Freesurface light emission from shocked Teflon

Kathleen G. Gallagher, Wenbo Yang, and Thomas J. Ahrens

Citation: AIP Conference Proceedings **309**, 1551 (1994); doi: 10.1063/1.46380
View online: http://dx.doi.org/10.1063/1.46380
View Table of Contents: http://scitation.aip.org/content/aip/proceeding/aipcp/309?ver=pdfcov
Published by the AIP Publishing

FREE-SURFACE LIGHT EMISSION FROM SHOCKED TEFLON

Kathleen G. Gallagher, Wenbo Yang, and Thomas J. Ahrens
Lindhurst Laboratory of Experimental Geophysics
Seismological Laboratory
California Institute of Technology
Pasadena, CA 91125

Shock initiated light emission experiments were performed on Teflon shock loaded to pressures up to ~17 GPa. Radiances up to 600 x 10^6W · m^{-2}/(ster · nm), were measured over a range of 390 to 820 nm. We have measured the spectra of light emitted upon reflection of the shock at the free surface and observed it to be distinctly non-thermal in nature. The light emission appears to result from bond destruction such as observed in shock recovery experiments on Teflon and in quasistatic experiments conducted on other polymers.

INTRODUCTION

Although shock wave propagation in polymers has been well studied [1-5], the light emission from shocked polymers has not. The equation of state of polytetrafluoroethylene (teflon) has been studied to 80 GPa by Morris et al. [2] and there is some evidence that other polymers exhibit breakdown into radicals upon shock loading and subsequent isentropic release. The present series of experiments was an exploratory study to try to understand the nature of the radiation emitted by shock loading a polymer. Three types of experiments were conducted.

The first type used high speed framing camera photography, to determine if photons were emitted as a result of shock-induced cracking or shear processes. This type of light emission was previously observed upon driving shock waves, with amplitudes in the ~ 10 GPa range, into crystalline and amorphous dielectric materials (e.g. NaCl, $CaCO_3$, and SiO_2 (amorphous and crystalline)) [6-10]. These experiments demonstrated that resulting irreversible deformation is largely localized about defects, giving rise to heterogenous optical radiation. The zones of high deformation which induce optical thermal radiation are called shear bands. These typically radiate as black bodies with temperatures constrained by the local melting point at the shock pressure achieved.

The second type of experiment was to determine when and where the radiation came from within the sample. The opacity of the sample at high pressure and the spectral radiance of the light emission were difficult to predict á priori, therefore, time-resolved streak camera imaging was conducted. Specifically, we wished to determine how close to the front surface of the sample the shock wave had to be before a measurable amount of light was emitted. We noted from one experiment that the absorption coefficient in the visible range for teflon was $\lesssim$10 mm^{-1}. The third type of experiment determined the nature of the spectrum of the emitted light. For this the spectrum was averaged in time over the entire light emitting event. However, we will show that the event was at most ~24 ns, so the average time was much smaller than the thermal diffusion time in teflon. Emission spectra can be used to determine whether or not radiation is thermal in origin, and if so, the temperature of the thermal radiation. For non-thermal radiation such spectra may be useful in identifying the source of characteristic radiation.

EXPERIMENT

The teflon (polytetrafluoroethylene) 12mm diameter extruded rod (Furon Corp., Anaheim, Ca.) had a bulk density of 2.171 ± 0.009 g/cm^3. The Archemedian density was 2.1678 ± 0.0074 g/cm^3.

Shock loading was conducted using impact of gun-launched 18 mm diameter 2.5 mm thick 304 stainless steel, tantalum and tungsten flyer plates at 1.25 to 1.74 km/sec inducing shock pressures of 8 to 17 GPa (Figure 1). Morris et al.'s data were used to calculate shock pressures using the impedance match method.

Three types of measurements were conducted to characterize light emission:

1. Framing camera imaging of light emission during shock propagation through samples 3 mm thick, was attempted. However, because of the $\lesssim$10 mm^{-1} absorbance (Figure 2) of samples, the duration of the observable flash was too short to easily capture it with 20 nsec exposures.

2. Streak camera imagery (Figure 3) conducted demonstrated that a highly visible flash occurred when shock arrived at the free surface. The 4.0 mm diameter circular image of the target observed was smeared in time by only ~0.5 mm. Using the 21 mm/μsec streak camera writing rate, implies a light flash duration of only ~24 nsec. Because the total shock propagation in the sample is 700-800 nsec, depending on shock pressure, the lack of observed imagery with the framing camera is explained

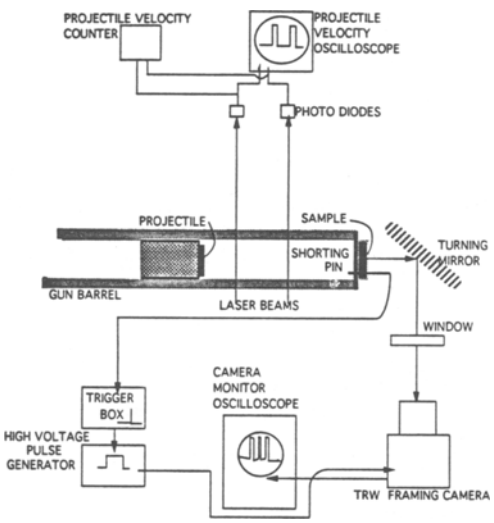

Figure 1. Experimental configuration for framing or streak camera recording of light emission from shocked teflon.

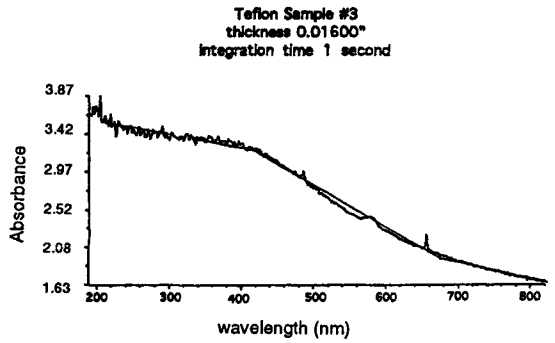

Figure 2. Absorbance versus wavelength for 0.34 mm thick teflon sample. Solid curve represents approximation used in calculations.

by the short light flash duration.

3. Optical multichannel analyzer recording of the spectra of the light emitted close to the time shock waves were internally reflected within the teflon samples. Notably, for one shot, when a steel shim was placed on the free surface of sample, essentially no light was recorded, demonstrating that the source of light was the sample and not shocked residual air in the vacuum chamber.

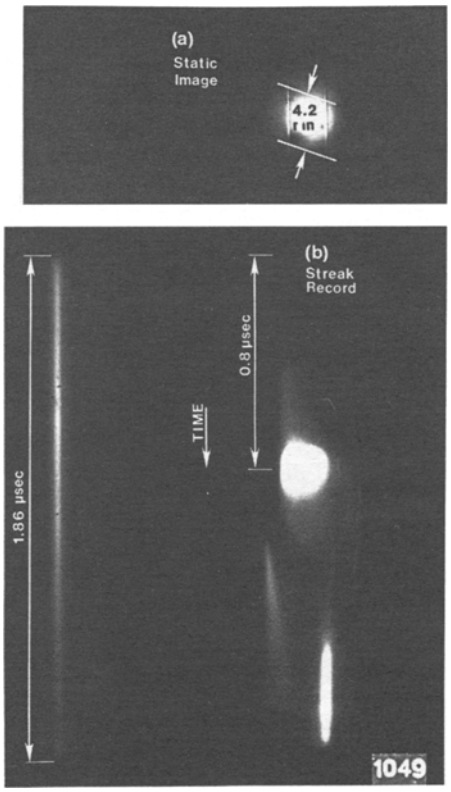

Figure 3. (a) Streak camera static image of 7.5 mm aperture in teflon shock experiment. (b) Streak camera record from Shot #1049 showing flash, corresponding to arrival of shock @ ~0.8 µsec.

RESULTS

In conducting the spectral analysis, we set the ~300 nsec time window of the pulse controlling the PARC optical multichannel analyzer instrument to be centered on the expected time of the shock arrival at the teflon free surface. The spectral analysis of the light emitted at the free surface was corrected for the attenuation of light due to the absorptivity of teflon, and then was fit to the Planck radiation law of the form:

$$R = \frac{\varepsilon C_1}{\lambda^5 \left(e^{C_2 / \lambda T} - 1 \right)}$$

where R is the spectral radiance, ε is emittance, T is temperature, λ is wavelength, and C_1 and C_2 are constants with values $1.191 \times 10^{-6} Wm^2/ster$ and 0.01438mK. For shot number #1052 (Fig. 4) the best fit temperatures and emissivities are T = 5857K and $\varepsilon = 1.17 \times 10^{-6}$.

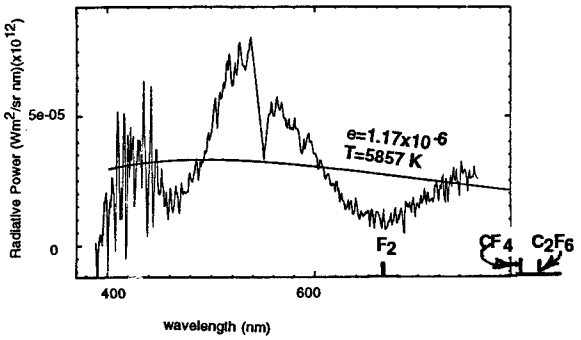

Figure 4. Absolute emission spectra from shot #1052, 15GPa. Parameters of fitted greybody curve is shown. The downward spike at 450nm is an artifact of the vidicon gating system. Vertical lines at lower axis represent expecter positions of spectral peaks from gaseous species.

For these values we assume that the emissivity is occurring over the entire 300 ns of the gate pulse of the PARC optical multichannel analyzer. This is an overestimate because the flash duration was shown in the streak experiment to be on the order of 30 nsec. Hence, the above values of ε should be corrected upward to as much as a factor of 10. Even allowing for this, the values of ε are still much less than unity. In addition, Morris et al. [2] estimated the values of the continuum shock temperatures in teflon shocked to 17 GPa to be only 800 K to 900 K, which is less than one sixth that inferred here even allowing the extremely untenable values of ε observed. For these reasons and the fact that the curve is not shaped so as to fit well to a Planck function lead us to the conclusion that the radiation is non-thermal.

DISCUSSION

Charged particle emissions from a wide variety of materials under a wide variety of conditions have been previously observed in both metallic and insulating elements, and both organic and inorganic, as well as polymeric dielectrics [11-13]. The conditions of observation were both plastic and brittle deformation, as well as both quasistatic and dynamic loading. The emissions have included both electrons and positive ions as well as photons ranging in energy from the optical (1 ev) range up to x-rays at 10^4ev.

In the case of teflon, dissociation appears likely as under quasistatic conditions, photodissociation has been observed upon heating to 10^3K. Shock recovery experiments reported by Morris et al. [2] indicate carbon is a residual phase with evidence of gaseous products including CF_4 and C_2F_6, as well as more complex species. Reactions among these species may induce some or all of the photons observed in the present experiments. Moreover, radiation from recombination of electron states in the solid state is observed upon quasistatic loading of polymeric substances such as polyethylenes. However, the gaseous species of elements and fluorine carbides all have ~5mm wide radiation bands, much narrower than ~50 - 100mm bands observed as in Figure 4. Also, none of the emission lines are consistant with the wavelengths of the observed radiation. Therefore, it is more probable that the radiation comes from the depolymerization of teflon into radicals. However, virtually all previous measurements of photon emission of deforming solids are less quantitative than the present study regarding both the photon flux and the energies of the photons.

ACKNOWLEDGMENTS

The experimental assistance of M. Long and D. Wickes and the helpful technical comments of Dr. L. Zernow are appreciated. The teflon sample material was donated by the Furon Corp., Anaheim, CA. Research was supported under ZSC-90-001-(3005), ARO-DAAL03-89-C-0005.

REFERENCES

[1] R.G. McQueen, S.P. Marsh, J.W. Taylor, J.N. Fritz and W.J. Carter, in *High-Velocity Impact Phenomena*, R. Kinslow (eds.), Academic Press, New York, 1970, p 249-419.

[2] C.E. Morris, J.N. Fritz and R.G. McQueen, *J. Chem. Phys.*, 80, p 5203-5218 (1984).

[3] A.R. Champion, *J. Appl. Phys.*, 43, p 2216-2220 (1972).

[4] L. Davison and R.A. Graham, *Phys. Rep.*, 55, p 255-379 (1979).

[5] R.A. Graham, *J. Phys. Chem .*, 83, p 3048-3056 (1979).

[6] D.E. Grady, *J. Geophys. Res.*, 85, p 913-924 (1980).

[7] K.-I. Kondo and T.J. Ahrens, *Phys. Chem. Minerals*, 9, p 173-181 (1983).

[8] D.R. Schmitt and T.J. Ahrens, *J. Geophys. Res.*, 94, p 5851-5871 (1989).

[9] D.R. Schmitt, T.J. Ahrens and B. Svendsen, *J. Appl. Phys.*, 63, p 99-106 (1988).

[10] D.R. Schmitt and T.J. Ahrens, *Geophys. Res. Lett.*, 10, p 1077-1080 (1983).

[11] S.C. Langford, J.T. Dickinson and L.C. Jensen, *J. Appl. Phys.*, 62, p 1437-1449 (1987).

[12] V.A. Zakrevskii and V.A. Pakhotin, *Sov. Phys. Solid State*, 20, p 214-218 (1978).

[13] A.G. Lipson, V.I. Berkov, V.A. Klyuev and Y.P. Toporov, *Sov. Tech. Phys.*, 12, p 536-537 (1987).