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Unreacted Equations of State of Sylgard and Hexanitroazobenzene Determined by Ultrafast Time Domain Interferometry

Brook A. Jilek[1], Ian T. Kohl[1], Darcie A. Farrow[1], Junji Urayama[1], Robert Knepper[1], Sean P. Kearney[1], Michael R. Armstrong[2], Jonathan C. Crowhurst[2], James Lewicki[2], and Joseph M. Zaug[2]

1. Sandia National Laboratories[1], Albuquerque, NM 87185, USA
2. Lawrence Livermore National Laboratory[2], Livermore, CA 94550, USA

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Abstract

Equation-of-state (EOS) models are based, in part, on shock Hugoniot data. Ideal high explosives (HEs) are characterized by rapid reaction kinetics, which make unreacted Hugoniot measurements difficult because particle velocities in the shocked material must be measured before reactions occur. For example, the highest-pressure measured Hugoniot point for PETN is 14.1 GPa [1], which is less than half of the established C-J chemical equilibrium pressure at detonation [2]. With the advent of ultrafast laser systems that launch ps rise-time shocks and the use of ps time resolution diagnostics, researchers have pulled away from intrinsic temporal and spatial limitations of gun-based shock Hugoniot experiments [3]. Recent density functional theory (DFT) modeling by Wixom and Mattsson extend the PETN Hugoniot to higher pressures beyond the C-J point. These DFT results agree well with experiment; however and in general, additional higher-pressure experimental measurements are necessary to fully validate theory [4].

Hexanitroazobenzene (HNAB) is an energetic material with properties that make it a model system to study the effects of microstructure on initiation. HNAB can be vapor-deposited as a fully dense amorphous film. If kept at room temperature, it crystallizes into a dense film (99.4% TMD) with nanometer-scale pores [5]. In the amorphous state, it shares some properties with liquid explosives: it has an isotropic molecular network (no long range order) and lacks micron-scale pores that can serve to nucleate shock-induced chemical initiation. Unlike liquid explosives, HNAB is a solid, so there are much stronger intermolecular bonds. Detonation studies may be conducted on crystalline and amorphous HNAB to elucidate how pores and molecular ordering affect shock initiation threshold.

Here we have implemented a laser-based tabletop diagnostic, Ultrafast Time Domain Interferometry (UTDI), originally developed by Benuzzi-Mounaix [6], recently refined by Armstrong, *et al.* at Lawrence Livermore National Laboratory [7,8], and closely related to work by Bolme, *et al.* at Los Alamos National Laboratory [9]. The method enables high-throughput measurements of unreacted Hugoniot of a wide variety of materials including HEs. UTDI overcomes time-resolution limitations of other diagnostics such as PDV and VISAR by encoding temporal information within the spectrum of a probe pulse. A diagram of the experimental setup is provided in Figure 1. A broadband (25 nm FWHM) femtosecond pulse is chirped so that the various wavelengths travel different path lengths and become more separated in time, resulting in a probe pulse that is 300 or more picoseconds (FWHM) in duration. One edge of a laser pulse is clipped

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in the beam stretcher to produce a ~ 10 ps rise-time profile. This chirped pulse is split into two portions: a higher energy pulse to generate a shock within a target and a low energy pulse that propagates through a Michelson interferometer to form a pulse-pair with a relative time separation of ~10 ps. The drive pulse is focused down to a ~ 30 µm spot on the substrate side of an aluminum target; rapid ionization within the skin-depth of the aluminum ablator impulsively launches a shock wave that travels through the Al and into a sample material. On the backside of the ablator, the probe pulses are focused to a ~ 100 um spot to illuminate the entire break-out area, including unshocked reference regions. An objective lens is selected to image the surface of the sample onto the slit of an imaging spectrometer. A CCD camera attached to the spectrometer records an interference pattern created by the relative path-length differences between corresponding wavelengths in the probe pulse pair.

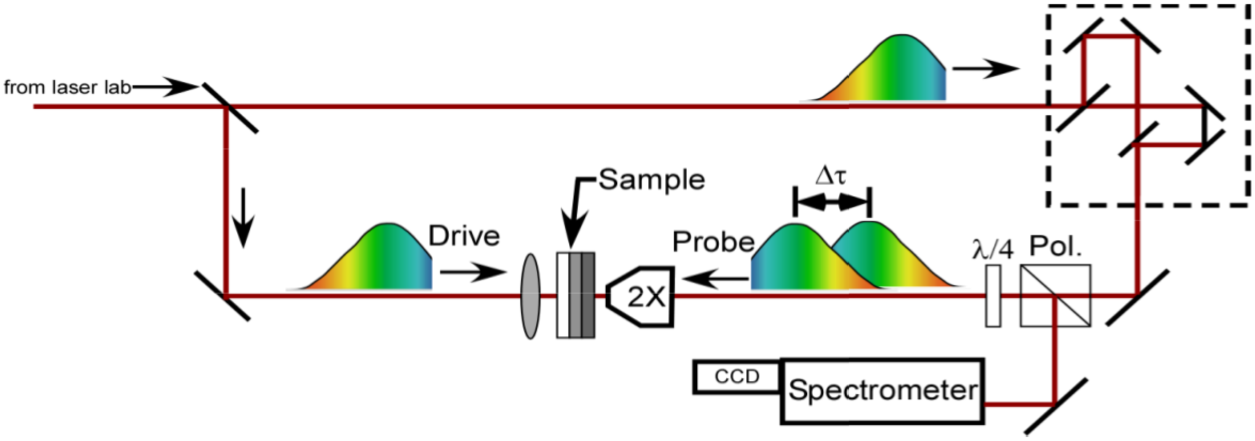

Figure 1. UTDI setup detailing the splitting of chirped pulses into drive and probe pulses and their subsequent measurement with time domain interferometry.

As time progresses, the accumulated phase difference between the probe pair signals the spatial propagation –every 10 ps- of the metal ablator relative to the shock front. A raw UTDI image is shown in Fig. 2. UTDI data are analyzed to yield the ablator or piston velocity (U_p), the shock velocity (U_s), and the shocked index of refraction (n_s) in the material. UTDI measurements are made over a range of shock drive pressures to develop the unreacted U_s-U_p Hugoniot. We present Hugoniot measurements on the polymer Sylgard®-184 and compare to available shock Hugoniot data. We also present the first measurements of the unreacted Hugoniot of hexanitroazobenzene (HNAB). Independent measurements made at SNL and LLNL are compared.

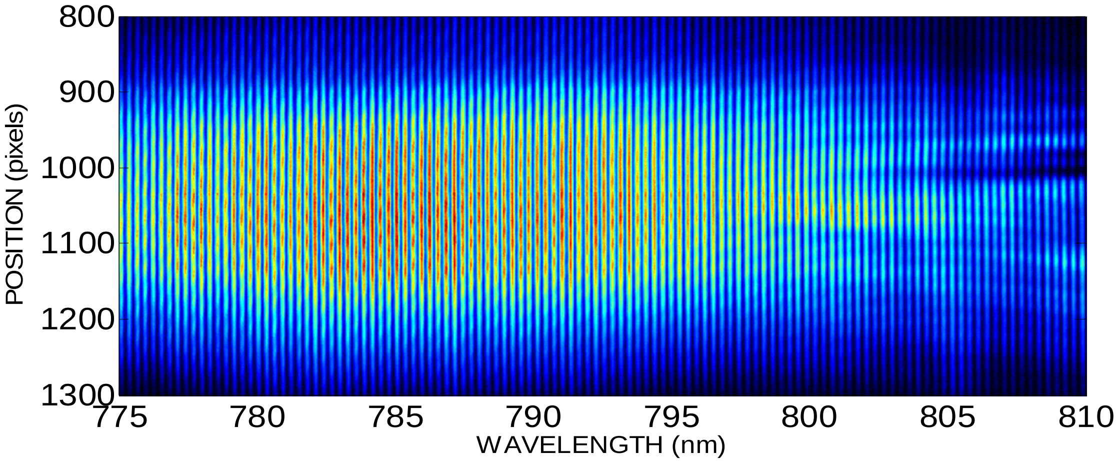

Figure 2. Interferometric fringes measured on a ps timescale with a spectrometer. Note the decay of fringe intensity near CCD row 1000 in the wavelength range of 800-810 nm due to time-dependent destruction (loss of reflectance and surface movement) of the ablator relative to the propagating shock front.

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