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Emission Diagnostics for Benchtop-Scale Explosive Fireballs

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Abstract: Quantitative optical measurements in post-detonation fireballs are challenging due to high optical densities and short time scales. This paper demonstrates the use of simultaneous imaging, multispectral emission, and spectrometry diagnostics at high speeds.

1. Introduction

Characterizing the dynamics of benchtop-scale post-detonation fireballs is crucial for the validation of numerical models and provides a convenient experimental platform for diagnostic development. However, these environments are experimentally challenging due to harsh-conditions and short timescales. (The experimentally interesting dynamics persists only a few hundred μs after the detonation wave.) Therefore, resolution of temporal dynamics requires instruments capable of hundreds of kHz or MHz rate recording speeds. Recently, techniques such as coherent anti-Stokes Raman scattering have been conducted in such fireballs to quantify gas phase temperature [1]. Developing additional simultaneous optical diagnostic techniques, as demonstrated in this paper, allows for further characterization of fireball evolution and provides additional data for model validation.

2. Experimental Configuration

The experimental configuration is shown in Figure 1 and consists of four separate diagnostics: (1) a multi-spectral emission instrument uses a 1500 μm diameter fiber optic (0.5 numerical aperture) to collect emission from the entire fireball. Within the instrument, two amplified Silicon detector photodiodes (2.3 ns rise time) and one amplified InGaAs photodiode (15 ns rise time) monitor wavelength bands of 675 ± 12.5, 800 ± 12.5, and 1450 ± 5 nm. These bands are isolated using dichroic and bandpass filters in a similar fashion to previously reported pyrometers [2]. (2) A high-speed emission spectrograph consists of a round to linear fiber optic, imaged through a vertical slit and visible light transmission grating. Spectra from ~400 to 800 nm are recorded at 200 kHz and 3.26 μs exposure with a Photron Fastcam SAZ CMOS camera. This spectral range is selected to capture atomic and molecular emission as described previously [3,4]. (3) Schlieren imaging is performed using a Cavilux Smart laser (640 ± nm, 10 ns pulses) imaged at 1 MHz with a Shimadzu HPV-X2 camera equipped with a 640 nm bandpass filter. Finally, (4) 1 MHz visible emission videos are recorded with a second Shimadzu HPV-X2 camera oriented perpendicular to the schlieren imaging.

Both commercial and custom exploding bridge-wire detonators are tested. Commercial detonators are Teledyne Risi RP80 units with both brass and clear plastic cylindrical sleeves. Custom detonators are similar in shape and function but contain various combinations of aluminum, barium nitrate, and PETN. All detonators have no closer disk, and fireballs are largely generated by the detonation products ejected from the exposed surface of the high-explosives. Detonators are fired in a custom polycarbonate containment chamber built at Sandia National Laboratories. A Teledyne Risi FS-43 firing unit initiates the bridge-wire at $t = 0$ and provides a trigger signal for the diagnostics.

3. Results and Discussion

Figure 2 shows select experimental results, highlighting differences in the emission and combustion behavior of detonators containing PETN plus various additives. Schlieren imaging in Figure 2(a) shows that detonators with PETN and PETN+barium nitrate produce qualitatively similar shock and emission features. In contrast, the addition of aluminum signifyingly increases post-detonator fireball emission and results in an optically dense late-time cloud.

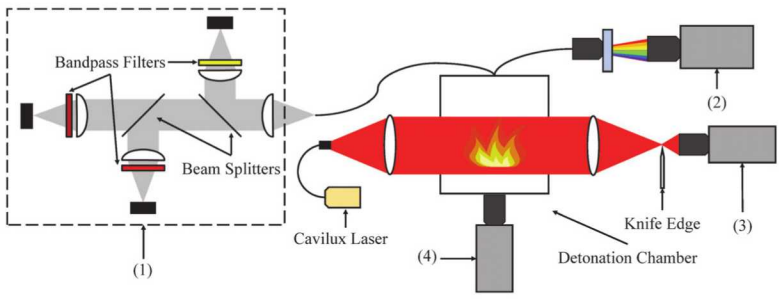

Figure 1: Experimental configuration for simultaneous (1) spatially-integrated multi-spectral emission, (2) spatially integrated high-speed emission spectroscopy, (3) schlieren videography, and (4) emission videography.

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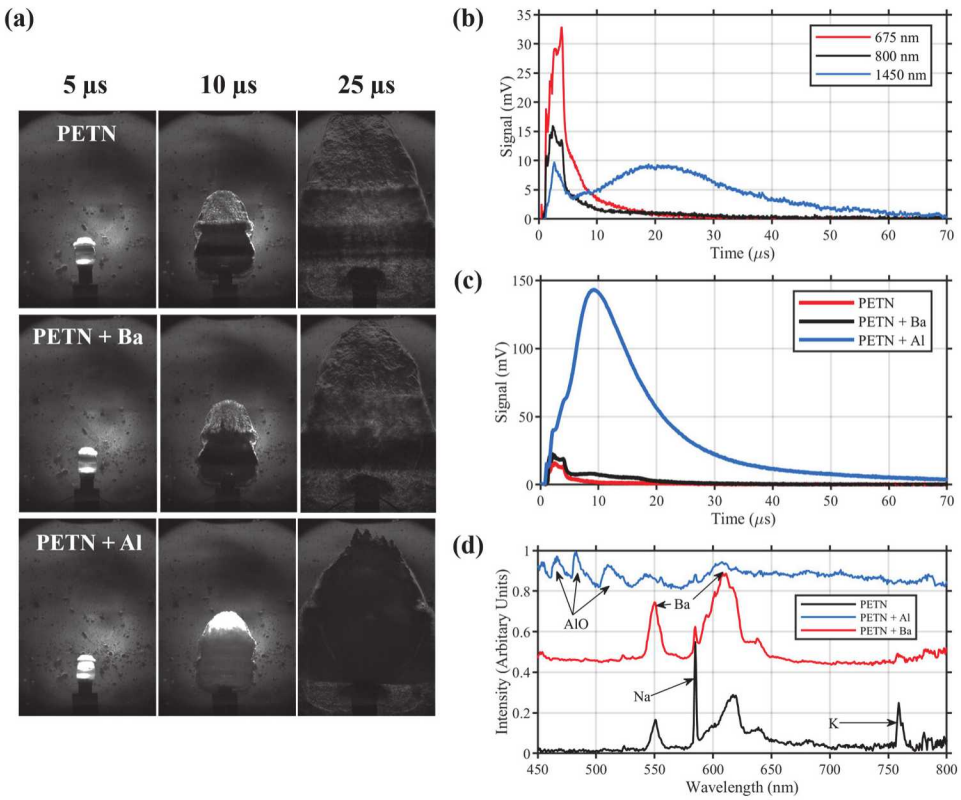

Figure 2 Select results showing: (a) schlieren images of three detonators (field of view ~112.8 by 70.6 mm), (b) multi-spectral emission from a PETN detonator; (c) 800 nm emission for all three detonators; and (d) molecular and atomic emission spectra.

Time histories are quantified by the multi-spectral emission bands shown in Figure 2(b) and (c). Figure 2(b) shows three emission bands from a PETN only detonator. A first peak in intensity around 5 µs corresponds with initial release of the detonation products (and possibly shock-heated air) as seen in the left-most column of Figure 2(a). A second peak in the IR band at around 20 µs likely corresponds with heat-release due to combustion of the gas-phase post-detonation products. (Note, in Figure 2(b) local minima/maxima observed in the 675 and 800 nm bands at $t < 5$ μs are suspected to originate from electrical interference due to the firing unit or emission generated within the clear housing.)

Figure 2(c) compares just the 800 nm band for the three detonators. Both the PETN and PETN+barium nitrate results are similar, providing at least preliminary indication barium nitrate is an effective molecular tracer that does not affect overall fireball dynamics [3-5]. In contrast, from the imaging in Figure 2(b) and measured emissions in Figure 2(c) added aluminum clearly enhances the post-detonation fireball.

Finally, as suggested by previous work in larger-scale explosives, fireball temperatures can be inferred by measures of molecular emissions [3-5]. Figure 2(d) demonstrates that the high-speed emission spectrometer can resolve molecular emission features for similar measurements at the bench-top scale, although more work is needed to improve the spectral resolution of these features. Each curve is offset for clarity.

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