated as the product of power density by the period from the beginning of the pulse to the appearance of an acoustic signal on oscillogram. The use of an acoustic sensor allowed us to reliably detect the fact of an explosion and also the period of time from the start of the initiating pulse to the appearance of the explosion acoustic signal.

3. Modeling details

The experimental results were compared with the theoretical calculations of the ignition process. In the numerical simulation of

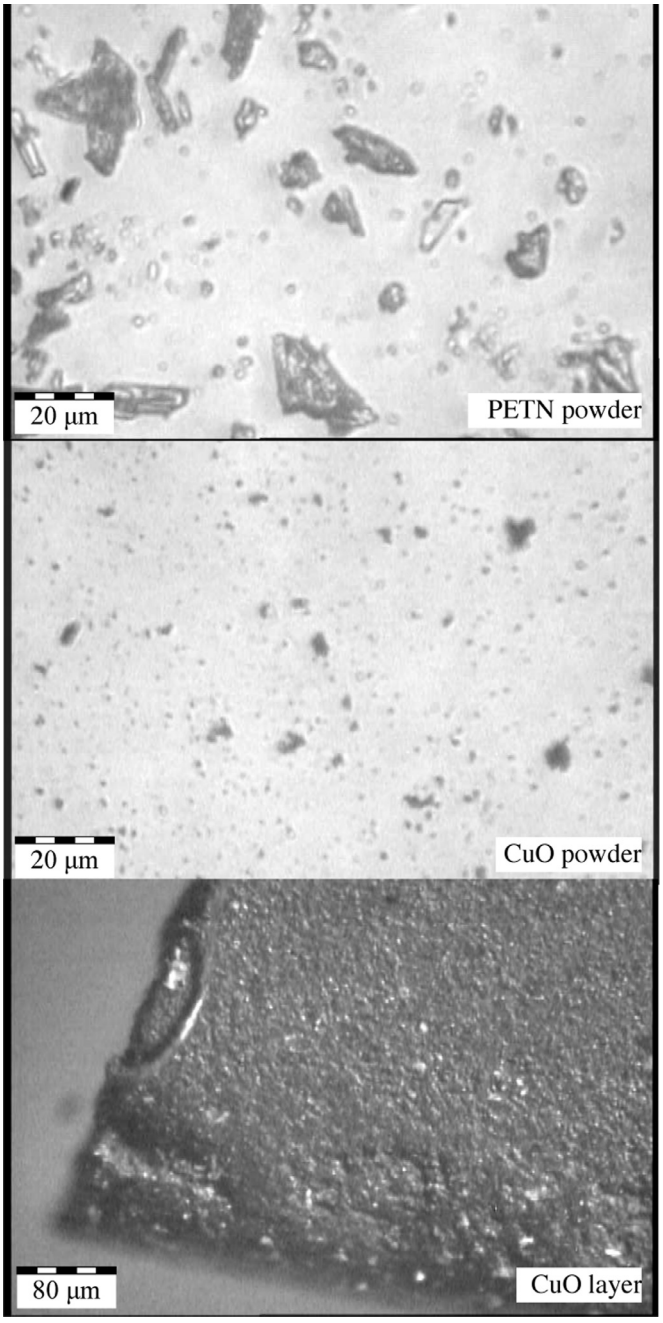

Fig. 1. Micrographs of CuO powder, PETN powder and pressed CuO tablet for the reflectance measurement. Optical microscope "Biolam-70" (LOMO, USSR) equipped with the digital camera MHD-63MN1PH-DICR (Mintron corp.) was used.

PETN ignition by the laser pulse in a three-layer heterosystem glass – light absorbing material – energetic material a system of three equations of thermal conductivity were solved:

$$\rho_1 \frac{\partial T_1}{\partial t} = \lambda_1 \frac{\partial^2 T_1}{\partial z^2}, \tag{1}$$

$$\rho_2 c_2 \frac{\partial T_2}{\partial t} = \lambda_2 \frac{\partial^2 T_2}{\partial z^2} + \alpha(1 - R_{12}) I_0(t) \exp(-\alpha z) \times \frac{[1 + R_{23} \exp(2\alpha(z - h_1))]}{[1 - R_{12} R_{23} \exp(-2\alpha h_1)]}, \tag{2}$$

$$\rho_3 [c_3 + H_f \delta(T_3 - T_f)] \frac{\partial T_3}{\partial t} = \lambda_3 \frac{\partial^2 T_3}{\partial z^2} + \rho_3 Q Z \exp\left(-\frac{E}{RT_3}\right) \tag{3}$$