Research paper

Optical measurements in visible and NIR bands of composition C-4 and argon flash hemispheres

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Received: November 2, 2017　Accepted: January 25, 2019

Abstract

Visible and near-IR measurements from two types of explosive units were conducted in support of an explosives characterization project. Cardboard tubes packed with Composition C-4 ranging from 0.5 to 136.2 kg and a novel argon flash hemisphere were detonated and emissions in eight bands covering the wavelength range from 325 nm to 1200 nm were measured with fast response photodiodes. Spectral and total intensity were measured in each band; additionally, radial measurements of each unit were also conducted to characterize spatial optical output. Composition C-4 charges indicated a linear relationship between peak intensity and total explosive weight. Argon flash hemispheres created a symmetric 2π sr optical source with a broadband temperature between 15,000 and 20,000 K. The influence of charge geometry on optical output is discussed. Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

SAND2017-11843 C

Keywords: argon flash, radiometry

1. Introduction

A series of explosive experiments were conducted to characterize the optical output from two explosive setups: novel hemispherical argon flash units and Composition C-4 cylinders. These experiments were conducted to establish design data for a larger explosive experiment with a tailored optical output; this paper highlights results from preliminary characterization experiments.

2. Theoretical

Optical signals from detonating high explosives and the subsequent shock interactions with surrounding atmospheres have been studied extensively for various objectives. Information such as detonation product composition and temperature, among others, can be determined from optical signatures.

Detonating high explosives typically feature a two-stage emission with distinct temporal, spectral, and intensity characteristics. For this study, only light between 325 nm and 1200 nm is considered. Initial output originates from the high-temperature detonation products from the explosives; emission is intense, but of short duration (on the order of the detonation time). As the explosive products expand, they initiate a prompt shock in the surrounding atmosphere and may cause shock-induced illumination (e.g. ionization) depending on the explosive. The expanding surface rapidly cools during expansion and emission may decrease substantially. Eventually, atmospheric air becomes entrained in the expanding products and afterburn can occur, which creates a second rise in intensity. A sample signature from a Composition C-4 (fuel rich) charge is shown in Figure 1.

In this study, measurements were also recorded for novel hemispherical argon flash units. Argon flash units are typically utilized to create intense light sources for high-speed optical imaging and are cylindrical or tubular in construction. They function by using a high explosive to propagate a shock into a noble gas (typically Ar, Kr, or Xe), which ionizes the gas and causes an intense, high spectral temperature emission (Conger et al.[1], Roth[2], and Davis et al.[3]).

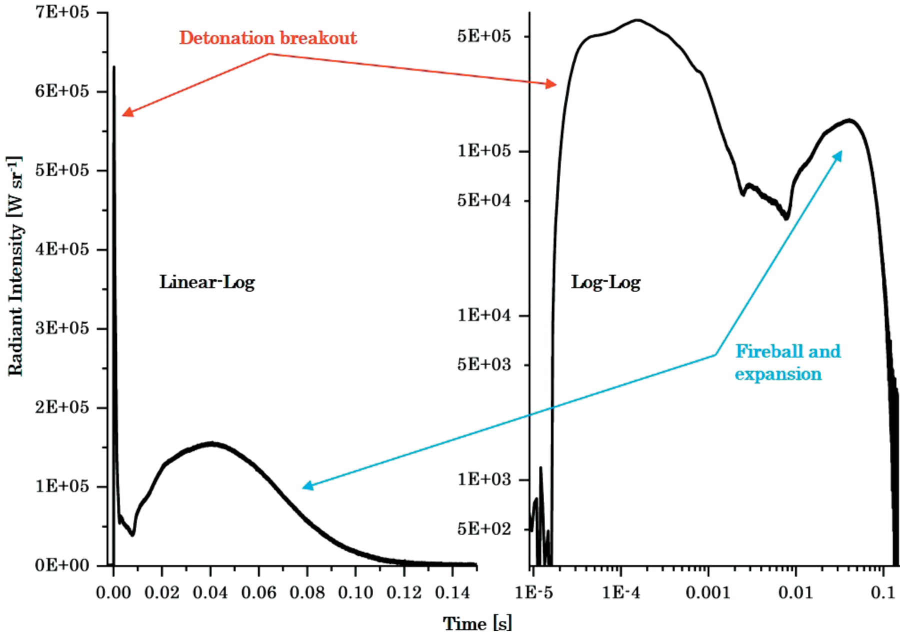

Figure 1 A sample broadband (Si-band) optical signature for 4.5 kg of Composition C-4 is shown in these images. Data are identical; however, they are plotted on linear-log and log-log plots. A short and intense light emission is observed at early times followed by a sharp decrease and then a second emission increase (fireball).

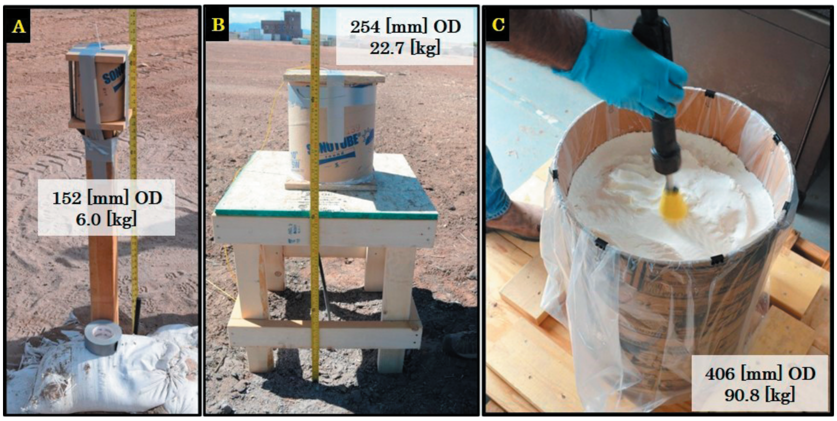

Figure 2 Optical measurements from Composition C-4 charges up to 136.2 kg were collected; these images illustrate "as-tested" configurations (A and B) and preparation (C) of representative charges. L/D ratios are approximately 1.0; height dimension appears larger than diameter due to internal wooden plates on top and bottom surfaces.

3. Experimental

Explosive experiments were conducted at Sandia National Laboratories in Albuquerque, NM, USA at sites 9920 and 9930. Charges were placed in an open field for unobstructed views for the optical instruments and remotely detonated.

3.1 Explosive charges

Cylindrical Composition C-4 charges were constructed using cardboard tubing capped with wooden end plates. Each charge was packed from bulk C-4 using a pneumatic or hand packer to 1.60 g cm^{-3} average density. Teledyne-Risi model RP-2 or RP-83 EBW detonators in a custom booster initiated each charge. A series of representative C-4 cylinders is shown in Figure 2.

Hemispherical argon flash units consisted of a UV-transparent acrylic outer window mounted to a wooden plate; a hemispherical C-4 charge was mounted concentric to the window on the plate. Charges were initiated using RP-2 EBW or PETN detcord and a custom booster. An open purge process replaced the air in the hemisphere with argon gas. The charge mass and window diameter were varied to investigate emission intensity and duration. An example of an argon flash hemisphere is shown in Figure 3.

3.2 Optical instrumentation

Optical measurements were collected using a custom radiometer setup consisting of seven bands in the VIS-NIR regime between 325 and 1200 nm. These bands, identified as Bands 1–7, are shown in Figure 4. Additionally, a Si broadband signal was measured (Band 8). These eight detectors directly viewed the explosive charges; an additional set of 6 each Si detectors were placed at 15° increments radially around the charge from 15° to 90° (Bands A1–A6; same wavelength range as Band 8). This detector setup allowed radial output signals to be characterized. Instrument layout and images of the radiometer setup are shown below in Figure 4.

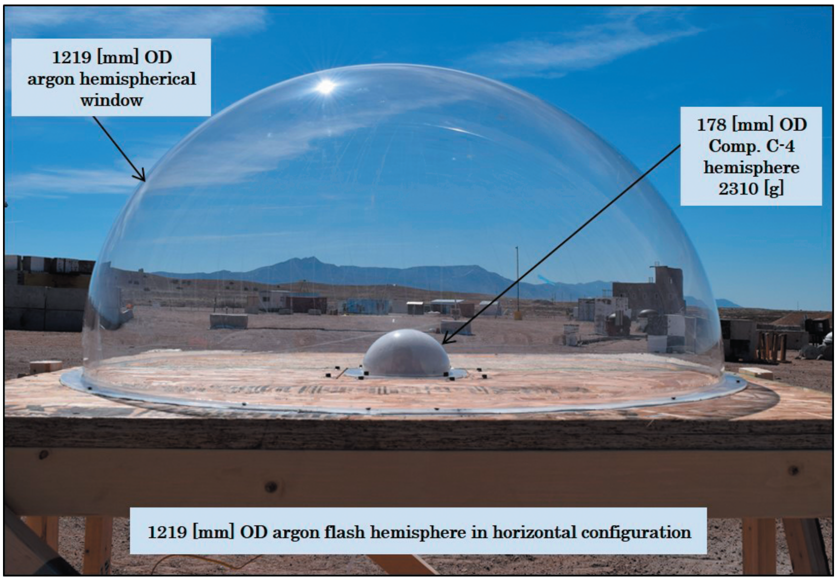

Figure 3 An argon flash hemisphere consists of an outer acrylic shell (1219 mm OD × 4.76 mm thick) mounted to a wooden base. A hemisphere of Composition C-4 (178 mm OD) is mounted concentrically to the wooden base; argon gas fills cavity through ports in the base (not shown).

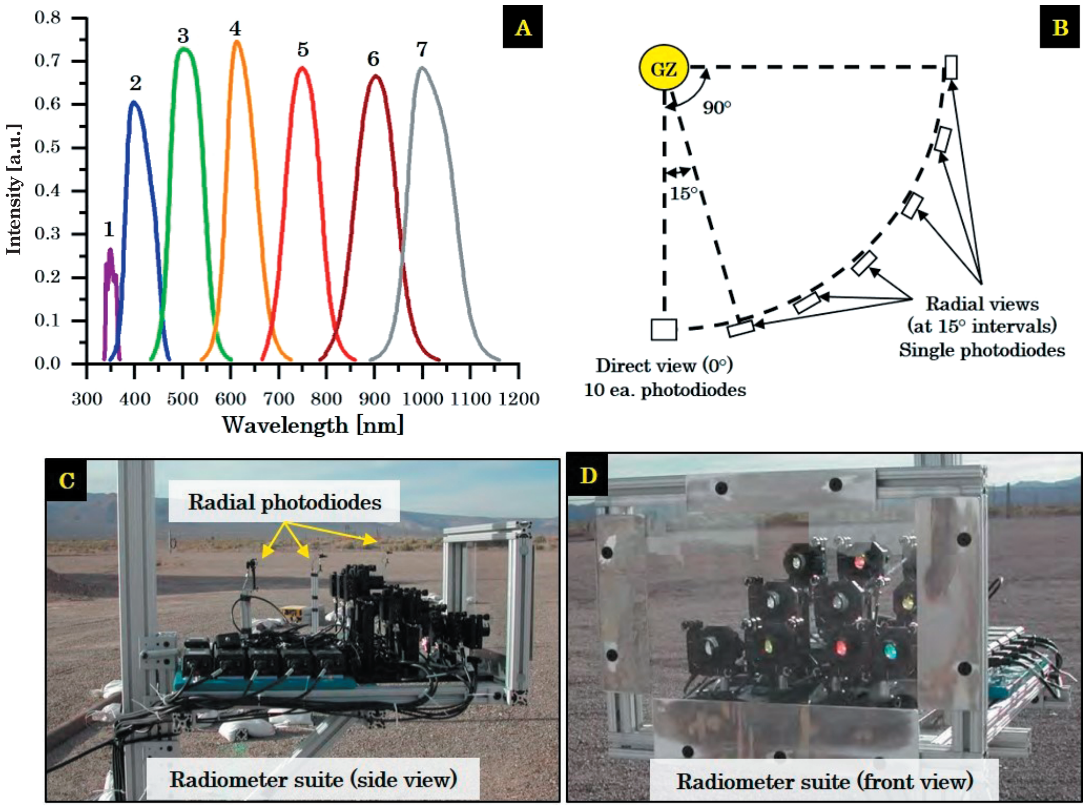

Figure 4 Details of the radiometer setup are summarized in this image: A) band coverage in visible and NIR regimes; B) radial layout (overhead view) of photodiodes in addition to direct view setup (“GZ” = Ground Zero); C) side view of direct and radial photodiodes, and D) front view of direct photodiodes. Note: two additional photodiodes were mounted in the direct view setup; their data are not reported.

4. Results

4.1 Composition C-4 charge optical output

Composition C-4 charge total emission in the Si band increased with increasing charge mass. Peak emission coincided with charge consumption (early time) and decreased rapidly. Maximum spectral intensity from the detonation event occurred in Bands 1–4 (UV-VIS) although shortly after detonation, spectral intensity increases to a similar level in Bands 5-7. The detonation event is considered the first peak (see Figure 1). Maximum second peak (fireball and expansion) spectral intensity was measured in Bands 6–7 (NIR). Relative spectra were consistent among all charges; however, intensity differences correlated with charge mass. Representative total and spectral emissions for a 5.0 kg charge is shown in Figure 5. Sixteen tests were conducted.

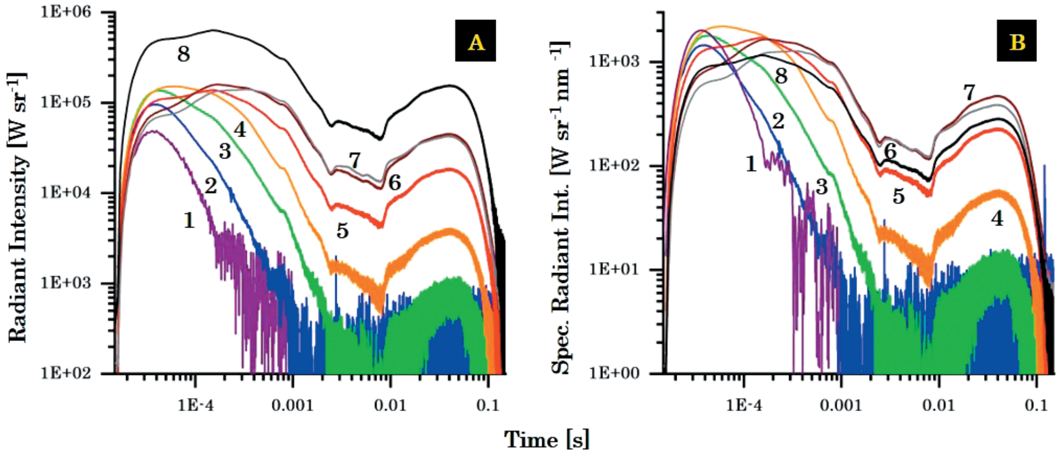

Figure 5 Total and spectral intensities in Bands 1–8 of a representative Composition C-4 charge are shown in this figure. Numbers next to each line indicate the optical band. Spectral measurements (B) are normalized to the FWHM of each band.

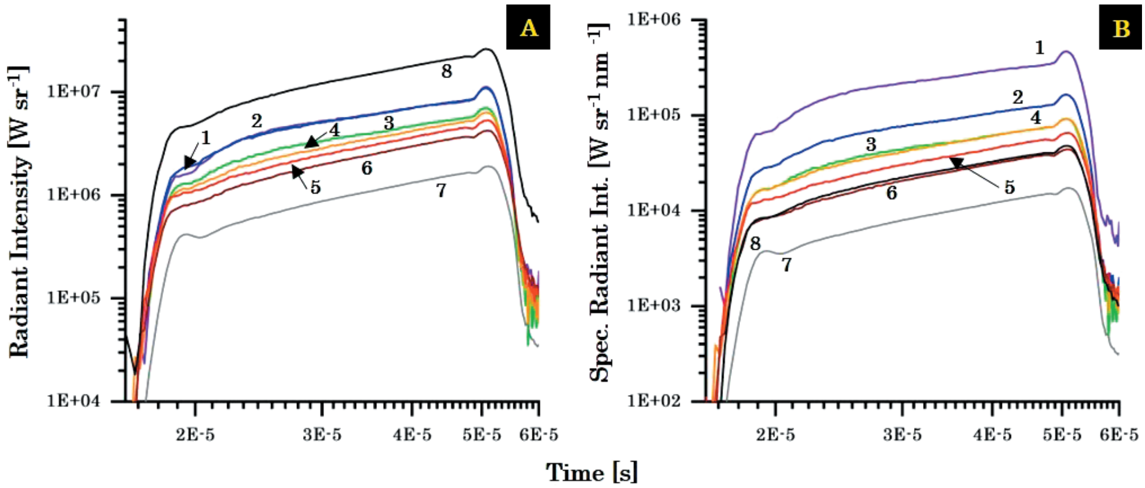

Figure 6 A 508 mm OD argon flash hemisphere's output in Bands 1–8 is shown in this figure. Note the high spectral temperature indicated in (B) by the peak output occurring in Band 1 (325–350 nm). Also, note the short output duration (approximately 60 μs).

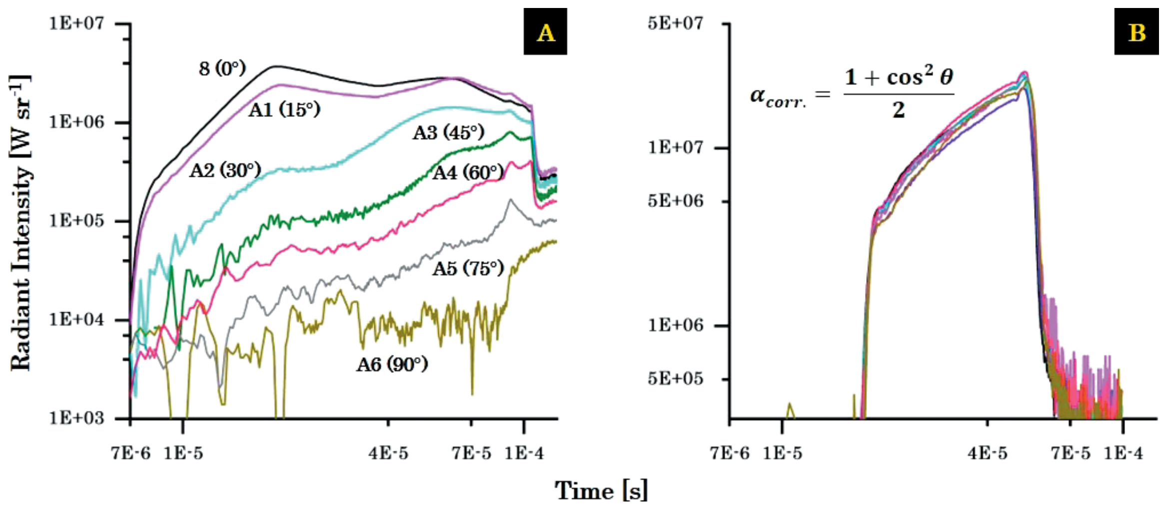

Figure 7 This figure summarizes the spatial output (Band 8) symmetry differences between cylindrical (A) and hemispherical (B) argon flash units. Note that data in (B) have been corrected for surface area by the correction factor shown (α), which ranges from 1 (direct view) to 0.5 (90° "side" view). These plots display radial photodiode output in Bands 8 and A1–A6. Overlapping signals in (B) highlight hemisphere flash unit symmetry. These graphs demonstrate an asymmetrical charge (cylinder) and a symmetrical charge (hemisphere); output symmetry is not dependent on charge size or gas volume.

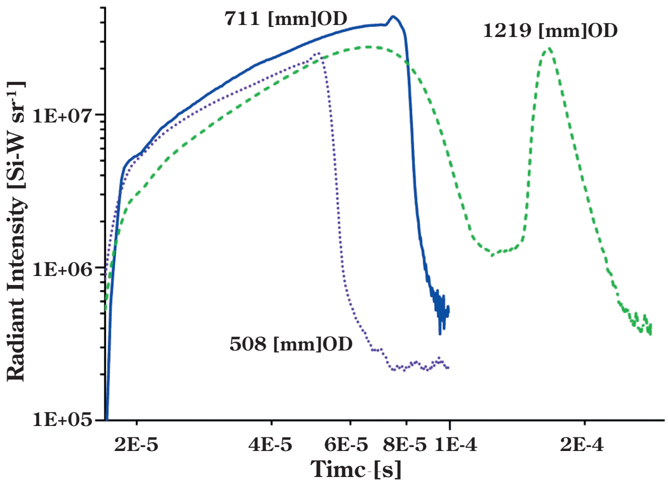

Figure 8 A comparison of total emission in Band 8 for three hemispheres is shown in this graph. Note that a 711 mm OD hemisphere is the optimal hemisphere diameter for the explosive charge; larger diameters result in shock attenuation leading to decreased emission (1219 mm OD). The sharp rise at late times in the 1219 mm signal is due to shock reflection at the acrylic window's inner surface.

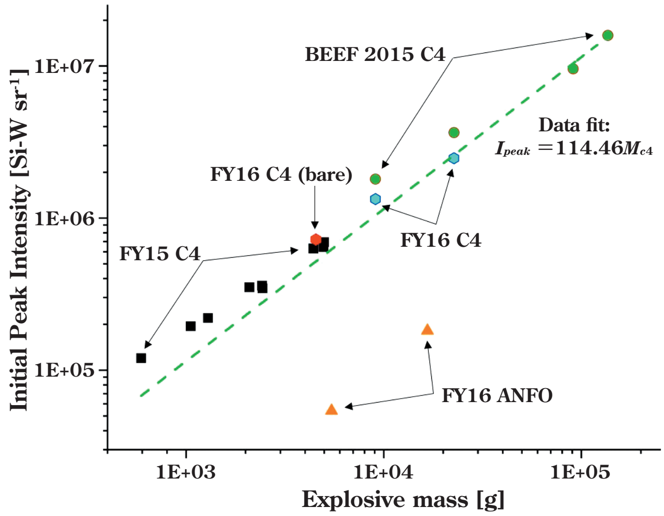

Figure 9 This plot summarizes the peak intensity in Band 8 (Si-band) from Composition C-4 charges. The peak intensity correlates well with charge mass over several decades of mass. The correlation fit only considers Composition C-4 explosive tests; two ANFO (lower detonation pressure) tests are also shown for comparison.

4.2 Hemispherical argon flash unit optical output and symmetry

Argon flash hemispheres featured spectral output approximating a 15,000–20,000 K blackbody. Total intensity in the Si band approached 50 MW sr^{-1}; spectral output peaked in the UV (Band 1). Hemispherical units also featured a symmetric output over 2π sr. Representative emissions in Bands 1–8 are shown in Figure 6 for a 508 mm OD flash hemisphere.

Figure 7 summarizes the radial differences between conventional argon flash tubes and argon flash hemispheres. Typical argon flash units feature a tube construction; this geometry results in a directional output. Radial measurements from an argon flash tube indicate peak emission in the 0° viewing angle; emission rapidly decreases through 90°. Argon flash hemispheres emit symmetrically in this regime. Output correlates exactly with surface area at radial observation points.

Three different hemisphere window diameters were tested: 508 mm, 711 mm, and 1219 mm. Results, shown in Figure 8, indicated that a 711 mm diameter optimizes output from a 2310 g Composition C-4 charge. This diameter corresponds to the maximum hemispherical volume of argon that can be driven to ionization by the specified explosive and explosive mass.

5. Discussion

Cylindrical Composition C-4 peak outputs in the Si visible band (Band 8) are shown to correlate well with charge masses ranging from 0.5 to 136.2 kg. Peak emission occurred during the detonation of the high explosive while no correlation was indicated with second peak emission (afterburn). The correlation and fitted data are shown in Figure 9.

Spectral output from hemispherical argon flash units is consistent with broadband temperatures in the range of 15,000 K to 20,000 K. Argon flash hemispheres exhibit an intense and symmetric visible output with total peak emission in the Si band greater than 50 MW sr^{-1} for tested geometries. Note that gases such as Xe and Kr could be used instead of Ar for a brighter emission.

6. Conclusions

Optical output from cylindrical Composition C-4 charges and a novel argon flash hemisphere in the visible (VIS) and near infrared (NIR) regimes were presented. The design and corresponding emission for a novel argon flash hemisphere, which creates symmetric point source emission, was described. A relationship between peak Si-band emission from Composition C-4 charges was calculated and discussed. Data presented may be useful for other engineers and scientists to design explosive experiments for optical emissions.

References

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