# Optical Temperature Diagnostics of After-Burning Phenomena in Expanded HE Detonation Products

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**Abstract**

The paper describes the results of experiments on emission/temperature measurements in the course of detonation of TNT and RDX based high explosives. Particular attention was given to the later stage of expansion of the cloud of detonation products. It was shown that the turbulent mixing between detonation products and surrounding air results in secondary burning (after-burning) process that is controlled by the carbon (soot) content.

## Introduction

Over many years, the application of optical pyrometers to study of HE detonations was limited to the temperature measurements at the stage of propagation of detonation wave inside the charge [1]. However, in recent years great interest has been expressed by some investigators in the late stages of the explosion. The reason is that detonation products of even conventional solid-state explosive composition such as TNT contains substances that can react with surrounding air thus supporting the after-burning processes. The experiments [2-3] showed that the additional energy release from burnout of detonation products results in increase of quasi-static pressure in the enclosures. Thus, it is not surprising that until now the after-burning phenomena were inspected by the implementation of pressure measurement techniques in the course of closed volume HE explosions. The opened-space conditions are a different matter. In this case the pressure elevation at the late stage of explosion seems to be negligible and the after-burning process is appeared as constant pressure combustion. This has an important bearing on the parameters to be measured, the temperature being the most informative among them. The temperature evaluations require simultaneous measurements of emission at least at two portions of spectrum. It should be emphasized that in difference to the conventional studies of HE detonations the investigation of after-burning phenomena calls for long-duration measurements of emission, namely from time scale of several hundreds of microseconds up to several hundreds of milliseconds. In the present work the peculiarities of various stages of expansion of HE detonation products were studied by the use of double-wavelength photodiode detectors.

## Experimental Details

The explosives under study were TNT, RDX, mixture 50% TNT + 50% RDX (TG 50/50) and mixture 95%RDX + 5% paraffin (RDX(p.)). Table 1 presents some properties of these high explosives: $\rho$ – initial density, $D$ and $p$ – detonation velocity and pressure, $T_p$ – temperature of detonation products and $C$ – content of carbon (soot) in detonation products (calculated by [4]). All the charges of mass 100 g were cylindrically shaped with diameter 40 mm. Initiation of detonation was performed by means of blasting cap and intermediate 8 g

Table 1 Properties of high explosives

| HE | $\rho$, g/sm$^3$ | $D$, km/s | $p$, Gpa | $T_p$, $K$ | $C$, mol/kg |
|---|---|---|---|---|---|
| TNT | 1.60 | 6.94 | 20.3 | 3140 | 16.51 |
| RDX | 1.71 | 8.39 | 31.4 | 3740 | 2.81 |
| TG 50/50 | 1.67 | 7.60 | 25.4 | 3460 | 9.30 |
| RDX(p.) | 1.67 | 8.34 | 26.7 | 3300 | 6.97 |

RDX charge.

Figure 1 presents relative displacement of the charge and photodetectors (PD) in the explosion chamber. The distance between horizontally hanging charge and the floor was 0.94 m. One of the photodetectors was positioned along the axis of the charge, while another PD was focused on the sidewall of the charge. The characteristics of the photodetectors were described in [5,6]. The main element of the photodetector is Si-Ge photodiode of sandwich structure containing the thin semi-transparent silicon layer that covers germanium substrate. The essential feature of Si-Ge photodiode is a very small intersection between the Si and Ge spectral responses. The advantage of the PD is the possibility of measuring radiation simultaneously in two portions of spectrum, namely $0{,}4 \le \lambda \le 1{,}1$ μm (Si-channel) и $1{,}0 \le \lambda \le 1{,}8$ μm (Ge-channel). The photodetectors are equipped by specially designed preamplifiers. The preamplifier features low-noise high-speed operational amplifiers AD823. Since the absolute values of the expected radiation fluxes can change in an extremely wide range (up to five orders of magnitude variation), special attention was given to the possibility of changing the proper measuring range. The preamplifier is designed to operate at six sensitivity values. The faster time response achieves 1 μs. PC-based analog-digital converter T512 was used to register the outputs of the PD units. The photodetectors were equipped by objectives thus providing view angle 0.04 rad.

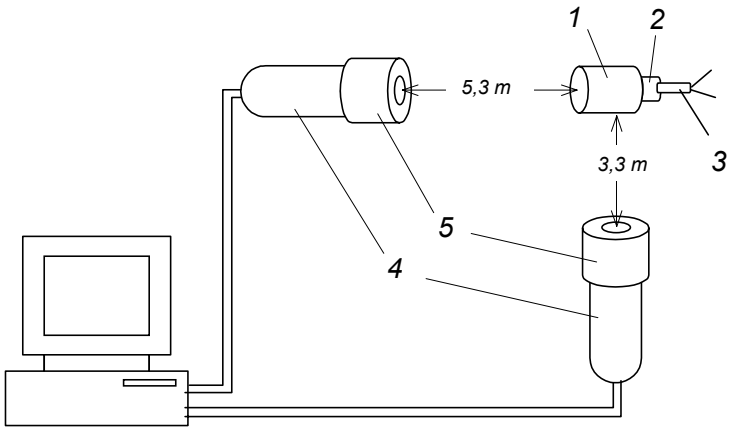


**Fig.1** Experimental arrangement. *1* – charge; *2* – intermediate charge; *3* – blasting cap; *4* – photodetectors; *5* – objectives.

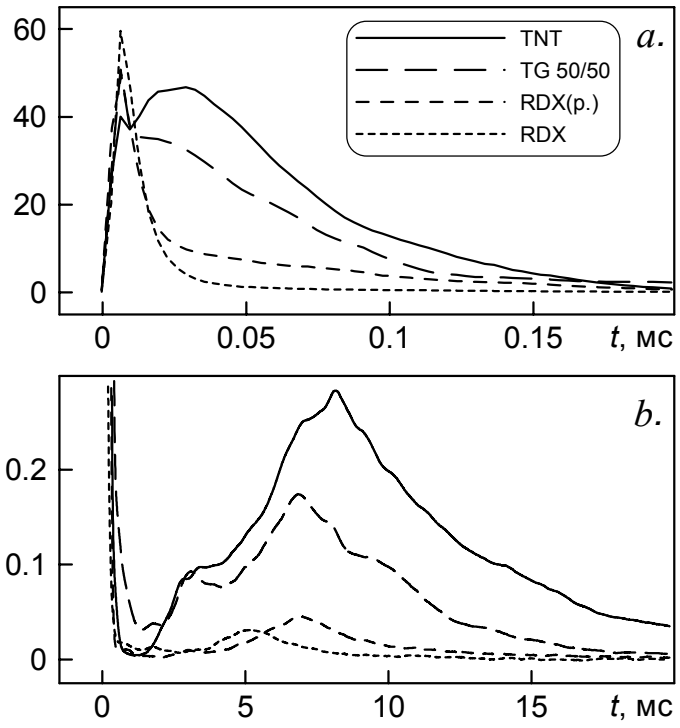


**Fig.2** Outputs of Si channel (arbitrary units) of the PD placed perpendicular to the charge axis (sidewall view). *a* – initial stage of explosions; *b* – full-time registrations.

Each photodetector unit (Si-Ge photodiode + preamplifier) was calibrated by the use of standard light source in accordance with commonly used procedure. Software package PHOPRO was used for processing of data records gathering from the PD. It incorporates unique algorithm for analysis of spectral properties of different combustible substances, PD calibration and temperature history calculation.

**Experimental Results**

Specific features of emission related to the HE explosions can be elucidate by the consideration of outputs of Si-channel of the photodetector placed across the axis of a charge (see Fig.2). As seen all the emission traces exhibit regular trends, namely, the presence of two amplitude-time stages. The duration of initial stage (Fig.2*a*) is about 200 μs after the initiation of a charge. During this stage the intensity of emission (radiation flux) changes significantly, i.e. sharply increasing up to some maximum value and afterwards smoothly decreasing. The second (later) stage (Fig.2*b*) also can be characterized by the appearance of a maximum (at $t$ = 5 – 8 ms). However, the value of this maximum seems to be one-two orders of magnitude lower than that at the initial stage of explosion.

The intensity and dynamics of variation of the measured radiation flax depend heavily on the composition of a given HE as well as on the orientation of the photodetector. The most pronounced differences are observed between the cases of TNT and RDX explosions. The parameters of emission related to the burst of TG 50/50 and RDX(p.) exhibit intermediate

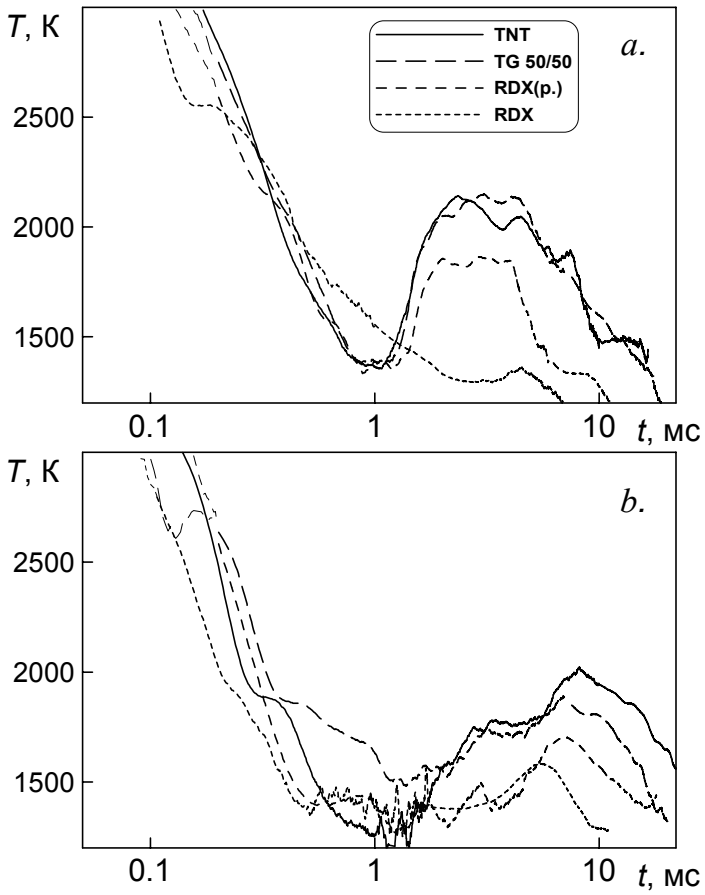


**Fig.3** Temperature-time histories in the course of longitudinal (*a*) and lateral (*b*) expansion of HE detonation products.

behaviors. These peculiarities reflect both qualitative and quantitative variations of explosion emissivity properties in the set RDX → RDX(p.) → TG 50/50 → TNT. As seen from the Table 1 this sequence is characterized by the monotonic increase of carbon content in detonation products. On the strength of these data one can interpret the observed photodetector's outputs in the following way. Initial sharply increasing emission seems to be associated with the air heated by shock wave. However, since short time interval (of order 10 – 20 μs) after initiation the optical thickness of the shock falls and expanded detonation products starts to be responsible for the luminosity. In this connection it should be noted that the intensity of radiation of carbon (soot) particles is substantially higher than that of gaseous components of detonation products. From this point of view at the initial stage of explosion (Fig.2*a*) the radiation flux in the case of RDX burst reflects the attenuation of shock wave and expansion of gaseous components of detonation products. Considerable increase of soot content, as in the case of TNT explosion, results in the fact that the contribution of soot particles into radiation intensity becomes dominant at least at 40 – 50 μs after initiation of the charge. Among other things the presence of carbon as a fuel is a likely reason for after-burning phenomena at the later stage of explosion. These phenomena result in increase of the observed radiation intensity at the later stage of explosions (Fig.2*b*).

The dynamics of after-burning processes can be clearly illustrated by the temperature-time histories calculated by the model of black body radiation. As it is seen from Fig.3 at the first 800 – 900 μs temperature of detonation products falls down to values about $T$ = 1200 –

1500 K. Further one can easily observe relatively smooth temperature rise to be associated with the burning phenomenon. The intensity of the after-burning process (i.e. heating rate and maximum temperature value) depends significantly from the soot content. Maximum temperature levels are achieved in the case of TNT and TG 50/50 explosions, while in the case of RDX burst the after-burning effects seem to be vanishingly small. An important thing is that the after-burning process is spatially non-uniformed. The longitudinal expansion (Fig.3*a*) results in more intensive combustion (i.e. combustion starts earlier and temperature seems to be higher) than that lateral expansion (Fig.3*b*).

## Concluding Remarks

To summarize, the performed tests show that the photodetector based on the double-wavelength Si-Ge photodiode presents a universal mobile tool for registration of emission and temperature measurements in expanding clouds of HE detonation products. Due to the simple design, it is especially suitable for multi-channel registration in both outdoors and laboratory conditions. The use of the PD system makes possible to compare the characteristics of emission in different kinds of explosives. Application of the double-wavelength photodetectors to the burst of TNT- and RDX-based explosives enables to reveal peculiarities of after-burning phenomena associated with turbulent mixing of detonation products with surrounding air.

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