REACTION ZONES AND CONDUCTIVE ZONES IN DENSE EXPLOSIVES

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Abstract. A technique is developed to measure the electrical conductivity profile behind the detonation front in dense high explosives. The resolution is better than 0.1 mm. The measurement range is extended for more than an order of magnitude compared with the previous realizations. In pressed RDX, HMX and PETN the conductivity peak is found of several Ohm^{-1}cm^{-1} in amplitude and 40–70 ns wide, which correlates with data on the reaction zone thickness. The peak is followed by a "tail", with several times lower conductivity.

INTRODUCTION

The reaction kinetics of detonating high explosives (HE) is an object of interest for decades. Often contradicting results are reported concerning the reaction zone width and the profiles of the parameters within this zone. This situation is natural since the problem is one of the most difficult in detonation physics. The high reaction rate imposes strict requirements for the experimental resolution. But the aggressive nature of the detonation prevents use of small-scale gauges. Some optical methods seem to avoid this trap but they involve an interaction of the reaction zone with window material which is likely to affect the process. Thus, the development of alternative approaches is needed. In this paper, a measurement procedure of electrical conductivity distribution and the results obtained are presented.

In 1947, unexpectedly high conductivity was found behind the detonation front.[1] Early studies showed that the conductivity may vary in much wider range as compared with the mechanical parameters such as flow velocity or pressure.[2,3] So the conductivity method is, potentially, more sensitive. The conductivity reflects the chemistry not "converted" into mechanical variables. This is an advantage but, on the other hand, may introduce uncertainty, i.e. from some by-product not crucial for the energy release. A "quasi-equilibrium" mechanism was also suggested, in which the ionization is governed mainly by thermodynamic conditions.[4] Nevertheless, also in this case the reaction zone may rise against the low-conducting background. The experiment only can clarify whether the conductivity diagnostics are useful in reaction zone studies.

At most, previous experiments had poor resolution and gave qualitative information at best. Acceptable resolution was achieved using the differential cell.[3] But, rather low conductivity (fractions of Ohm^{-1}cm^{-1}, typical for loose-packed explosives) could be measured. The role of such an important parameter as the initial density was unknown.

We present here a modified differential method which has good resolution and is quite reliable for dense HEs. The results are given for three HEs which do not produce much carbon soot: RDX, HMX and PETN. Some preliminary results were published.[5]

EXPERIMENTAL PROBLEMS

To examine the detonation wave structure, one has to scan the conductivity with at least submillimeter resolution. Only contact methods may fit this goal. Several factors complicate such experiments.

The most obvious problem is the current spreading. When conducting medium contacts the electrodes, a finite region is connected instantly. The resolution is typically determined by the electrodes dimensions.[6] But thin conductors are not practical. Sub-millimeter "scars" are found on the metal surfaces contacted with detonating HE. So, the electrode diameter should not be less than 1 mm for the controlled geometry. Similar restrictions for the resolution follow from gas-dynamic phenomena like reflection of the wave from electrodes.

The spreading occurs even in the uniformly conducting medium. More subtle effect arises from the non-homogeneity. The electric potential distribution is governed by the equation[3]

$$\nabla^2\varphi + \frac{(\nabla\sigma\nabla\varphi)}{\sigma} = 0\,. \tag{1}$$

Electric field component along the conductivity gradient produces the space charge with density of $(\nabla\sigma\nabla\varphi)/(4\pi\sigma)$. Since the field distortions depend on the σ distribution, the characteristic length of the conductivity changes is a limit for the resolution.

Difficulties considered above affected results of most authors.[1,2,4,7] Simple cells can be used if the conductivity changes are slow enough.[6] The differential cell may have sub-millimeter resolution.[3] An improved cell of such type is described below.

EXPERIMENTAL PROCEDURE

The coaxial conductivity cell used is shown in Figure 1. An explosive charge of b = 8 mm in diameter was pressed into copper casing of 40 mm in diameter. Parts 1, 2 of this outer electrode had a threaded connection. The axial copper electrode 3 (c = 2 mm in diameter) was mounted in the PMMA plug 4, held by the hollow bolt 5.

The outer electrode had a chamber containing the conductivity gauge 7 – a toroidal coil. The mutual inductance M between the gauge and the chamber contour was about 15 nH. Thin slit connected the gauge chamber and the coaxial. The slit width was fixed by the dielectric layer 6 (0.3 mm Teflon or 0.3 ÷ 1 mm PMMA).

As soon as the detonation reaches the axial electrode, the cell becomes conductive. The current flow around the gauge chamber produces the magnetic flux in the coil and the gauge voltage pulse. When the detonation front passes the slit, the current is switched directly to the electrode 2, the chamber current and the magnetic flux decrease and the second peak of the coil voltage U arises, of inverse polarity. This second $U(t)$ pulse is, in essence, the conductivity in the slit plane:[3]

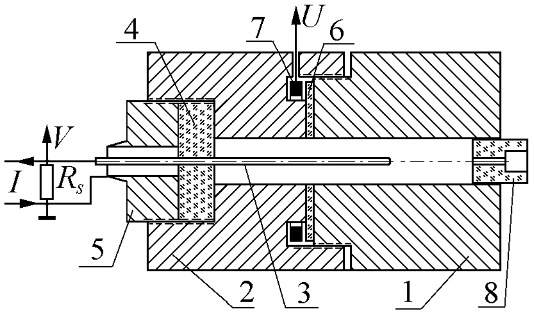

FIGURE 1. The sketch of the experimental cell.

$$\sigma(x) = \frac{\ln(b/c)}{2\pi DM}\frac{U(t)}{V} \tag{2}$$

Here $x = Dt$ is the distance the detonation front moved after the slit at a time t, D is the detonation velocity, V is the voltage between the electrodes produced by the feeding current I through the shunt R_S and the charge connected in parallel. The current source was a capacitor C (100 μF, 1000 V), acting through a limiting RL-circuit. The source was connected up ≈ 30 μs before igniting the detonation.

Actually somewhat different voltage U_{in} is observed due to the coil inductance $L \approx 1$ μH; the corrected voltage in (2) is $U = U_{in} + (L/R)dU_{in}/dt$, here R = 50 Ohm is the input oscilloscope impedance. Since the signal derivative is needed, the experimental record was spline-smoothed to get rid of the small-scale noise yet keeping the main dependence.

The current spreading is suppressed in the cell shown in Figure 1 because the conductance of well-defined volume is measured (between the wave front and the slit plane). Since the electric field is perpendicular to the conductivity gradient almost everywhere, the space charge is also negligible, see (1). The cell also minimizes the gas-dynamical disturbances. Thin slit causes weak rarefaction while most other methods involve strong reflected shocks.

The resolution of the method is about a quarter of the slit width.[5] Numerical simulations of the current flow in the cell confirmed this estimate. For 0.3 mm wide slit the resolution is 0.075 mm.

The advantage of the present strictly coaxial setup is extremely low inductance L_c of the chamber contour (less than 1 nH). The old scheme had an external measuring contour (short wire) of about 50 nH inductance[3]. Thus, the range of the measured conductivity is extended up to ≈ 10 $\mathrm{Ohm^{-1}cm^{-1}}$ as against fractions of $\mathrm{Ohm^{-1}cm^{-1}}$. The restriction is caused by the parasite voltage $L_c dJ/dt$ producing bypass current in the conducting medium across the slit. Similar low-inductance configuration was used by Tasker et al. but in plane slab geometry.[8]

The explosive was pressed by 5 mm increments, the slit being near the middle of one of these portions. 2 to 4 shots were done for each HE density. As a rule, the charge uniformity was better at higher densities. The charges were initiated by an electrodetonator through a PMMA stopper 8 (Figure 1) having an axial channel (2.4 mm in diameter) filled with RDX. Thus, the main charge was ignited within 1.2 mm from the axis. Estimations involving an optical model of detonation propagation give the deviation of the front from the slit plane (40 mm from the ignition point) below 0.24 mm. Actually this deviation was much less due to more symmetric initiation and heavy walls. The scattering in peak widths was about 0.05 mm. The explosives studied detonate quite reliably in 8 mm diameter even without confinement. In a thick copper casing the detonation was all the more stable.

MEASURING AND DATA PROCESSING

The typical experimental record for pressed PETN is shown in Figure 2. The negative U signal (upper channel) at about 0 μs is produced by the starting current when the detonation front reaches the axial electrode. This first peak was used to calibrate the coil directly during the shot. For constant feeding current, the proportion

$$M(V_0 - V) = R_s \int_0^t U dt$$

could be used. Actually, during the experimental time interval, the voltage at the capacitor C was effectively constant, while the current slightly changes. The limiting inductance L_b was rather large (≈ 15 μH), and the limiting resistance R_b was not as high (≈ 17 Ohm). Thus, the outer circuit was important, and more complex equation was solved:

$$M(R_b + R_s)(V_0 - V) = R_b R_s \int_0^t U dt +$$
$$+ L_b R_s U + M L_b \, {dV}\big/{dt}.$$

Varying the parameter M, the best agreement between calculated and measured $V(t)$ dependencies was sought. The $V(t)$ record was matched within the line thickness, and the error in M was less than 1%.

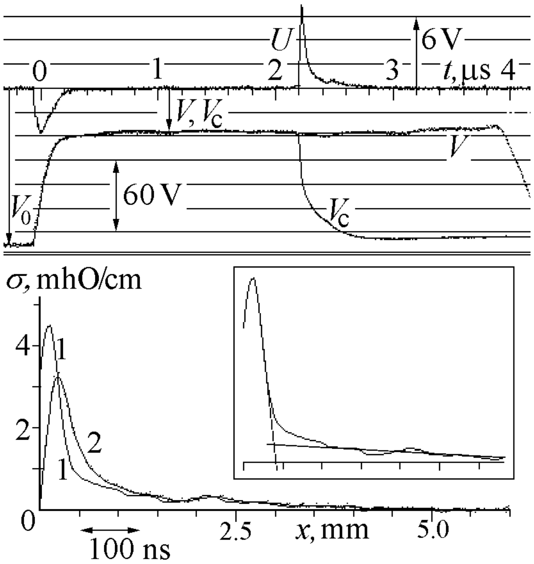

FIGURE 2. Top: experimental records (U and V) for PETN at initial density of 1.59 g/cc. V_c is a calibrating curve. Bottom: electrical conductivity profile (curve 1) and the profile deformed by the coil inductance (curve 2).

The main coil signal U begins at 2.2 μs. Since its polarity is opposite to that of the first peak, the calibrating curve goes aside the $V(t)$ record as soon as the wave passes the slit (this branch is marked as V_c in Figures 2–5).

Ideally the calibrating curve should return to the V_0 level, which means that the first and second U peaks have equal areas. One can see that a rather accurate return occurs indeed. So, the possible errors from the coil cavity deformations are small. In some experiments the V_c return was not complete, e.g. due to the slit closing (see below). The moment of closure was quite clearly seen, and in such cases the part of data after closing was disregarded. Note that interruption of the cell current at the charge end (starting at 3.9 μs in Figure 2) does not produce any conductivity gauge signal. Thus, the measuring contour and the feeding circuit are well decoupled.

The reference points of the signals and the known distances were used to evaluate the wave velocity D. It was always lower than the ideal detonation velocity for expected (loading) density. For example, for the shot in Figure 2, the expected density was ρ_e = 1.6 g/cc, while the measured detonation velocity 7.67 km/s corresponds to the 1.2% lower density ρ_D = 1.581 g/cc assuming ideal detonation.[9]

For PETN, a correlation $\rho_D = 0.982\rho_e$ was obtained. The origins of difference may be explosive losses during pressing and the wave attenuation due to the expansion of outer electrode. The actual HE density was found to be between ρ_e and ρ_D, the more definite conclusions were not possible because of the limited weighing accuracy of small charges in a heavy casing. Below, the true initial density ρ is assumed to be $(\rho_e + \rho_D)/2$; the error of such definition is less than half the difference between ρ_e and ρ_D (≈ 1% for PETN). For the shot shown in Figure 2, the estimated $\rho = 1.59$ g/cc.

The conductivity profile calculated from (2) is shown in Figure 2 (bottom, curve 1). The slit width was 0.6 mm (PMMA layer) so the resolution was 0.15 mm. For three HEs studied, quite non-uniform distribution was obtained. The initial peak (here 4.5 $\text{Ohm}^{-1}\text{cm}^{-1}$ in amplitude) is followed by the "tail" in which the conductivity is much lower (≅ 0.5 $\text{Ohm}^{-1}\text{cm}^{-1}$) and decays slowly. For comparison, the line 2 is shown drawn through "raw" experimental points, without coil inductance corrections. This line, essentially a scaled oscillogram, is more smooth. Below only corrected curves are presented.

The initial conductivity jump was usually 70 – 80% of total amplitude. Since the maximum was reached quite fast, its delay probably is an artifact and the real maximum may coincide with the wave front. The procedure determining the peak width is illustrated in Figure 2 (inset): an intersection of the tangent to the drop-down part of the peak and a straight line fitting the tail was found. Here, the width was 0.39 mm. Experiments with a short central wire not producing current around the slit gave no coil signal. Thus, the polarization of explosive or slit insulator was not of any importance.

RESULTS OF EXPERIMENTS

Experimental results for PETN at ρ =1.74 g/cc are shown in Figure 3. For this shot, the portions to be pressed were weighed as for density 1.8 g/cc, i.e. higher than TMD: 1.77 g/cc, to approach the latter. Note the much better charge uniformity (the $V(t)$ signal is smooth, whereas in Figure 2 small peculiarities are seen correlating with the edges of portions). The conductivity increases with the initial density, while the peak width decreases.

In the bottom of Figure 3, a calculated conductivity profile is shown. For comparison, the profile at moderate density is added (curve 2, corresponding to Figure 2). Between 1.0 and 1.5 g/cc PETN could not be pressed with acceptable uniformity. For a loose-packed PETN (≈ 1 g/cc) peak conductivity of ≈ 0.3 $\text{Ohm}^{-1}\text{cm}^{-1}$ was obtained, the tail conductivity was at least an order of magnitude less. The peak width was ≈ 0.58 mm.

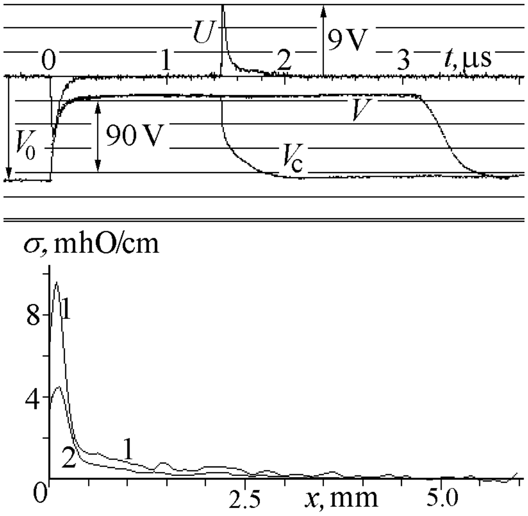

FIGURE 3. Top: experimental records for PETN at initial density of 1.74 g/cc. Bottom: electrical conductivity profiles, obtained in this experiment (curve 1) and at a smaller density of 1.59 g/cc (curve 2).

The conductivity in RDX and HMX also increased with charge density. One may note rather fast closing of the slit in RDX, especially for narrow gaps. Figure 4 demonstrates an experiment with RDX at slit width of 0.3 mm (PMMA). The main U signal falls off to zero at 2.2 μs, or 0.3 μs after the start. The calibrating curve does not return to the initial V_0 level. The closing took place in the tail part of the signal. For more thick PMMA insulator (0.6 mm) the gap is closed later. Comparison of the profiles (bottom part of Figure 4) demonstrates quite good agreement up to the moment of closing. The peaks are 0.38 mm and 0.37 mm wide, respectively. Good agreement of the profiles 1 and 2 in Figure 4 shows that the 0.6 mm slit fixed by PMMA is a reasonable choice. Most data in this work were obtained under these conditions.

In Figure 4, a profile for loose-packed RDX is included also (curve 3, gap 0.3 mm, Teflon), demonstrating rather sharp difference from the pressed explosive case. RDX was pressed uniformly enough within the range from 1.6 to 1.8 g/cc, the correlation $\rho_D = 0.953\rho_e$ was obtained.

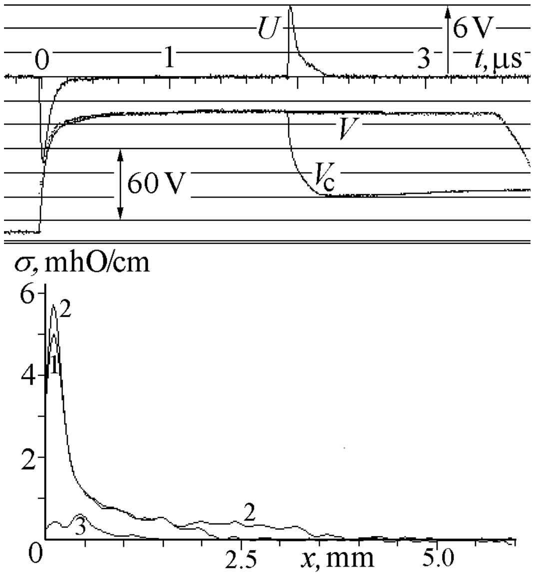

FIGURE 4. Top: shot with RDX at 1.66 g/cc. The slit width was 0.3 mm. Bottom: conductivity profiles for this shot (1), for different slit width = 0.6 mm (2) and in loose-packed RDX (curve 3).

The comparison of RDX and HMX is interesting. But the interpretation of HMX data at the highest densities proved to be quite complex. In Figure 5, two experiments with HMX are shown: at 1.75 g/cc (A) and 1.85 g/cc (B). Even visual comparison of the V signals points to the substantial difference, the denser charge having higher conductivity. But the standard processing did not confirm this, and even slightly lower peak was obtained at a higher density (compare curves A and B in the bottom).

This discrepancy can be explained by the current leak over the slit. If the conductivity around the slit is high enough, the cell current switching to the electrode 2 can be delayed thus reducing the signal. The calibrating curves in Figure 5 fail to return to the initial level, especially in the case B. In both shots, the metallic closing takes place at ≈ 2.4 µs, and before this moment both U signals exhibit quite distinct tails. One can see also that the sharp fall of the V_c curve in the case B results in a smaller jump ΔV_c than the similar zone in the case A. This means the loss of certain part of U peak. The V_c data in Figure 5 become consistent if the $U(t)$ peak area in the B case were enlarged by a factor of 1.5, i.e. the peak conductivity should exceed 10 Ohm^{-1}cm^{-1}.

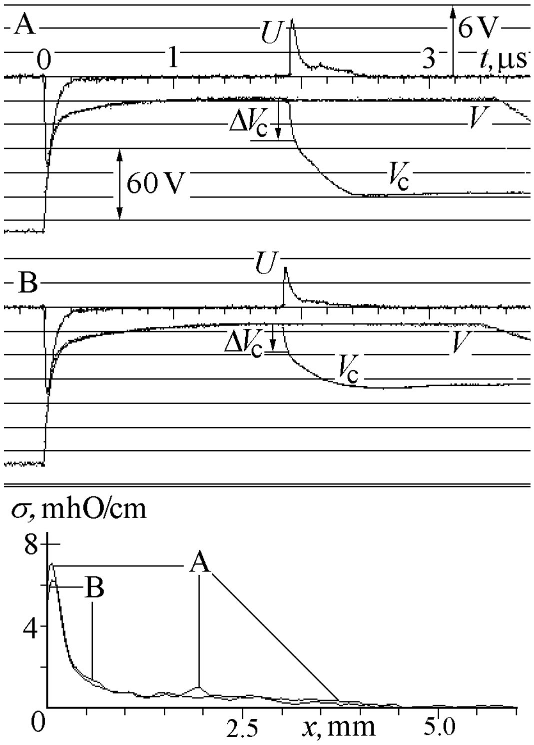

FIGURE 5. Top: HMX; A: 1.75 g/cc; B: 1.85 g/cc. The slit width 0.6 mm, insulator is PMMA. Bottom: calculated conductivity profiles.

The effect depends on the leakage resistance R_l and the gauge cavity inductance L_c. For example, instead of an instant jump the $U(t)$ will increase during $\approx L_c/R_l$ time. Later the gauge signal becomes adequate (in Figure 5B – approximately at $x \geq 0.25$ mm). The resistance over the gap is about $1/(b\sigma)$ in our conditions. For $\sigma = 10$ Ohm^{-1}cm^{-1} and $L_c = 0.9$ nH, $L_c/R_l \approx 7$ ns. If the peak width is 40 ns, ≈ 18% of its area could be lost due to the leakage. But in the experiment, much larger loss in ΔV_c was found: ≈ 33%. Besides, no leakage was observed in PETN for the same conductivity amplitude (Figure 3).

Probable factor enhancing leakage in dense HMX is an interaction of the explosive with the insulator. For instance, the mixing of the insulator with the reacting material, with local conductivity increase (in a way, partial closing), seems to be possible at the highest pressures. The character of voltage increase after completion of detonation speaks in favor of such effect (Figure 5: 3.525 µs for A and 3.4 µs for B). At a high density, the voltage V is recovered more slowly. Note that in all cases the interruption of the cell current is significantly slower than it should be were the conductivity vanishing at the charge end according to the measured profiles (compare the rates of $V(t)$ and $V_c(t)$ recovery in Figures 2–5). So, for HMX of a maximal density, the direct measurements are distorted, and the value of ≈ 10 Ohm^{-1}cm^{-1} is estimated using the complete data set. The same result for HMX at 1.8 g/cc was reported by V.V. Yakushev.[10]

The maximal peak conductivities for three HEs are plotted in Figure 6. Points are averages, the experimental scattering was about 20%.

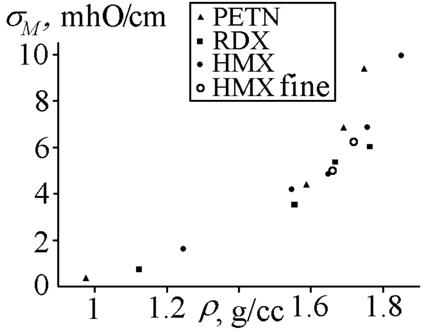

FIGURE 6. Maximal conductivity vs the explosive density.

Widths of the conductivity peaks vs the Jouguet pressure are shown in Figure 7.

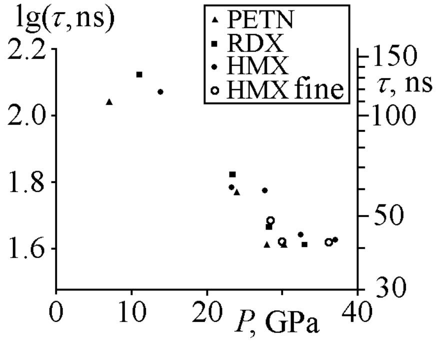

FIGURE 7. Conductivity peak duration vs the detonation pressure.

DISCUSSION

RDX and HMX have identical elemental percentages. Their peak conductivities at the same density are quite close (Figure 6). This suggests the similar medium composition within the peak and similar course of reactions. Moreover, peak conductivities in PETN are also close to that in RDX and HMX (except probably the maximal PETN density). But the peak times seem to be somewhat different, peaks in PETN being the shortest (Figure 7). Results obtained for fine HMX (~ 5 μm grain size) did not differ much from that for coarse HEs (200 – 300 μm), see Figures 6 and 7.

Reaction Zones

To compare with our results, we consider papers dealing with pure RDX, HMX and PETN, in which binders do not complicate the reaction. Dremin et al. summarized the data of large work, based on the electromagnetic method.[11] Their data differ from ours (zones are 2–4 times longer), which is of no wonder since the resolution was rather low (≈ 100 ns).[11] The initial density effect was qualitatively similar, but our dependence is less sharp.

Later fast optical methods were developed, in particular those based on the measurements of the velocity history of the interface between the explosive and inert window material.[12,13,14,15] Also, the shock front luminosity in test liquids was measured.[16,17] Front velocity of the transmitted wave was employed as well.[18] In our experiments the conductivity peaks in pressed explosives lasted 40–70 ns (see Figure 7), in general agreement with the reaction zone times obtained by optical methods. A wide range of densities was covered by Utkin et al.[14,15] The durations of interface velocity peaks (when such peaks were present) are close to our results (30–70 ns). Also agree rather well with ours the results of Loboyko et al.[16,17] (Figure 7 is an analog of their diagram).[17] In the paper of Fedorov, for pure explosives the peak was blurred by the flow pulsations (to which much of the attention was paid).[13] So, the comparison is complicated. We conclude that in the explosives studied and within our density range the reaction zone is quite close to the high conductivity zone.

At the highest densities (about 99% TMD) acceleration of the reaction was reported in many works. No chemical peak was found in agatized (pressed with acetone to ≈ 99% crystal density) HEs.[18,16] This was interpreted as dramatic narrowing of the reaction zone, under the resolution limit (about 5 ns). The peak vanished in RDX and HMX pressed with 1% acetone above 1.72 and 1.84 g/cc (but, at still higher compaction, with ordinary 10% acetone, the chemical peak was observed).[14,15] In Fedorov's work the peak persisted in agatized HEs; the time was not specified though it was apparently nanoseconds.[13] In PETN of 1% porosity no chemical peak was found at 4 ns resolution.[12]

In our experiments, the shortening of the conductivity peaks occurred gradually, including the maximal densities reached; the minimal time measured (RDX at 1.74 g/cc) was 36 ns. Certain peculiarities were observed for RDX, apparently due to the poor initiation symmetry, however all the peaks were dozens of ns wide.[5] Probably the thin zones were absent due to different charge structure. Also the real charge density might be somewhat lower (the maximal ρ_D based on the detonation velocity were 1.73 g/cc for PETN, 1.74 for RDX, 1.8 for HMX). In fact, the results of optical methods at the extremely high densities are contradictory, and further work is needed to clarify this matter.

Conductivity Nature

At present analysis of the conductivity data can be qualitative at best. In typical conditions behind the detonation front (density around 2 g/cc, temperature – several kK) all important lengths (intermolecular distance, gas-kinetic free path, inverse electron wave vector, molecular size) are roughly equal to $3 \cdot 10^{-8}$ cm. Such an exotic medium is an intermediate state for which the traditional approaches of plasma physics and of condensed media are ineffective. For instance, the “plasma-like” estimates of ionization potential lowering ΔI give about 10 eV. Such a large value approaching the typical ionization potentials of detonation products species cannot be regarded as reliable correction.

Dissociation of water may produce the ionic conductivity.[4] Water is a common part of detonation products. In shocks it dissociates notably at ≈ 20 GPa.[19,20,21] Recent experiments confirmed the ionic nature of water conductivity below 100 GPa, and demonstrated the shift to electronic conductivity above this pressure.[22] Dissociation is expected to provide the conductivity of about $1 \div 4$ $\text{Ohm}^{-1}\text{cm}^{-1}$.

To our opinion, in the explosives studied, the ionic conductivity can prevail in the equilibrium zone, i.e. within the tail (which begins just at about 1 $\text{Ohm}^{-1}\text{cm}^{-1}$ and for all HEs is more pronounced at higher density). However, the peak conductivity of $\cong$ 10 $\text{Ohm}^{-1}\text{cm}^{-1}$ does not agree with the ionic mechanism. Around 30 GPa, the water conductivity weakly depends on pressure, thus a moderate extra pressure in the reaction zone cannot explain the peak. High over-equilibrium water concentrations are hardly probable. Dissociation of some intermediate product is not a solution since the water is most perspective species producing mobile H^+ ions.

From the other hand, in non-equilibrium reaction zone a wide variety of parent molecules' fragments are present, including easily ionized ones. Since the electrons are much more mobile than ions, they can provide the conductivity at comparatively low concentrations. Besides, the associative ionization reactions are possible between intermediate products. The reaction $CH + O \rightarrow CHO^+ + e^-$ explains the non-equilibrium flame ionization[23]. The energy required for each electron is less than an ionization potential by a value of dissociation energy of the product. The endothermicity of the reaction above is about 0.35 eV.[24] At high density, this reaction may become exothermic.

Interesting possibility is an over-equilibrium free carbon in the reaction zone.[25] The carbon particles can create the peak conductivity forming conducting chains.[2] The increase of carbon yield with pressure can have some effect also in the tail zone.

CONCLUSIONS

An electrical conductivity method is developed to study detonation wave structure in dense explosives. The cell differentiates the conductance of well-defined volume at the “hardware level”. The measuring range is extended to 10 $\text{Ohm}^{-1}\text{cm}^{-1}$, and the resolution is sub-100 μm. The conductivity behind the detonation front is strongly non-uniform. The peak conductivity is of non-equilibrium nature and is produced by the chemical reaction. The peak is followed by a tail of mainly equilibrium conductivity. Peak amplitude increases with initial density while the peak width decreases. In RDX, HMX and PETN, the measured peaks widths agree rather well with the known data on reaction times.

ACKNOWLEDGEMENTS

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DISCUSSION

Allen Kuhl
Lawrence Livermore National Laboratory
Livermore, CA, USA

We measured the conductivity of the combustion products gases from shock-dispersed-field charges in shock tubes. With flake aluminium as a fuel the conductivity of the Al-air combustion cloud was a factor of ten larger than the conductivity of the TNT-air combustion cloud. Have you measured the conductivity at the detonation front for aluminized charges, and do you see the same trends?

REPLY BY A. P. ERSHOV

In detonation, aluminium also was found to increase the conductivity, see, e.g. paper of Gilev and Trubachev at preceding Symposium. We did not work with aluminized explosives as yet.

DISCUSSION

Douglas Tasker
Los Alamos National Laboratory
Los Alamos, NM, USA

How did you avoid contact errors caused by spaces between the electrodes and the explosive charge?

REPLY BY A. P. ERSHOV

There is such problem. More exactly, one should speak about the gaps between the electrodes and the pressing ram. We tried to make these gaps as small as possible. Since the explosive under pressing transmits the stress, the zones of non-perfect compaction at the boundaries between the pressing portions are about of same size as the gap. These zones are seen in experimental records as small voltage irregularities, e.g. in Figure 2. The charge as a whole was in quite good contact with the electrodes. For instance, after pressing we could not pull out the central electrode (2 mm dia. copper), it rather was torn off.

DISCUSSION

Edward Lee
Lawrence Livermore National Laboratory
Livermore, CA, USA

Are your peak values for conductivity in PETN detonation comparable to values you observe for RDX and HMX? B. Hayes found σ(peak) for PETN much lower than RDX and TNT and concluded that conductivity was associated with carbon formation. Do you find otherwise?

REPLY BY A. P. ERSHOV

Yes, our peak values for PETN were about the same as for RDX and HMX at the same density. I am not aware about Hayes's measurements of the peak conductivity in PETN and RDX. In his paper cited above, the conductivity profiles for TNT and Composition B are presented while for PETN only integral conductance was found[2]. But you are right that in TNT the conductivity is much higher than in PETN and it is a consequence of high free carbon release. Our experiments confirm this observation[6]. However, in reaction zones of PETN and other explosives with low carbon content the principal origin of conductivity may be different.

DISCUSSION

Yehuda Partom
RAFAEL
Haifa, Israel

Do you know anyone who tried to relate chemistry to electrical conductivity?

REPLY BY A. P. ERSHOV

At present, there are attempts, more or less successful, to relate the conductivity with the composition for quite simple systems, e.g. hydrogen is shock waves. Such complex medium as the reacting dense explosive cannot be properly analyzed thus far. So, the relation which you mentioned may be expected in future.

DISCUSSION

Richard J. Lee
Indian Head Division, NSWC
Indian Head, MD, USA

I have measured conductivity profiles, using your method, in aluminized PBXs. The conductivity was much lower when aluminium was added. The conductivity began to increase at later times behind the detonation front. This is the reverse of Allen Kuhl's observations with aluminized TNT. (He saw higher conductivities when aluminium was added to TNT). However, I do not see any contradiction between our separate observations from the perspective of carbon concentration. I believe that the technique of measuring conductivity profiles can be useful to monitor aluminium oxide melting and aluminium combustion in the detonation products.

REPLY BY A. P. ERSHOV

Of course, the aluminium effect depends on the quantity of Al added. My preceding answer to A. Kuhl was related to high Al concentrations, when direct contact conductivity mechanism prevails. For smaller concentrations, no published data are known to me, so your observations are quite interesting. As for using the conductivity measurements to monitor the Al interaction with the explosive, I think you are right.