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# Laser initiation of RDX crystal slice under ultraviolet and near-infrared irradiations

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ABSTRACT

Interactions between energetic materials and laser beams of specific frequency are of both scientific and engineering importance for understanding and manipulating the laser-induced ignition of energetic crystals. In this work, we investigate the effects of laser irradiation of variable energy densities from ultraviolet (355 nm) to near-infrared (1064 nm) on the ignition properties of a well-treated cyclotrimethylenetrinitramine (RDX) crystal slice (9.3 mm × 9.1 mm × 2.9 mm). The laser-induced damage and initiation dynamics were characterized in detail by using optical microscopy as well as an ultrafast pump-probe imaging technique at nanoseconds. It discloses that both ignition probabilities ($p$) of 355 and 1064 nm change exponentially with increasing laser fluence ($H$, J/cm$^2$): $p(355) = 1 - e^{-1.72^*(H-3.981)}$, $p(1064) = 1 - e^{-0.74^*(H-7.898)}$. RDX crystals can be more easily ignited under ultraviolet laser irradiation than by near-infrared one due to its different absorptions ($\alpha(355) = 1.6306$ cm$^{-1}$, and $\alpha(1064) = 0.5313$ cm$^{-1}$) and the effects of photochemical initiation mechanism. The damage induced by either 355 nm or 1064 nm laser exhibits three typical morphologies varied with laser exposure. In addition, damage generated by ultraviolet laser appears on the incident surface of the crystal slice, while it is mainly located on the exit surface when being ignited by near-infrared laser. Our work sheds light on the dedicated interaction mechanism between energetic crystals and laser beams of various frequency and energy density.



## 1. Introduction

Nowadays, laser ignition/initiation [1–4] has become one of the most promising methods in initiating combustion, deflagration, or detonation of energetic materials ascribing to its several advantages, such as high safety, precisely timed release, easy-to-realize multipoint ignition, and more efficient energy coupling [5]. Understanding the interactions between lasers and energetic materials becomes significantly important for laser initiators and firing systems. Up to the present, many factors, including laser parameters [6–11], environmental atmosphere [12, 13], confinement conditions [11], and light-scattering additives [14–16], etc., have been found to produce significant effects on the laser initiation properties of energetic materials. In particular, effects of laser irradiation parameters, such as initiation energy/power, wavelength, pulse duration, and beam diameter, have been explored in some representative works. For example, Aleksandrov and Tsipilev [8] and Volkova et al. [17] studied the influence of pulse width on the initiation energy threshold of PETN and their results indicated that initiation energy density increased with increasing laser pulse duration. Tarzhanov et al. [10] reported that laser ignition energy density

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of PETN decreases with increasing irradiation-spot diameter at a wavelength of 1.06 μm and pulse with of 40 ns. With regard to wavelength, Lisitsyn et al. [6] investigated the initiation behaviors of heavy metal azides, $AgN_3$ and $Pb(N_3)_2$ when irradiated at multiple wavelengths and discussed interaction mechanisms through aspects of the bandgap width of explosives. Ahmad and Russell [11] also compared the ignition properties of pyrotechnics by Arion Laser and Diode Laser, and discovered that ignition threshold of energy density at near-IR laser was lower than that at visible laser.

These studies give out some useful relationships between laser parameters and initiation characteristics of explosives, and provide general guidelines for ignition of energetic materials in various engineering applications. However, the samples studied in those works are always traditional explosive powders or micro-crystals, which are pressed into high-density powder compacts or mixed with a polymer binder to form polymer-bonded explosives. Indubitably, the chaotic configuration of explosive crystals makes it difficult to establish quantitative investigations on the laser ignition dynamics in aspect of crystallography discrimination [18]. Therefore, it is extremely hard for researchers to establish precise and reliable interaction models between laser and explosive crystals.

To date, bulk explosive crystal [18–21] has been reported as an ideal candidate for investigating the interaction between laser and energetic materials. Ramaswamy and Field [20] and Chen et al. [21] have explored, respectively, the fundamental initiation mechanisms between laser and RDX single crystals via Nd/glass laser and $CO_2$ laser. Besides, in previous works, we have also investigated the defect-induced damage [18,22] of RDX crystals during laser ignition and discussed the laser initiation dynamics process through damage morphology analyses [18]. In this work, we investigate effects of ultraviolet and near-infrared laser on ignition properties of RDX energetic materials and analyze directly the laser ignition dynamic processes via the bulk explosive crystal. For convenience, naturally grown large RDX single crystal was first cut into slices parallel to the $(2\bar{1}0)$ facet, and treated by polishing, ultrasonic and laser cleaning processes. Then it was irradiated successively by a nanosecond pulse laser operated under near-infrared (1064 nm) and ultraviolet (355 nm) modes, respectively, to explore the laser sensitivities. Finally, the laser-induced damage morphologies were characterized by high magnification optical microscopy (OM, NIKON ECLIPSE LV100) and the laser ignition dynamic processes are directly observed and analyzed by ultrafast pump-probe imaging techniques.

## 2. Material and methods

### 2.1. Materials preparation

In our study, RDX single crystals were first prepared by the solvent evaporation recrystallization technique from their saturated solutions in acetone at a constant temperature [19,23]. In this approach, 22 g of RDX powder was dissolved into 380 ml acetone solvent in a 500 ml breaker, which was tightly sealed by a preservative film with several pinholes in order to obtain a slow crystal growth rate. Then the solutions were stored in an un-vibrated incubator (SPX-150) at 30 °C with the temperature control precision ±0.1 °C. After about 40 days, naturally grown RDX single crystals (often >10 mm) were collected on the bottom of the evaporating breaker. Figure 1(a) shows the image of a typical tabular crystal [23], which can be frequently observed amongst larger RDX crystals. Among all the natural facets of RDX crystals, {210} are often dominant ascribed to their slower growth speed compared with other counterparts.

Herein, in order to better comprehend the effects of ultraviolet and infrared laser on energetic materials, the natural RDX single crystal (Fig. 1(a)) was sectioned into inerratic crystal slices (~3 mm in thickness, ensuring the same laser beam area on the incident and exit surfaces of the sample) parallel to the $(2\bar{1}0)$ facet via a diamond wire saw (STX-202A, 0.3 mm/min, 260 rpm). Then these slices were polished with $ZrO_2/CeO_2$ polishing solutions, followed by deionized-water ultrasonic cleaning to remove polishing defects. Finally, a non-contact, environmentally friendly and undamaged laser cleaning technique (about 1 $mm^2$ ultraviolet laser at a low level fluence 1.2 $J/cm^2$) was applied to remove contaminations adhered on the crystal slices. It proved to be effective and allowed us to focus simply on correlations between laser parameters and the nature of energetic materials, and eliminated the influence of heterogeneous surface contaminations [19].

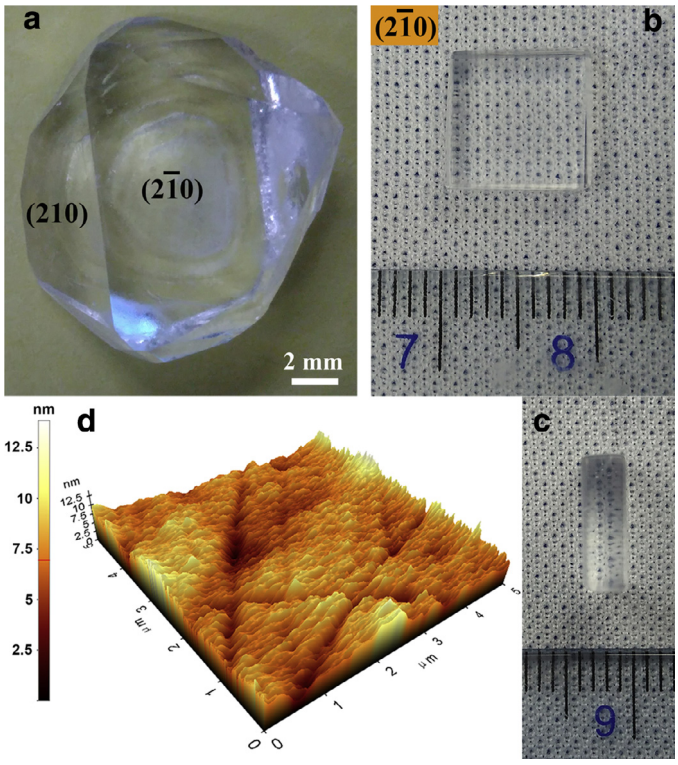


**Fig. 1.** (a) The image of naturally grown RDX single crystal. (b, c) The well-treated RDX slice obtained by sectioning large single crystal along with $(2\bar{1}0)$ direction followed with polishing, ultrasonic and laser cleaning methods: (b) top view, (c) side view. (d) Surface morphology of the crystal slice characterized by AFM.

Figure 1(b) and (c) shows the top and side views of the largest well-treated RDX crystal slice (9.3 mm × 9.1 mm × 2.9 mm), which is relatively bright under naked eyes. Figure 1(d) reveals the surface morphology of the crystal slice characterized by a contact mode atomic force microscope (AFM, PSIA XE-100). It is worth noting that although there are some defects (such as scratches and voids) on the slice surface, it can be also recognized as a homogeneous crystal since the average root mean square (RMS) of crystal surface roughness is as low as 1.436 nm [19].

### 2.2. Laser ignition system

In our experiments, the experiment platform is designed without constraints in an open atmosphere, which leads to the materials ejection and the self-sustaining chain reaction dying out without detonation to the whole energetic material, so that ignition properties of RDX crystal irradiated at 355 nm and 1064 nm can be explored at the same sample. As the laser ignition system demonstrated in Fig. 2, the RDX energetic crystal slice was successively irradiated by a Nd: YAG pulse laser [24] respectively operated with