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TITLE: Prompt Detonation of Secondary Explosives by Laser

AUTHOR(S): Dennis L. Paisley

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Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

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PROMPT DETONATION OF SECONDARY EXPLOSIVES BY LASER

Dennis L. Paisley
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

Secondary high explosives have been promptly detonated by directing a laser beam of various wavelengths from 266 nanometers to 1.06 micron on the surface of the explosives. For this paper "prompt" means the excess transit time through an explosive charge is ~250 nanoseconds (or less) less than the accepted full detonation velocity time. Timing between laser pulse, explosive initiation and detonation velocity and function time have been recorded. The laser parameters studied include: wavelength, pulse length, energy and power density, and beam diameter (spot size). Explosives evaluated include: PETN, HNS, HMX, and graphited PETN, HNS, and HMX. Explosive parameters that have been correlated with optical parameters include: density, surface area, critical diameter (spot size), spectral characteristics, and graphite as an additive to alter spectral characteristics and enhance absorption. Some explosives have been promptly detonated over the entire range of wavelengths, possibly by two competing initiating mechanisms. Other explosives could not be detonated at any of the wavelengths or power densities tested.

INTRODUCTION

Numerous experimenters since the mid-1960s have used lasers of various wavelengths (usually 694 nm and 1.06 micron) to initiate primary and secondary explosives. (1,2,3) Initiation can be accomplished by three methods: 1) ablating a metal film in contact with the explosive (EBW-mode), 2) ablating a metal film to launch a high velocity flyer plate to impact the explosive, and 3) directing a laser beam on the confined (or unconfined) explosive surface. This paper covers experimental results for the third case of direct laser initiation of explosives. Direct laser initiation incorporates knowledge of optical properties of the lasers and explosives, and optical coupling efficiency. Literature(4,5) and explosive chemists suggest the UV end of the spectrum is better absorped by most crystalline explosives and the higher energy photons (248 nm = 5 eV) could break molecular bonds. Spectral transmission studies indicate that most secondary explosives are about an order of magnitude more absorping at 250 nanometers than from 550 nanometers to 1.06 micron. Therefore we decided to begin our experiments at UV wavelengths. We will present the functional performance of several explosive to various wavelength laser pulses, correlate traditional explosive and spectral parameters with performance results, and offer several possible hypothesis as to the mechanisms of initiation and transition to prompt detonation.

EXPLOSIVE PROPERTIES

CHEMICAL and PHYSICAL

The explosives tested include PETN, HNS, HMX, and 5-and 10-% graphite mixtures of each explosive. Surface area, batch number to identify processing method, and other charateristics were recorded for each explosive sample. For ease of handling and experimentation, all explosives were pressed in small aluminum cups. Except for special tests, all explosive column lengths were 3.5-mm and 7.5-mm in diameter. Explosives powders under test were pressed to densities ranging 0.9 - 1.5 g/cm^3 over a 1.6-g/cm^3 PBX-9407 output charge 3.00 mm long (Figure 1).

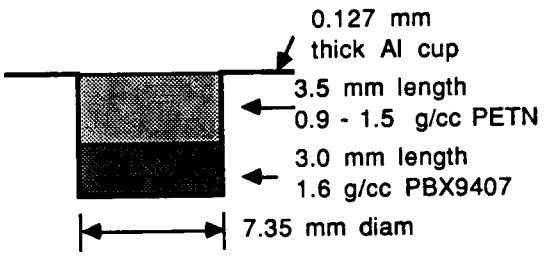

FIGURE 1: EXPLOSIVE TEST SAMPLE FOR LASER INITIATION (UV-QUARTZ WINDOW, OPTIONAL)

OPTICAL

Optical extinction coefficients at various wavelengths for most explosives of interest have been determined.(1,2). H. H. Cady, Los Alamos, made additional measurements on large single crystals of PETN (Figure 2). Most optical measurements are made in solutions, suspensions, or single crystal transmissions. Since our experiments involved compacted explosive powders, it seemed appropriate to measure reflection (R) from the surfaces of compacted powder samples and determine absorption by (1-R) assuming no transmission. W. Fleming, Unidyanmics-Phoenix (UPX), used a Varian Carey 2300 spectrophotometer to record the spectral reflection from samples of PETN, HMX, HNS, and graphited PETN, HMX, and HNS. Typical data are reported (Figure 3). These data are not absolute values but are relative to one another. Different particle size and density explosives were tested by UPX with a fixed solid angle for collection of reflected light. To evaluate the affect of angle dependence and wavelength on optical scattering from compacted explosive powder surfaces, John Stephens, Los Alamos, made reflection optical measurements that were angle and wavelength dependent (Figure 4). These data correspond to UPX data, H. H. Cady's single crystal PETN and published optical data (4,5).

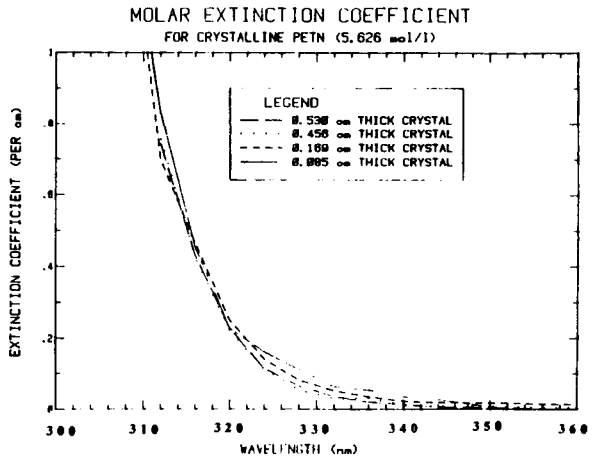

FIGURE 2: MOLAR EXTINCTION COEFFICIENT FOR SINGLE CRYSTALS OF PETN

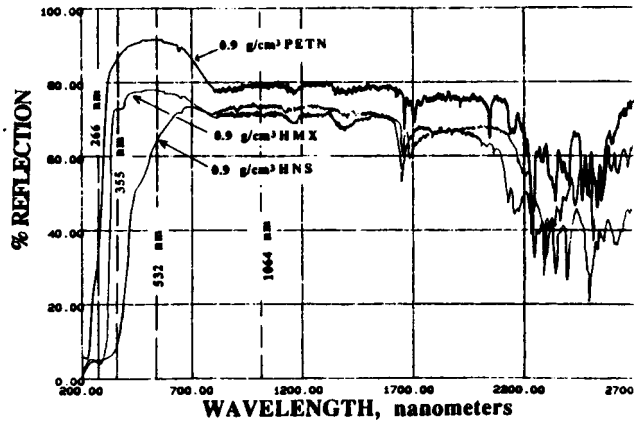

FIGURE 3: REFLECTION OF PETN, HMX, AND HNS SURFACES

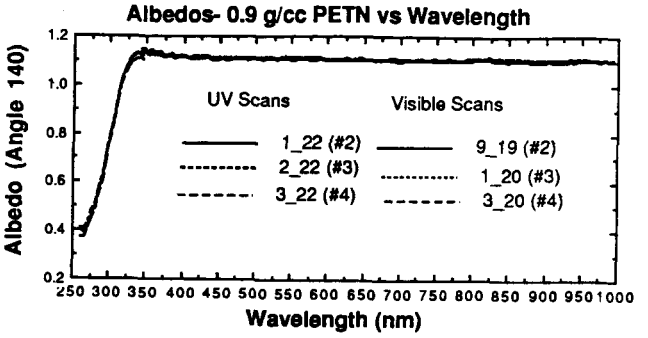

FIGURE 4a: WAVELENGTH VS. REFLECTION

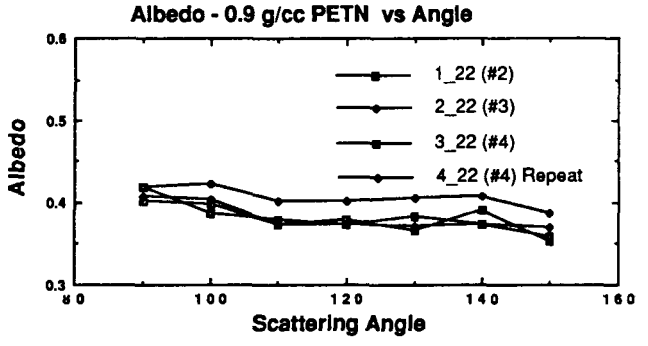

FIGURE 4b: SCATTERING ANGLE VS. REFLECTION

EXPERIMENTAL TECHNIQUE

Initial testing was begun using a XeCl Excimer laser (308 nm) with a 20 ns pulse length and up to 180 mJ on target. Most tests were conducted with a Quanta-Ray Nd:YAG laser operating at 1.06 micron, 355 nm, or 266 nm. The Nd:YAG pulse length was 10 ns with a pseudo-annular ring beam profile resulting from the diffraction coupled resonator (DCR). The experimental set-up and technique (Figure 5) involve operating the laser at near maximum output and attenuating the beam for the desired energy on target. The laser beam was focused through a barricade window and on the surface to the explosive sample. The lens used was a 250-mm focal length lens with f/28 and large depth of field. The explosive surface to be initiated was either unconfined or confined with a UV-quartz window. Care was taken to assure that dielectric breakdown did not occur in the air or UV-quartz window before the beam reached the explosive surface. All tests were performed at ambient atmospheric conditions for Los Alamos. No gap existed between the window and the explosive surface. Each sample was aligned to the laser beam using an autocollimator/ alignment telescope. In all tests, 8% of the beam was split off and sent to a energy meter and recorded. Extensive testing was performed to assure correlation between on-target energy and energy measurement readings were accurate. A fast (500-ps risetime) biplanar photodiode detected the laser pulse for a time zero (t_0) to be used for explosive timing purposes. A conventional electrical pin switch was placed on the ouput side of the aluminum cup opposite the 1.6 g/cm^3 PBX9407 explosive for measuring function time (t_f), Both signals were recorded on a digital oscilloscope and digital time interval counter. Since we are interested in prompt detonation, function timing is essential to distinguish between prompt detonation and deflagration-to-detonation transition (DDT). Many previous experimenters apparently did not have the need to record function time, making their data essentially unrelatable to our work where we must distinguish prompt detonation from DDT. The initiation process cannot be understood without timing considerations. Midway in our testing, we acquired and installed a Beamcode® CID two-dimensional beam profiler (200 nm - 1100 nm) to record beam profile for each individual test. Each test data includes: explosive parameters (particle size, batch number, density, physical dimensions), laser parameters (energy, power, energy/power density, pulse length, beam profile), and function time of the explosive. Special tests were performed to evaluate explosive run distance to full detonation and induction time (time from laser pulse to onset of chemical reaction).

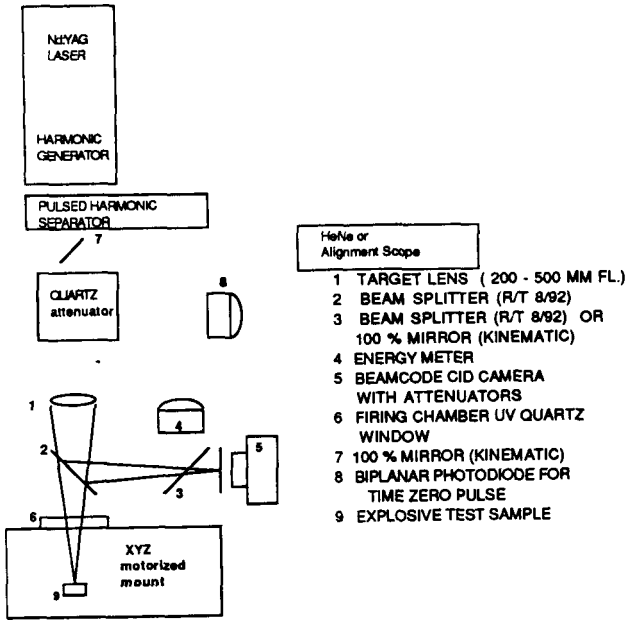

FIGURE 5: OPTICAL TEST SET-UP FOR LASER INITIATION OF EXPLOSIVES

EXPERIMENTAL DATA AND RESULTS

PETN and HMX was promptly detonated at 308 nanometers at power densities that relate to explosive type and density (Figure 6). These data represent approximately 30 tests at each density. The threshold value and error bars were determined by the ASENT (6) computer code. HNS could not be detonated at any power density up to the lasers maximum of ~5 GW/cm^2. The reason is uncertain, since the optical reflection data for all three of the explosives is not significantly different.

Approximately 400 PETN and 100 HMX total tests were performed at 1.06 micron, 355 nm, and 266 nm at explosive densities 0.9 - 1.3 g/cm^3. The explosive function times (t_f) were measured from the time the laser beam impacted the explosive surface (t_o) to the time of pin switch closure at the output side of the explosive sample (Figure 7,8,9). In all tests as the stimulus increased the function time decreased to an asymptotic limit of ~100 - 150

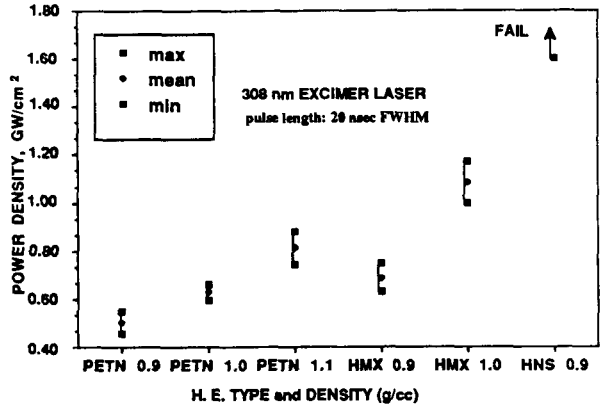

FIGURE 6: THRESHOLD FOR INITIATION OF PETN, HMX, AND HNS AT 308 nm

nanoseconds longer than the full detonation velocity through the sample would predict. As the stimulus was decreased to near threshold, the function time would increase by ~300 nanoseconds and at lower stimulus fail. The mixed region stimulus between fire/fail was usually small (~0.05 GW/cm^2).

Since power densities (> 0.7 GW/cm^2) resulted in an excess function time of ~100 -300 nanoseconds, we conducted experiments to evaluate the explosive surface during the imparting of the laser energy at various power densities from threshold to well above threshold. We added to our experimental setup (Figure 10) to include the ability to view the surface of the explosive with an electronic streak camera synchronized with the laser pulse. Streak records were recorded from below threshold (0.7 GW/cm^2) to 1.62 GW/cm^2 (Figures 11 a-f). These streak records show the plasma from the laser pulse interacting with the explosive, the time delay between laser pulse and initiation, and the detonation front expanding out radially at the explosive/window interface. One can see the slope (detonation velocity) increase and then continue at a constant detonation velocity. These data have been quantified (Figure 12). and compared with full detonation velocity for 0.9 g/cm^3 PETN, The measured function time (t_f) less the inherent delay time from laser pulse to initiation should result in the full detonation

velocity. The streak record in Figure 11c was tested near threshold (0.75 GW/cm^2) and exhibits an unusual initiation profile. The explosive, initiated along the periphery of the laser pulse, propagates radially outward, but not inward, at least on the surface of the PETN.

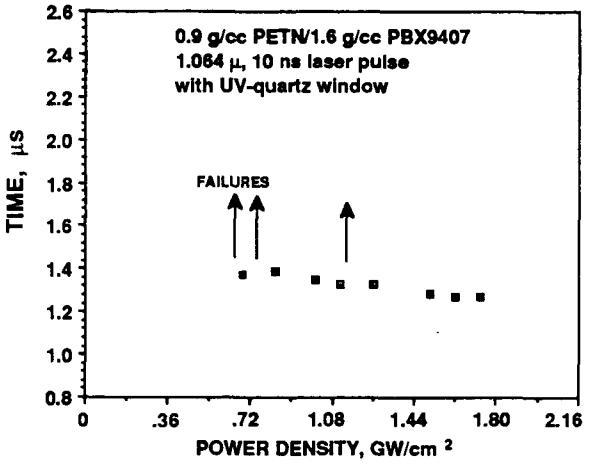

FIGURE 7: POWER DENSITY VS. FUNCTION TIME AND THRESHOLD FOR PETN AT 1.06 micron

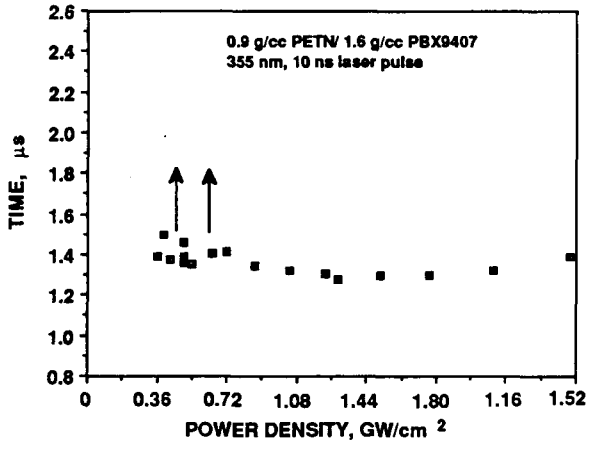

FIGURE 8: POWER DENSITY VS. FUNCTION TIME AND THRESHOLD FOR PETN AT 355 nm

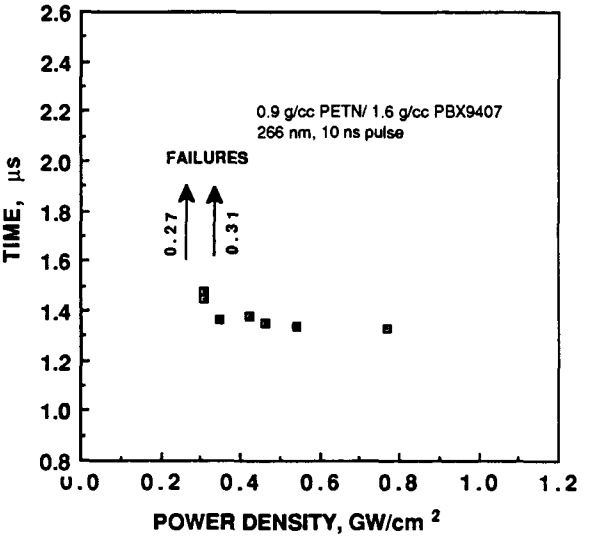

FIGURE 9: DETONATION OF 0.9 g/cc PETN AT 266 nm, 10 ns LASER PULSE WITH WINDOW

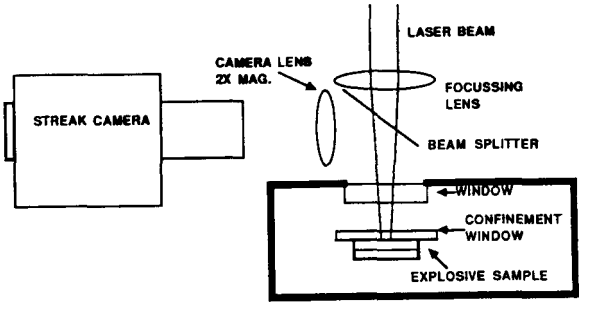

Figure 10: STREAK CAMERA TECHNIQUE FOR INDUCTION TIME MEASUREMENT

DISCUSSION OF EXPERIMENTAL RESULTS

XeCl (308 nm) Excimer beam diameters were measured by laser burn patterns on laser burn paper. The CID beam profiler was incorporated early in the Nd:YAG test data. The beam envelope on target was essentially the same on all Nd:YAG tests, but energy/power distribution in the envelope did vary. However, we have not been able to attribute any unpredictable performance because of energy distribution within the envelope.

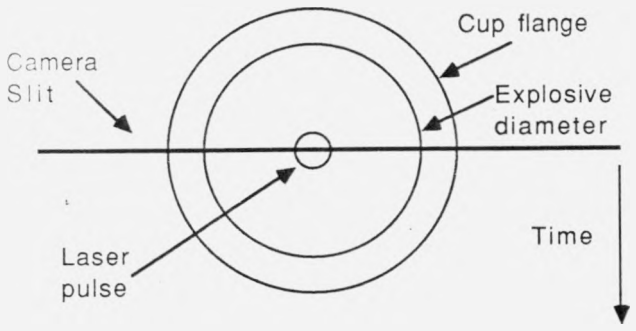

FIGURE 11A : STREAK CAMERA VIEW OF EXPLOSIVE/ LASER PULSE INTERACTION SURFACE THROUGH A UV-QUARTZ WINDOW

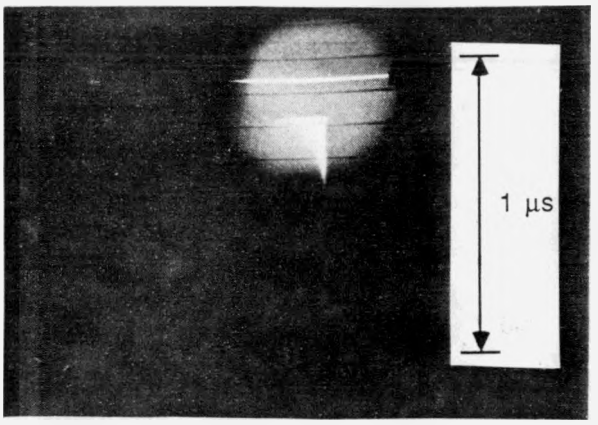

FIGURE 11C: FIRED AT 0.62 GW/cm^2; LASER PLASMA ONLY

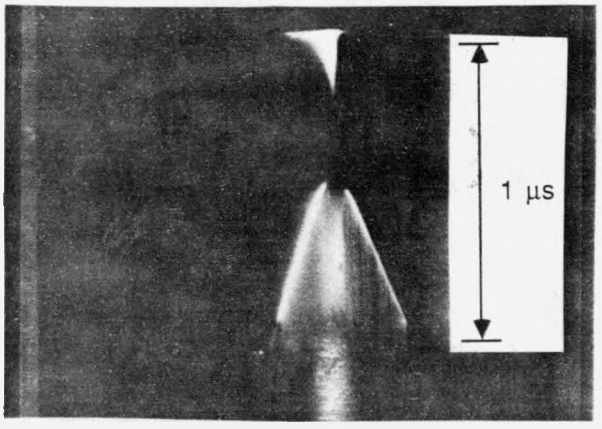

FIGURE 11C: FIRED AT 0.67 GW/cm^2; LASER PLASMA AND DETONATION FRONT RECORDED

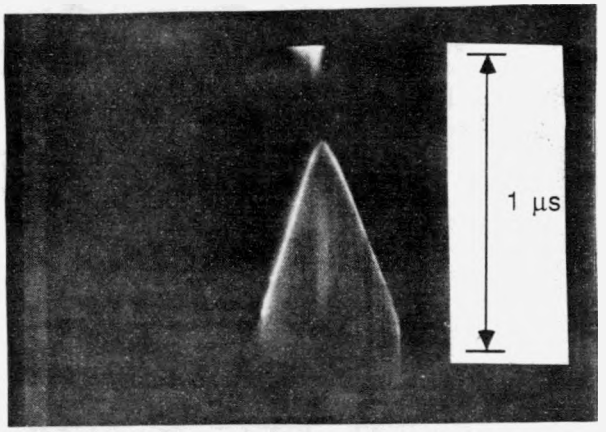

FIGURE 11D: FIRED AT 0.73 GW/cm^2; LASER PLASMA AND DETONATION FRONT RECORDED

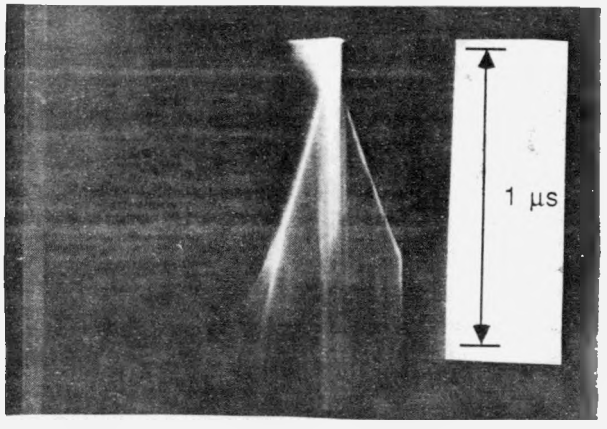

FIGURE 11E: FIRED AT 1.13 GW/cm^2; LASER PLASMA AND DETONATION FRONT RECORDED

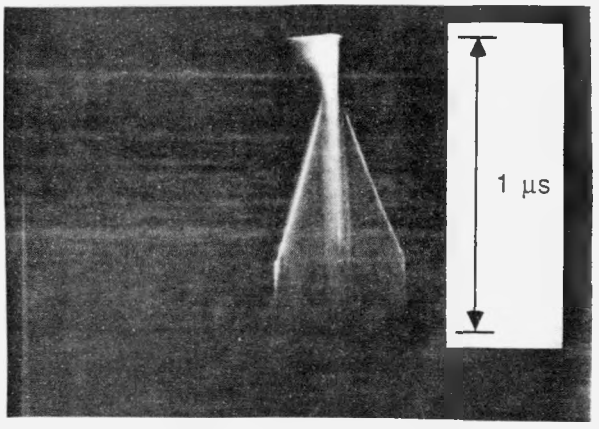

FIGURE 11F: FIRED AT 1.60 GW/cm^2; LASER PLASMA AND DETONATION FRONT RECORDED

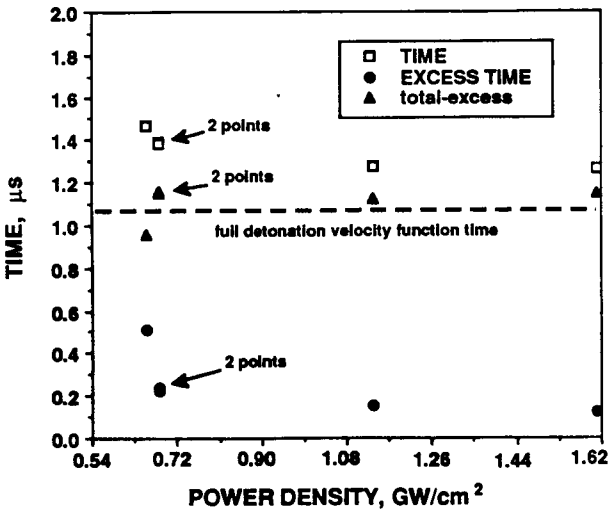

FIGURE 12: QUANTIFIED DATA FROM FIGURE 11; EXCESS TIMES, FUNCTION TIMES, AND DIFFERENCE IN TIMES COMPARED TO FULL DETIONATION VELOCITY

Prompt laser initiation of PETN is easier than HMX at wavelengths 1.06 micron, 355 nm, and 266 nm. HNS (0.9 g/cm^3) cannot be initiated at power densities as high as 5.0 GW/cm^2 at any of the wavelengths tested even though spectral data would suggest otherwise. The addition of graphite (5-10%) does not decrease the power threshold. Streak camera records of laser/explosive surface interaction show how the lower optical power density input affects the initiation and build to full detonation velocity. The lower power densities result in longer times between laser pulse and first reaction of the explosive. This phenomonon is similar to streak records for initiating PETN by exploding bridgewires(7). Streak records can help interpret earlier timing data. One particular test (Figure 11 c), fired at near threshold condition, exhibits an unusual initiation begun on the periphery of the laser pulse. We orginally thought this streak record to be an anomaly, however, review of earlier theoretical calculations (8) suggest periphery initiation is possible. R.J. Harrach, Lawrence Livermore National Laboratory, has calculated a thermal initiation model indicating under certain circumstances the center of a beam could ablate the explosive surface and initiate on the beam edge. This is exactly what we observed under slightly different, but similar conditions, and thus adds credence to a thermal initition mechanism at 1.06 micron. At UV wavelengths, confinement of the initiating surface is not as significant as with 1.06 micron. Since an order of magnitude increase in optical absorption in the UV and confinement at UV wavelengths has no appreciable affect on initiation, one can speculate that different mechanisms might be taking place at 1.06 micron and 266 nanometer (possibly thermal and photodissociation, respectively).

CONCLUSIONS

The longer wavelengths (i.e. 1.06 micron) appear to cause initiation by thermal hot spots that grow to detonation, whereas the shorter wavelengths (266- 308 nanometers) may possibly initiate by bond-breaking (or at least energy deposited inside crystals, Table I). These hypotheses are partly supported by the fact that for longer wavelengths, the laser pulse/explosive surface must be confined by an optically transmitting window in order for prompt detonation to occur, but short wavelengths can promptly detonate the same explosive at lower energy and power densities with or without physical confinement of the interface.

ACKNOWLEDGEMENTS

We greatly appreciate the technical assistance of N. Montoya and D. Stahl, and J. Meier in conducting tests and collecting data. We also thank H. H. Cady, J. Stephens, and W. Fleming for their discussions and optical measurements on explosive samples.

TABLE I: PETN DATA SUMMARY

WAVELENGTH (nm)	DETONATION POWER DENSITY THRESHOLD WITH UV-QUARTZ CONFINMENT (GW/cm^2)	DETONATION POWER DENSITY THRESHOLD WITHOUT UV-QUARTZ CONFINEMENT (GW/cm^2)
1064	0.71	>5.00
355	0.50	2.50
308	0.50	0.70
266	0.25	0.50

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