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TEMPERATURE MEASUREMENTS OF SHOCKED TRANSLUCENT MATERIALS BY TIME-RESOLVED INFRARED RADIOMETRY

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TEMPERATURE MEASUREMENTS OF SHOCKED TRANSLUCENT MATERIALS BY TIME-RESOLVED INFRARED RADIOMETRY*

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ABSTRACT

Infrared emission in the range 2-5.5 μm has been used to measure temperatures in shock-compressed states of nitromethane, cyclohexane and benzene and in polycrystalline KBr. Polymethylmethacrylate shows anomolous emission probably associated with some heterogeneity.

INTRODUCTION

Early work on the time-resolved measurement of infrared emission from shock heated explosives proved valuble in the experimental investigation of "hot spots" produced in pressed explosives by low amplitude shocks.[1] It became necessary to extend the investigation of "mock" explosives and inert materials reported at that time. Except for the work of Raikes and Ahrens[2] on silicate minerals, very little other work has been done on temperature measurements by radiation pyrometry in non-metals shocked to low pressures. This paper presents the highlights of the work in shocked inert materials showing the contrasting responses of organic liquids, a polymer and a polycrystalline solid.

EXPERIMENTAL

Space does not permit a complete description of the experiment, which can be found in a recent paper.[3] Plane shock waves were introduced into the samples by 102 mm plane projectile impact in a gun facility. Two radiometers were used to measure the infrared radiance of shocked samples in two overlapping bands, 2-5.5 μm (Band #1) and 4-5.5 μm (Band #2), with a response time of about 0.4 microsecond.

All liquids were analytical reagent grade except nitromethane, which was spectrochemical grade, containing at least 98.7% CH_3NO_2. 12mm-OFHC copper flyer plates impacted 3.2 mm thick x 51 mm dia stainless steel driver plates polished to a mirror finish in contact with the liquid. Liquid path lengths were approximately 21 mm, followed by a 2 mm sapphire window.

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The polymethylmethacrylate (PMMA) samples were 6.4 mm thick by 51 mm diameter and were backed by 6 mm thick KCl crystals with Kel F-90 grease between to prevent gaps and transmit infrared. The impact face was covered with either a 3.2 mm 2024 Aluminum driver plate without grease or .08 mm aluminum foil and silicone grease.

The polycrystalline potassium bromide (KBr) targets were prepared by pressing infrared quality KBr powder onto 1.5 mm stainless steel disks at 30,000 psi.

RESULTS

The time-resolved radiance from the neat liquids resulted in signals which increase exponentially until the sapphire window is reached. Figure 1 shows the brightness temperatures from one band for the three liquids where the arrows indicate the approximate time of arrival of the shock at the sapphire which causes an impedance mismatch . Figure 2 is a typical logarithmic plot of the observed signal. Peak brightness temperatures (at sapphire arrival) for single shocks in nitromethane are plotted in Figure 3 and compared with a calculated curve.[4]

The solid polymer PMMA was examined for comparison to the liquid results. Figure 4 shows the Tektronix 7903 oscilloscope traces for the 2-5.5 μm band for two experiments with identical Al flyer plate velocities of 0.98 mm/μs. The only difference between the two was that the lower trace resulted when a film of silicone grease was used between the driver plate and the PMMA surface. The lower trace is similar to that resulting from a 2.0 GPa shock into the PMMA (not shown). The radiance at PMMA/KCl breakout corresponds to a brightness temperature of about 100°C for about a 3.8 GPa first shock into PMMA.

The infrared response from shocked polycrystalline KBr is illustrated in Figure 5. This nearly linear increase in radiance with time starting from impact contrasts with the above results.

DISCUSSION

Solution of the radiation transfer equation[5] for a planar system with only normal emission is given by expression (1)

$$S = \int_{\Delta\lambda} (1-e^{-\alpha_1 d}) e^{-\alpha_2 x} W^{bb}(\lambda,T) d\lambda \qquad (1)$$

where S is the signal; d is the thickness of shocked material with absorption coefficient α_1; x is the thickness of remaining unshocked material of absorption coefficient α_2; $W^{bb}(\lambda,T)$ is the Plank black body function into which is incorporated the responsivity of the detector.

The case of the shocked liquid is approximated by assuming that $\alpha_1 d$ becomes large and that the wavelength-dependent absorption coefficient, α_2, can be replaced with an average quantity, $\bar{\alpha}_2$, over the wavelength range $\Delta\lambda$. Equation (2) then

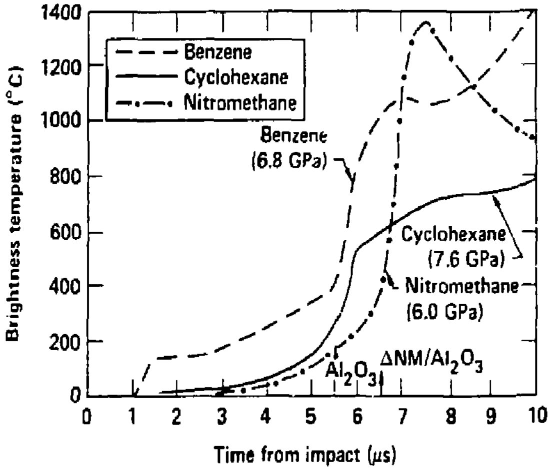

Fig. 1. Brightness temperatures for 3 shocked liquids (2-5.5 μm). Arrows indicate shock arrival at sapphire interface.

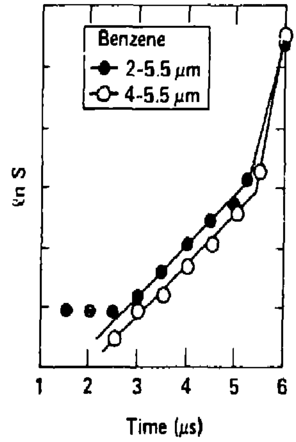

Fig. 2. Logrithmic plots for benzene signals.

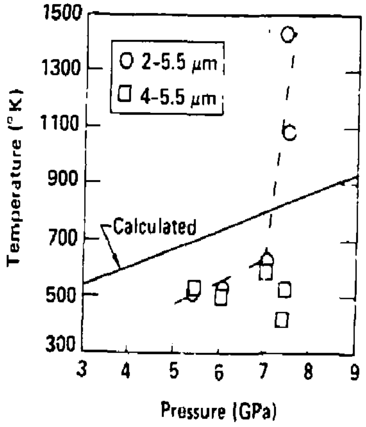

Fig. 3. Shocked nitromethane brightness temperatures. Points are experimental.

describes the resulting radiance as a function of time, t, where d_o is the unshocked path length.

$$S(t) = \exp\left\{\bar{\alpha}_2 \; (U_2 t - d_o)\right\} \int_{\Delta\lambda} W^{bb}(\lambda,T) \; d\lambda \qquad (2)$$

Linear plots of the logarithm of the signal vs time are expected and observed for all the liquids studied (see Figure 2). The brightness temperature can be derived from these plots independently of the peak measurement. Although there is more scatter

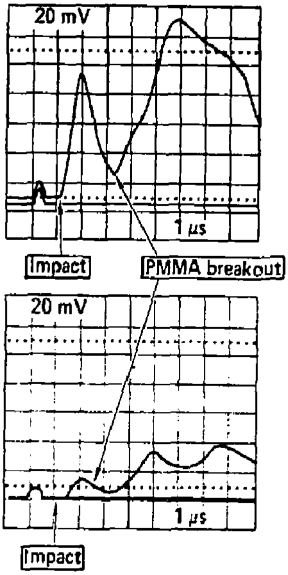

Fig. 4. Oscilloscope traces from two PMMA experiments (2-5.5 μm band)

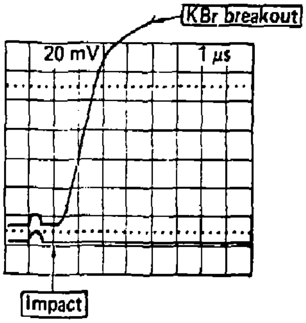

Fig. 5. Pressed KBr radiance history (4-5.5 μm) for 10.9 GPA.

in the data, results are generally in agreement with the peak temperatures. This indicates that our assumption that $\alpha_1 d \to \infty$ is correct and that our derived temperatures are the true temperatures within experimental random error. For nitromethane shocked to less than 7.0 GPa the near coincidence of the results for Bands 1 and 2 supports the above conclusion. For the 7.4 GPa experiments, non-resonant emission from reaction products is postulated to explain the sharp divergence of the two brightness temperatures.[3]

The results for polycrystalline KBr typified by Figure 5 can be explained by assuming that $\alpha_1 d$ is very small (optically thin) and α_2 is nearly zero. Again, if we expand the exponential and use an average value $\alpha_1 = \bar{\alpha}_1$, under the assumptions under which equation (1) is valid, equation (3) describes this case for the early part of shock travel.

$$S(t) = \alpha_1 d \int_{\Delta\lambda} W^{bb}(\lambda,T)\,d\lambda \qquad (3)$$

where

$$d = (U_s - U_p)t.$$

One must explain of the origin of the optical radiation in KBr, which is perfectly transparent in this wavelength range. The results are consistent with the emission from impurities situated near inhomogeneities which are heated to higher temperatures than the bulk KBr.

Finally we turn our attention to the PMMA results of Figure 4. It is not surprising that the two adjacent 600 grit polished surfaces result in a large radiance spike near impact due to intense heating, but elimination of this gap by using a film of silicone grease also greatly reduces the radiance following the PMMA-KCl breakout. For these experiments the time of PMMA-KCl breakout corresponds approximately to the arrival of the rarefaction at the Al-PMMA interface. Therefore, the large signal increase commencing at PMMA breakout time in the upper part of Figure 4 could be the result of some phenomena associated with this rarefaction in material damaged by the initial impact. Imbedded thermocouple[6] and copper foil[7] temperature measurements on shocked PMMA exhibit large changes in the 2 to 4 GPa range which the authors ascribe to chemical reaction in the shock-compressed material. There is no indication of reaction from the infared emission histories. Exothermic chemical reaction would most probably result in large signals before the shock breaks out of the PMMA, as in the case of nitromethane above 7.0 GPa. Although peliminary, these data indicate the extreme care to be taken in data interpretation when introducing inhomogeneities even at moderate shock amplitudes.

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