Exploring the Insensitive PBXs Allowing the Higher Performance of Inertial Confinement: European Defense Agency' Research and Technology Project *"RSEM-HPIC"*

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"2010-IMEMTS": Insensitive Munitions and Energetic Materials Symposium, October 11-15 2010, Munich, GERMANY

ACKNOWLEDGEMENT

Experimental efforts on kinetic localizations spatially resolved measurements in PBXs were supported by the Office of Naval Research under the ONR Grant No 0014-08-1-0096 with Dr. Clifford Bedford as Program Manager.

Experiments with the RS-PBXs were conducted in terms of the WEAG Research Program ERG-114.009 “Particles Processing and Characterization”.

Authors address acknowledgements to Drs. Paul Wanninger and Helmut Muthig for opportunity to present our contribution at 2010-IMEMTS

Scope of Presentation

1. **EDA "RSEM-HPIC": GENERAL OBJECTIVE & EDA/MoDs RELEVANCE**
2. **Concepts for designing PBX: "Maximum paking HE particles" vs. "Minimum Kinetic Desequilibrium in the DRZ 3D-structure"**
3. **Oscillating Instabilities/Local Perturbations in the PBX-driven liner and cumulative jet – <u>As a courtesy</u>: LLNL Shaped Charge**
4. **Instrumentation of small-scale Detonation Perfomance & Shock Initation Tests with the Multichannel Optical Analyzer - MCOA**
5. **DRZ Quality vs. Kinetic Equilibrium of PBX Components. Poorly-equalized and well-equalised DRZ structures spatially resolved in PBX detonations**
6. **Kinetic non-equilibrium at detonation conversion: meso-scale probing coarse HMX particle vs. "dirty binder"**
7. ***Effect of the kinetic non-equilibrium between the coarse HMX particles and "dirty binder"* on the DRZ homogeneity**
8. **Effect of the reaction localizations on the shock performance of PBX-driven copper-liner & cumulative jet**

EDA “RSEM-HPIC”: GENERAL OBJECTIVE & EDA/MoDs RELEVANCE

The specific goal is addressed to development and optimization of the *Reduced Sensitivity PBX (RS PBX)* formulations distinguished from the known prototypes by higher homogenicity of the Detonation Reaction Zone (DRZ) structure and consequently, lesser deterioration of the IC caused by the DRZ’ local perturbations.

For the elaboration of the higher performance RS-PBXs, a new criterion needs to be incorporated. Instead of the conventional concept “Particles Maximum Packing” generally used at designing PBX formulations, we apply a criterion of the *minimum kinetic non-equilibrium between the coarse HE crystalline particles (RS RDX, RS HMX) and mixture of the polymer binder with the fine and ultra-fine RS-HE particles* (so called *“dirty binder”*).

Application of the new, *“kinetic equilibrium”* concept will allow obtaining the RS-PBX formulations distinguished by the minor scale of reaction localizations within the DRZ that provides the higher DRZ homogeneity, quality and performance

Concept for designing PBXs: “Maximum packing HE particles” vs. “Minimum Kinetic Desequilibrium in the DRZ 3D-structure”

- “Maximum Packing HE particles” is a conventional criterion, historically applied for designing Polymer Bonded Explosives (PBX),
- Ab-initio, “Maximum Packing” criterion ignores a difference between kinetics of detonation conversion of coarse and fine HE grades mixed with binder: “Coarse HE grades” vs. “Dirty Binder” (Mel Baer, SNL)
- Ab-initio, “Maximum Packing” criterion ignores further reaction localizations occurring in the DRZ structure as a function of the kinetic non-equilibrium.
- Disclosing the spatially-resolved kinetic localizations history in the DRZ 3D-structures allows obtaining detailed information about mechanisms of reaction initiation and energy conversion in the DRZ (Refs. 3-7)
- New approach to build up a PBX is under development (Refs. 1 & 2)
- New approach is based on the criterion of the minimum kinetic disequilibrium in the detonation conversion zone

Conceptual approach: Shaped-Charge Jet Performance vs. DRZ Quality

Shock reactivity of PBX components: Coarse particles vs. "dirty binder"

Reaction localizations in the DRZ & ejecta

Impact upon the IC: Micro-perforation, over-heating, swelling and growth of oscillating instability

Impact upon the shaped-charge jet performance: swelling, over-heating, growth of local perturbations, and earlier fragmentation

Coarse HE particles, HE fine fractions + binder ("dirty binder") – all demonstrate different kinetics of shock decomposition. **These becomes much more pronounced for RS-PBXs containing the RS-RDX & RS-HMX**

Non-equilibrium between kinetics of detona-conversions results in local perturbations (LP) within the DRZ. The LP-scale exceeds in 6 times (min.) a size d_{50} of coarse HE particles. **Approximately 20% of detonation energy is localized in ejecta**

The thickness of the IC-boundary layer, wherein LPs are dissipating to heat, exceeds in 6 times (min.) a size d_{50} of coarse HE particles.

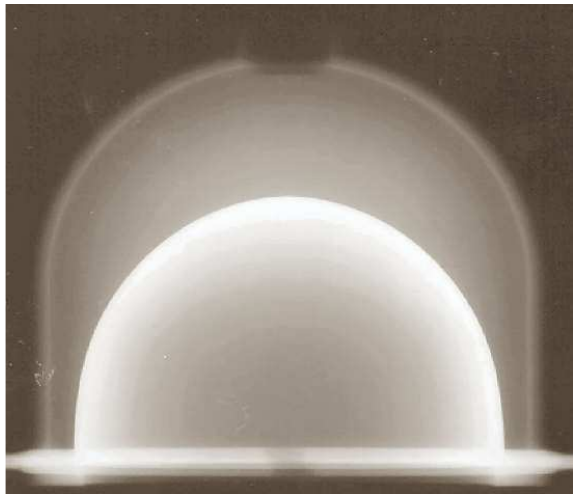
In real 3-D convergent motion of the IC, the dissipation of the DRZ-induced LPs is attended with the origination and further evolution of the oscilating instability. **The oscillating instability is a main factor suppressing a cumulation**

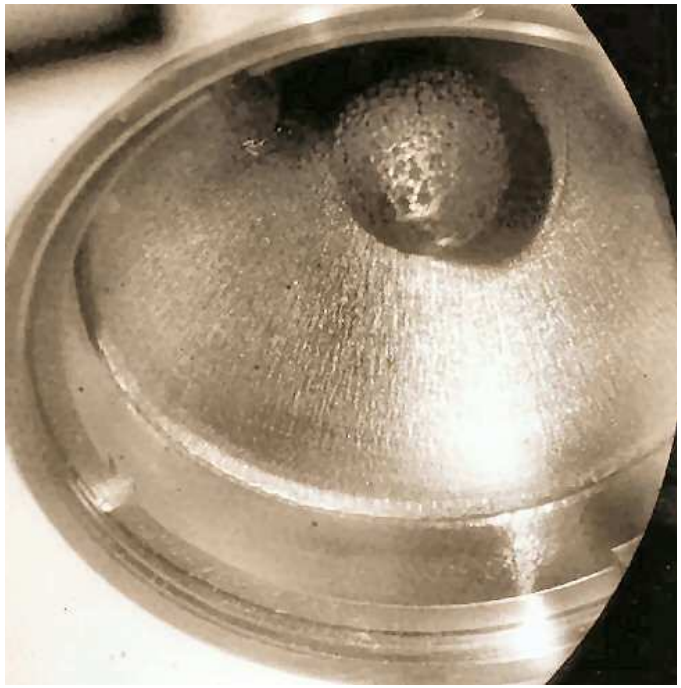
Performance of the shaped-charge jet might be enhanced through the improvement of the DRZ homogeneity.

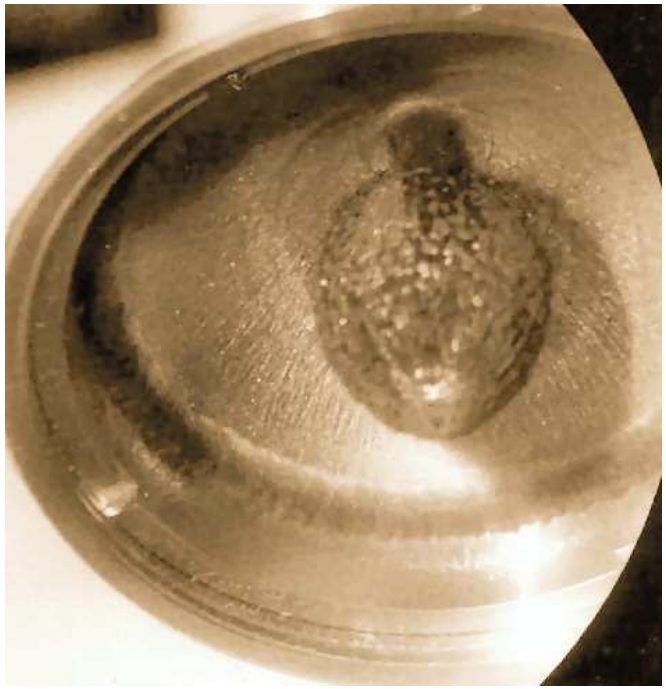
This is also true for any ICs driven by the convergent detonations

Figure 1. The relationship between the Shaped-Charge Jet Performance and the DRZ homogeneity

Jet Formation (LLNL Shaped Charge): Oscillating Instabilities/Local Perturbations Origination & Growth







<u>As a courtesy</u>: Lawrence Livermore National Laboratory, Shaped Charge Hydrotest Program, Jon Maienschein, maienschein1@llnl.gov, 925-423-1816-4/28/06- 4

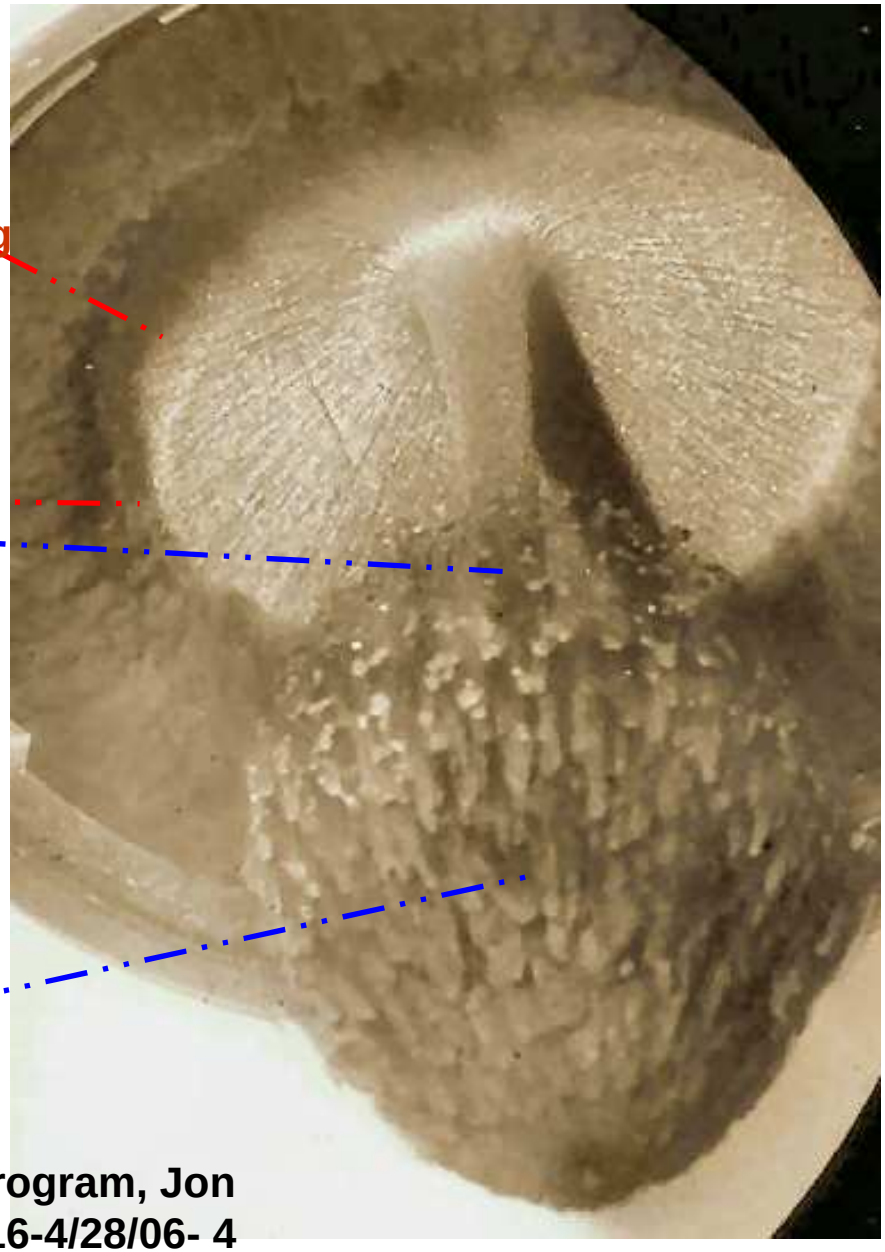
Oscillating Instabilities/Local Perturbations in the PBX-driven liner and cumulative jet

PBX-driven liner:

Deterioration, swelling & growth of oscillating instability caused by the DRZ localizations

Cumulative Jet:

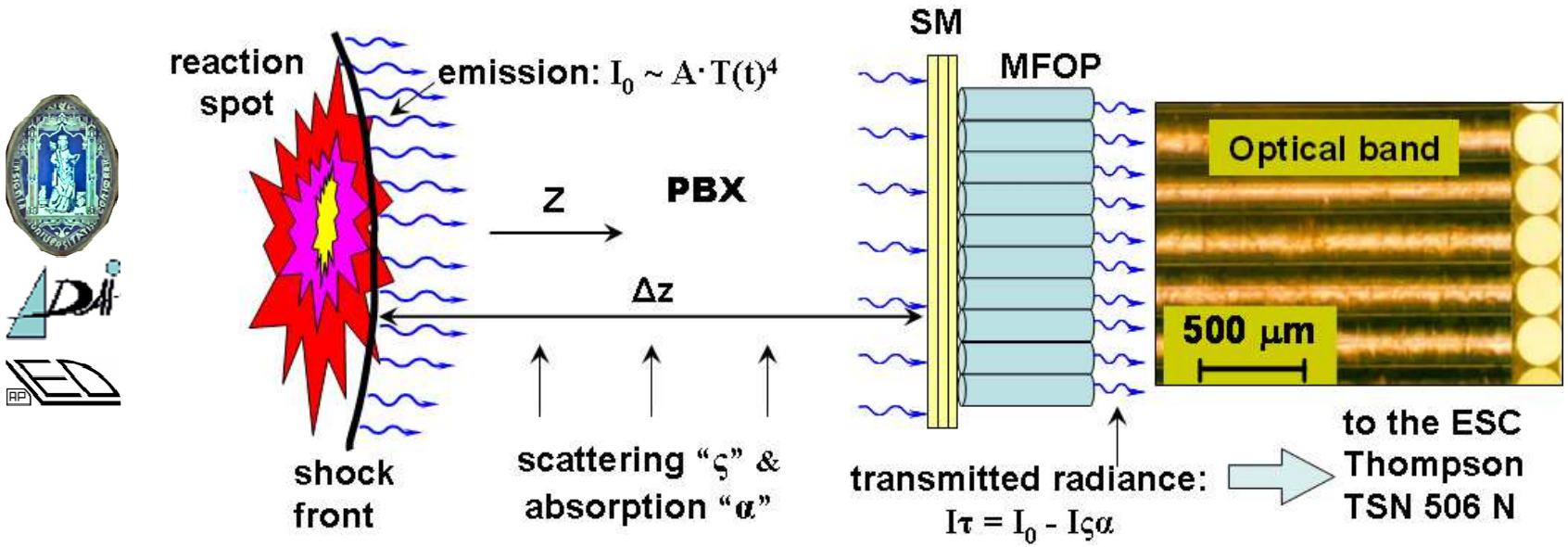
localizations / fragmentation caused by oscillating instability



As a courtesy: LLNL, Shaped Charge Hydrotest Program, Jon Maienschein, maienschein1@llnl.gov, 925-423-1816-4/28/06- 4

Multi-Channel Optical Analyzer MCOA instrumented with the Multi-Fiber Optical Probes MFOP (Refs. 3-8)

Time-resolved measurements of the detonation/reaction zone structure were performed by mean of the 96-channel MCOA [3-8]



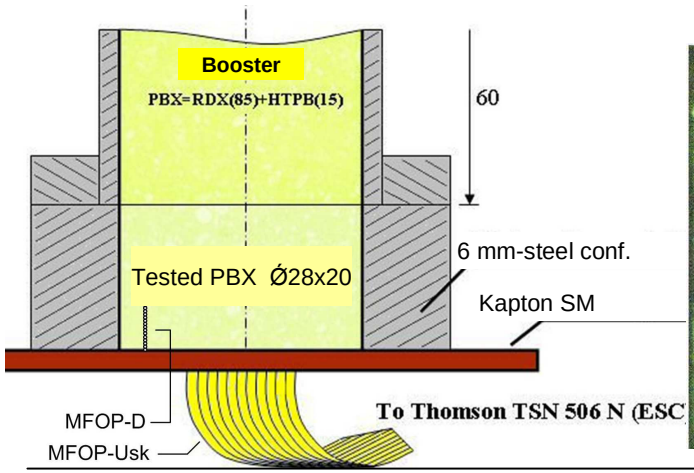
-Spatial and temporal resolution of hot spots with the 0.2 ns and 100 μm accuracy

-Kinetic parameters: ⇨ time history of reaction radiance, 450 < λ < 850nm spectrum

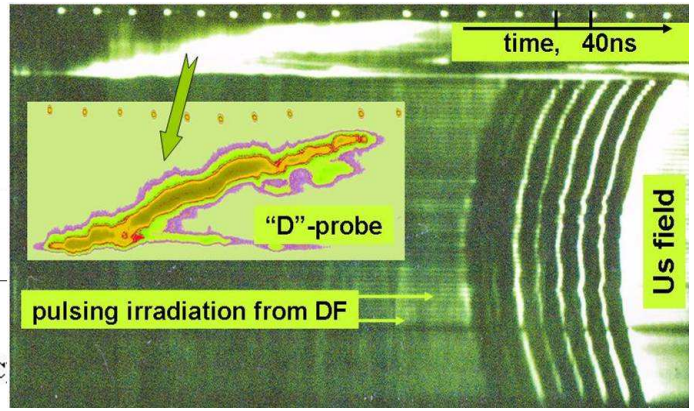
-Dynamic parameters ⇨ stress field in optic monitor

-The application of the MCOA has provided meso-scale resolution of reaction zones structure in PBX and energy localizations/dissipation history in the PBX-driven Copper-IC [1-7].

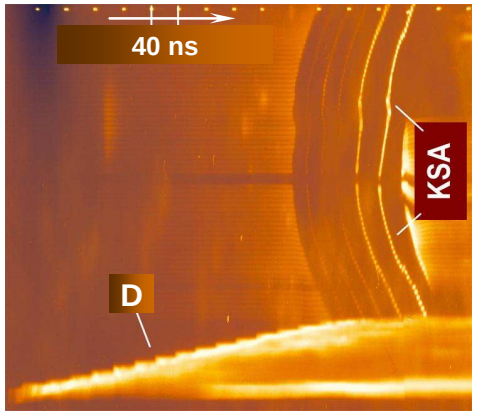
DRZ Quality vs. Kinetic Equilibrium of PBX Components



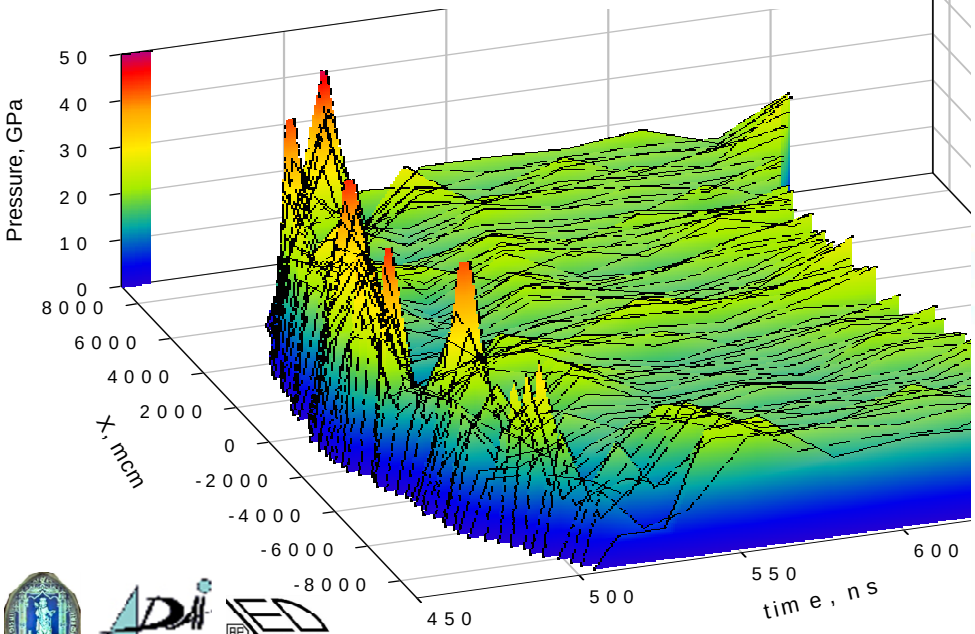
HMX Class-3 82/18 Epoxy



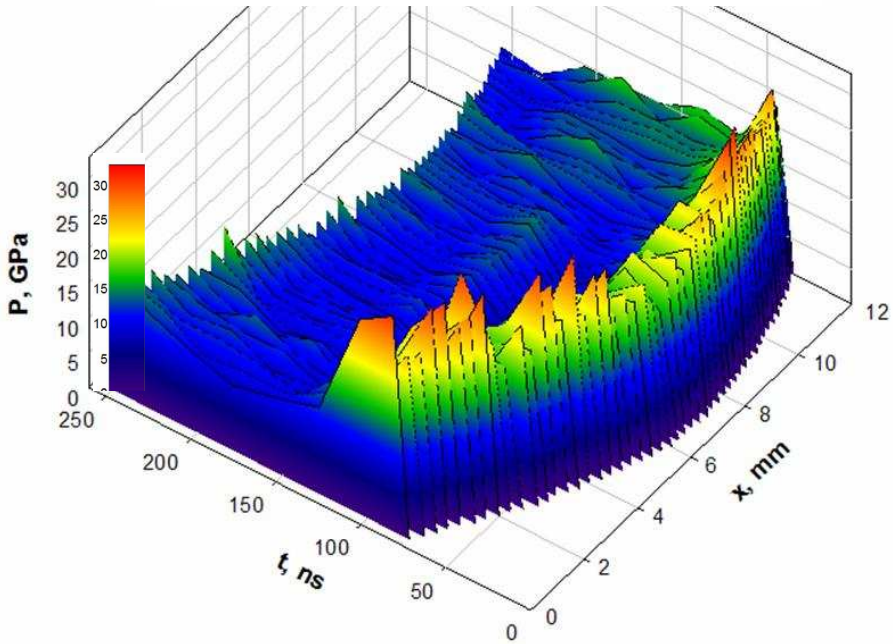
HMX Class-2 82/18 GAP



$HMX_{Class-3}$ 82/18 Epoxy (d_{50}=203.7μm): D_{mean}= 8.30 mm/μs + large scale localizations in DRZ



$HMX_{Class-2}$ 82/18 GAP (d_{50}=16.46μm): D_{mean} = 8.07mm/μs + small scale localizations in DRZ



DRZ Quality vs. Kinetic Equilibrium of PBX Components

►***Effect of non-equilibrium between reactivity*** of coarse-grained and fine-grained HMX particles-in-binder on the scale of DRZ perturbations occurring as a result of kinetic localizations

► The 3D-structures of the shock fields *{**P** (t, X)}* induced in the Kapton Stack optical Monitor illustrate:

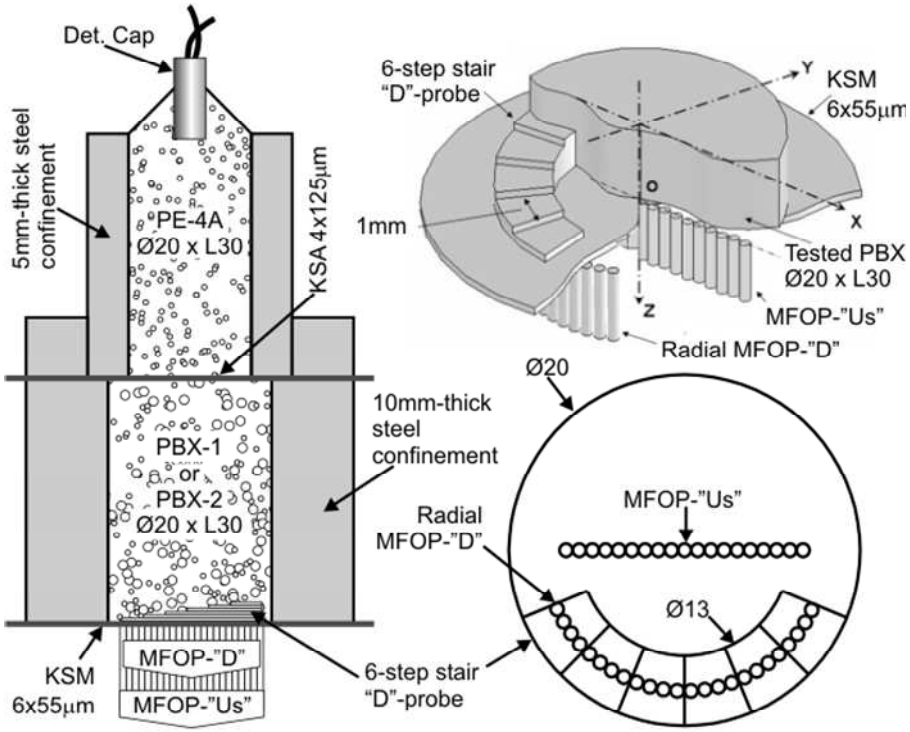
- ►strongly pronounced DRZ perturbations in the coarse-grained PBX
- ►smaller scale DRZ perturbations in the fine-grained PBXs;

► Although the coarse-grained PBX "HMX $_{\text{Class-3}}$ 82/18 Epoxy" has in ≈3% higher detonation velocity than the VoD of the fine-grained PBX "HMX $_{\text{Class-2}}$ 82/18 GAP" (8.30 mm/μs vs. 8.07 mm/μs), its DRZ contains strongly pronounced localizations, whereas the DRZ of the fine-grained composite bonded with the energetic binder GAP has much better equalized DRZ structure.

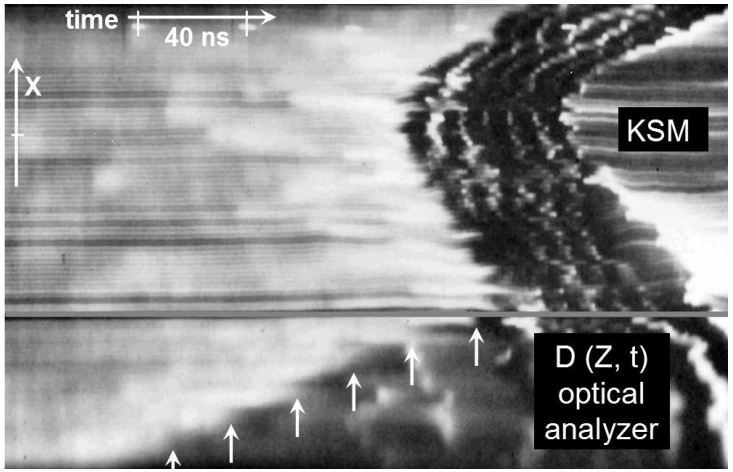
► The ratio between the scales of local perturbations within the *"kinetically worse-"* and "*kinetically better equalized"* DRZ structures, allows predicting that, in the case of shaped charges, the cumulative jet produced by the first PBX will be more perturbed and less effective than one produced by the second PBX.

Effect of the kinetic non-equilibrium between the coarse HMX particles and "dirty binder" on the DRZ homogeneity

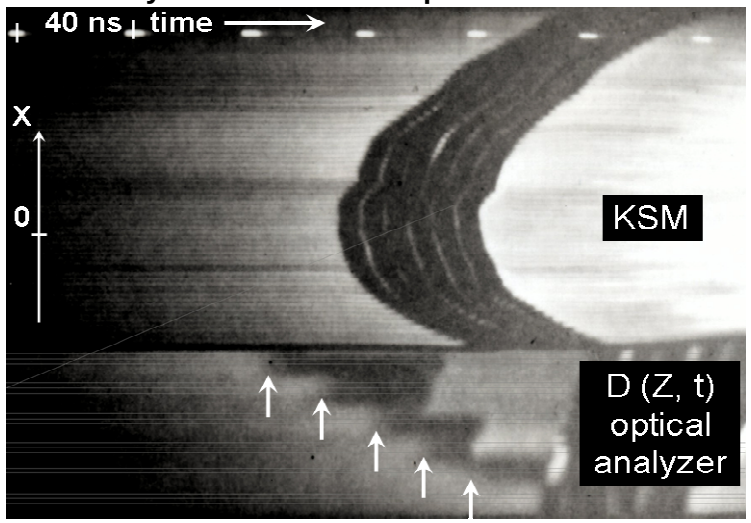
Long Charge Test for the time- & spase-resolved measurements of reaction localizations/local perturbations in the DRZ structure



Strongly pronounced localizations in the DRZ structure of the PBX-1, wherein the kinetics of the coarse HMX and "dirty binder" are not equalized



Slightly pronounced localizations in the DRZ structure of the PBX-2 (RS-PBX), wherein the kinetics of the coarse HMX and "dirty binder" are well equalized



KSM ≡ Kapton Stack Monitor (spatially resolved measurements of the DRZ-indused shock field)

MFOP ≡ Multi-Fiber Optical Probe

PBX-1 ≡ HMX(d_{50}=106μm)/HMX(d_{50}=11.06μm)/HTPB 60.8/15.2/24; D=8.31 mm/μs

PBX-2 (RS-PBX) ≡ RS-HMX(d_{50}=104μm)/RS-HMX(d_{50}=1.64μm)/HTPB 60.8/15.2/24; D=8.20 mm/μs

Effect of the kinetic non-equilibrium between the coarse HMX particles and "dirty binder" on the DRZ homogeneity

► PBX-1 ≡ Conventional PBX ≡ HMX(d_{50}=106μm)/HMX(d_{50}=11.06μm)/HTPB 60.8/15.2/24:

► strongly non-equalized DRZ
► 1.5-2-mm-reaction localization spots in its DRZ structure
► non-homogeneous reaction radiance field & strongly perturbed shock field in optic monitor

► PBX-2 ≡ RS-PBX ≡ RS-HMX(d_{50}=104μm)/RS-HMX(d_{50}=1.64μm)/HTPB 60.8/15.2/24

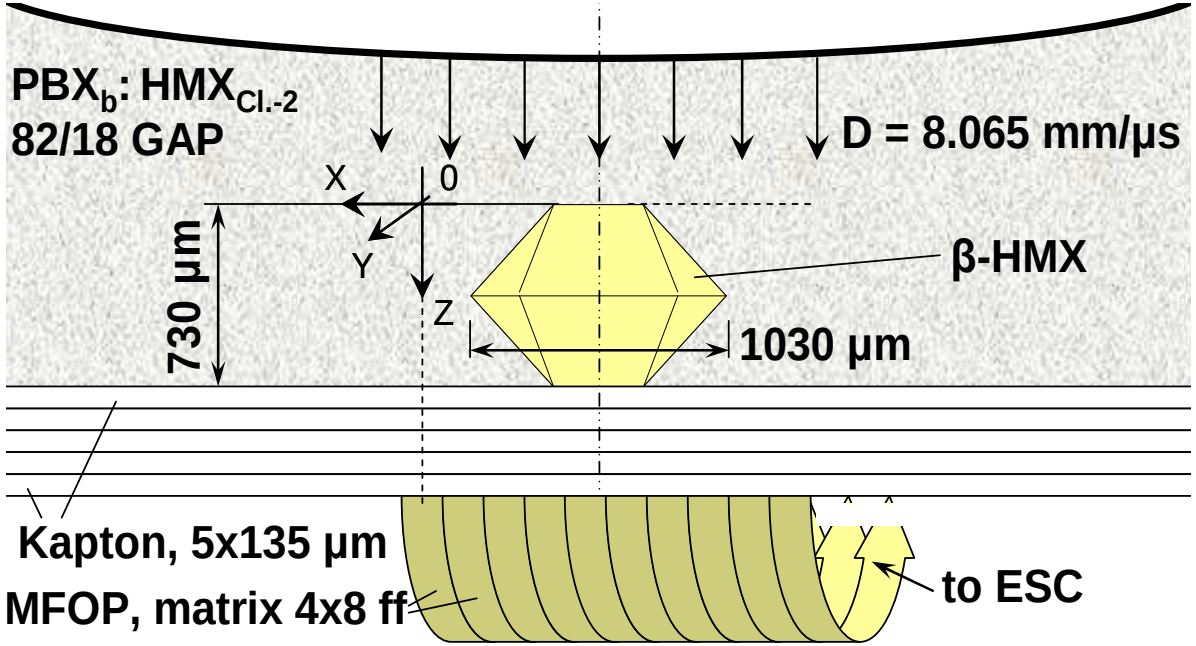
► Although the RS-PBX has in 1% lesser VoD than the conventional sensitivity material PBX-1 (8.20 mm/μs vs. 8.31 mm/μs), it demonstrates much better equalized DRZ structure

► Comparison between the DRZ structures of PBX-1 and PBX-2 allows concluding: the PBX-2 (RS-PBX) material is preferable for application in the shaped charges

► Support to general conclusion: incorporation of the novel *"kinetic equilibrium criterion"* is of considerable interest for designing the advanced RS-PBX materials & IS/RS explosive devices containing the explosively-driven ICs

► The reasonable kinetic equilibrium in the DRZ structure might be attained through variation of particles sizes of the coarse RS fraction and the mass-concentration of the RS "dirty binder" component.

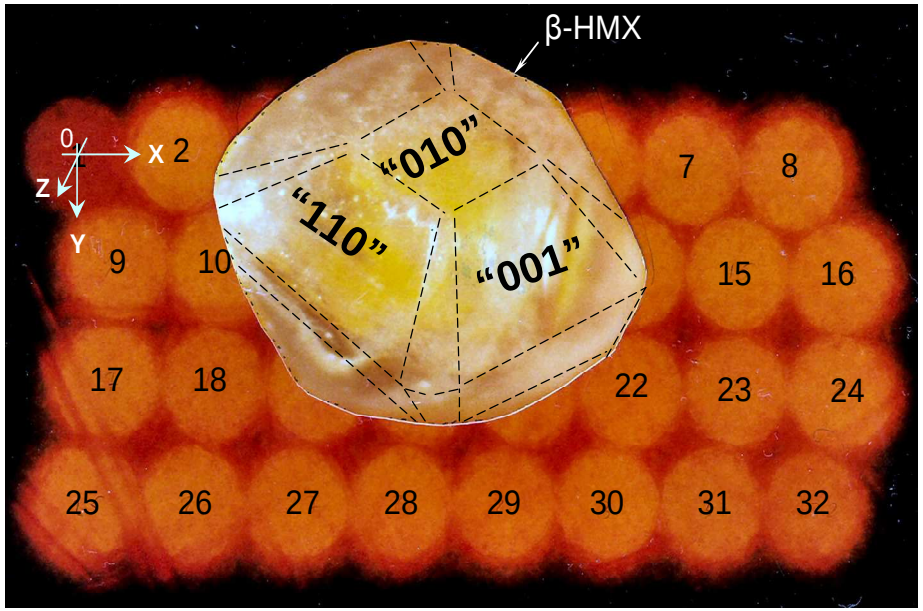
Kinetic non-equilibrium at detonation conversion of single β-HMX crystal: meso-scale probing coarse HMX particle vs. “dirty binder”



- β-HMX crystal (≈1 mm) is embedded in the PBX$_b$ and subjected to PBX$_b$ detonation
- <u>At the input to the “010”-face:</u>

43 GPa Von Neumann spike

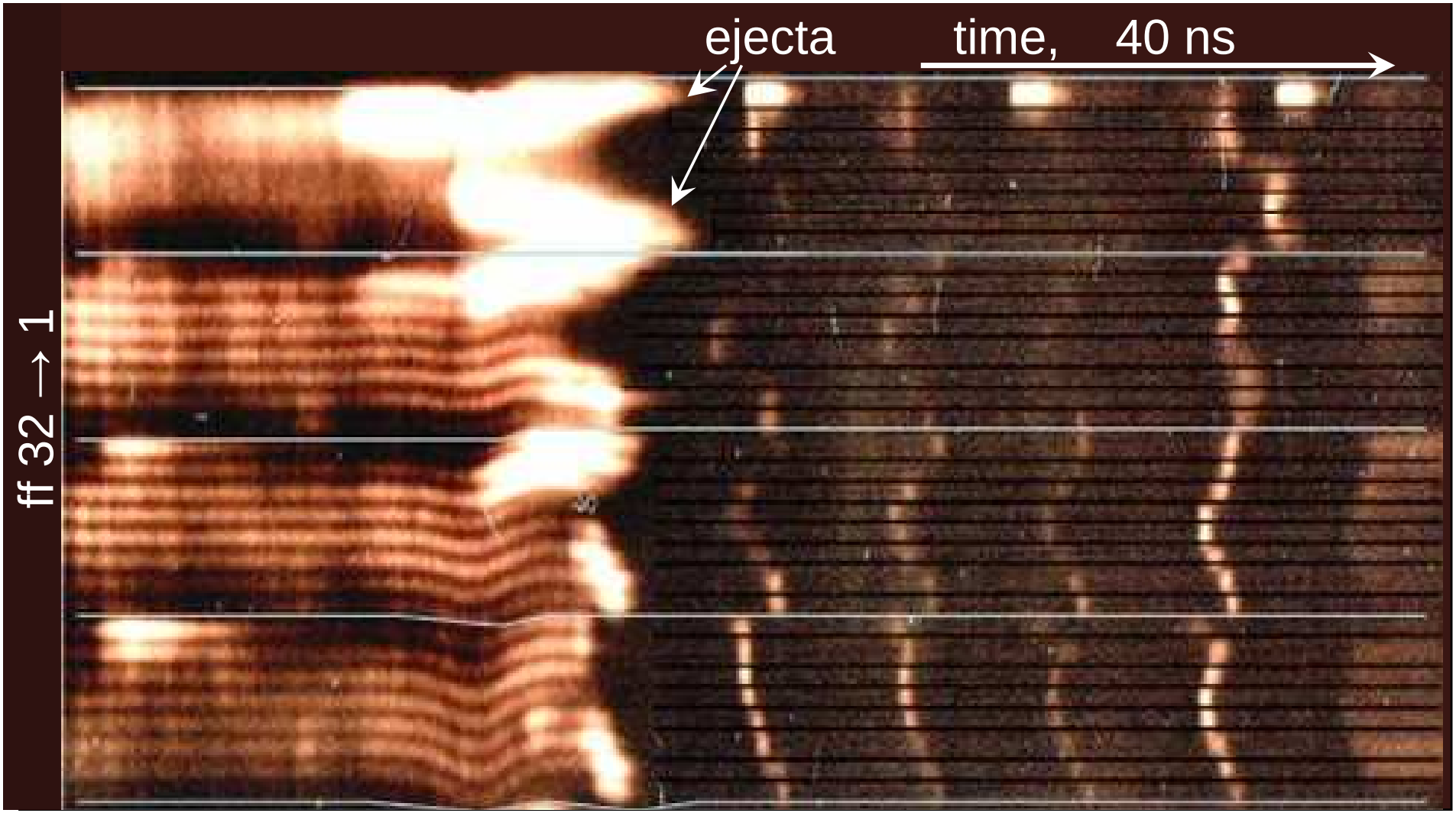
21.5 GPa Chapman-Jouguet pressure



- Superposition of the HMX crystal and the 4 x 8 ff. MFOP

Kinetic localizations in β-HMX coarse crystal subjected to the PBX $_b$ detonation

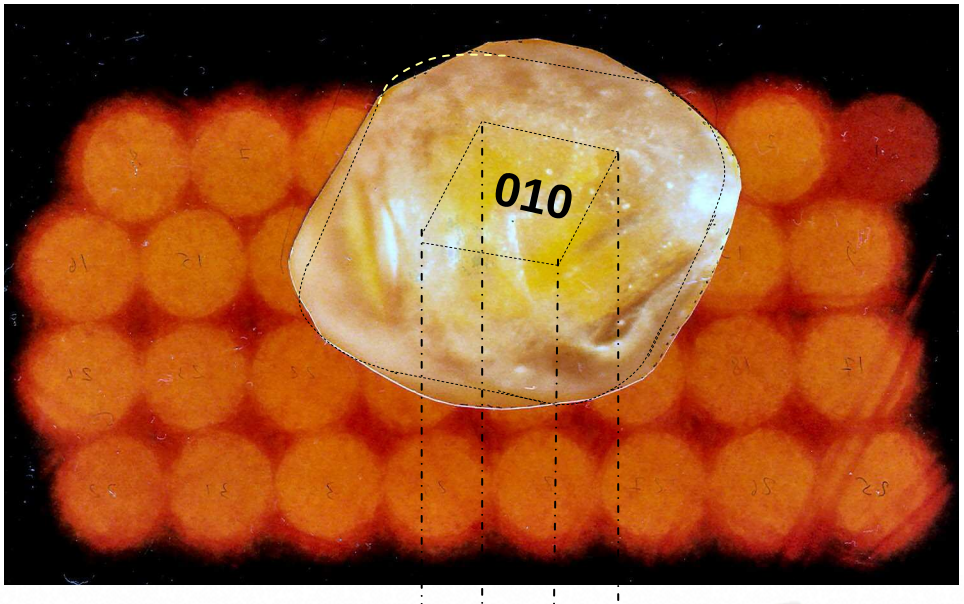
Spatially resolved reaction radiance fild and shock field in the Kapton Stack Monitor

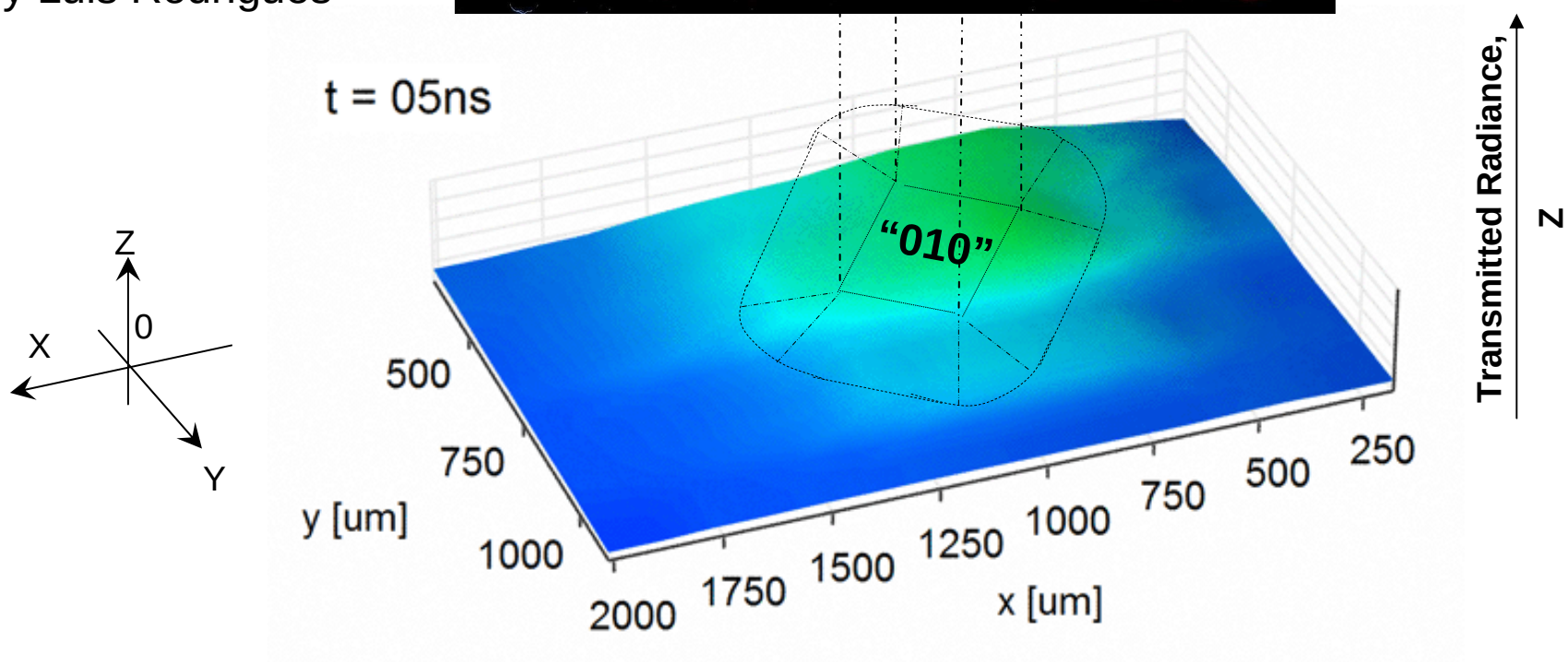


Reaction localizations in β-HMX coarse crystal subjected to the PBX_b detonation

Time-resolved scenarion of reaction localization / reaction light emitted from reaction spots

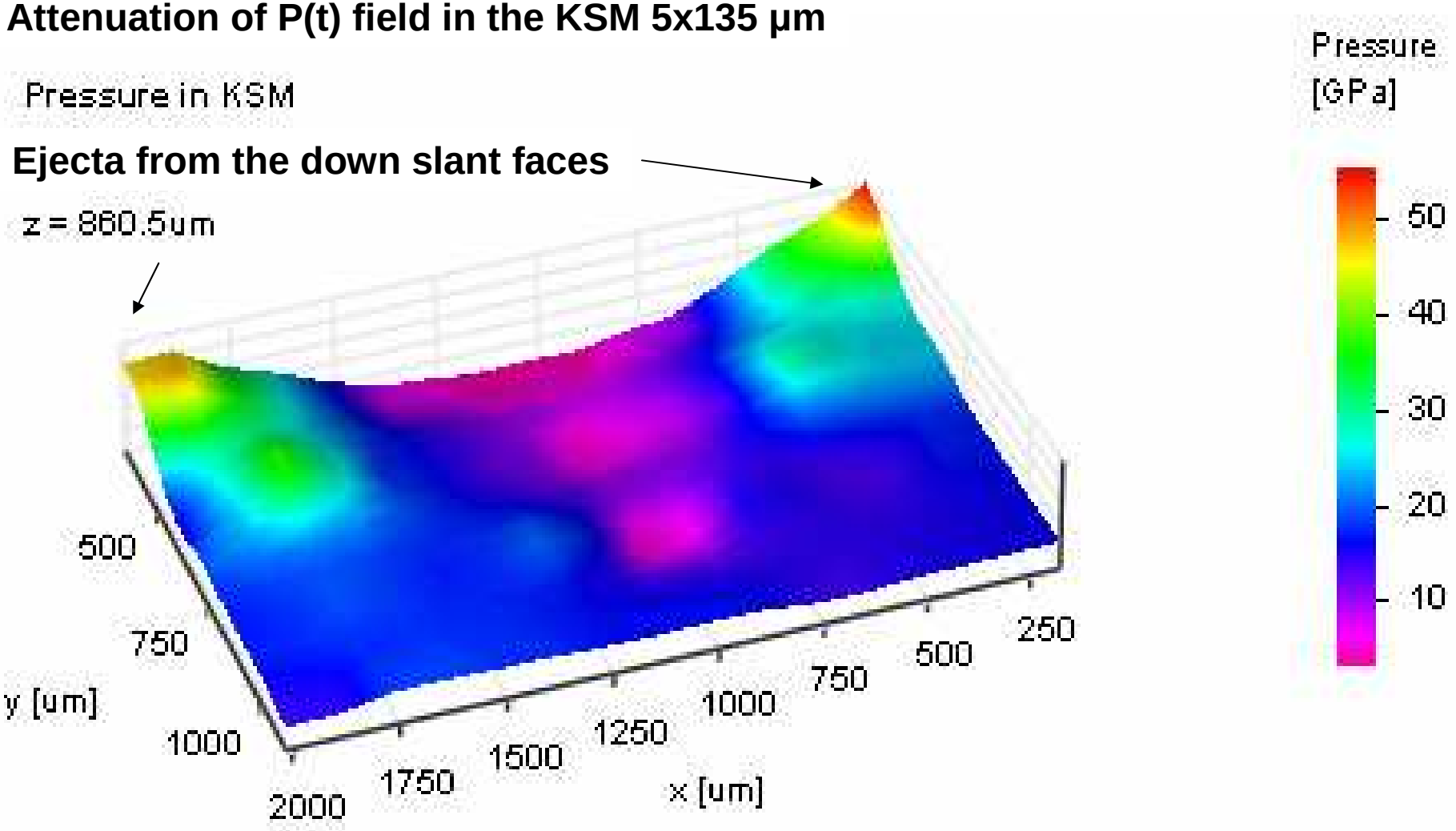
- by Luis Rodrigues



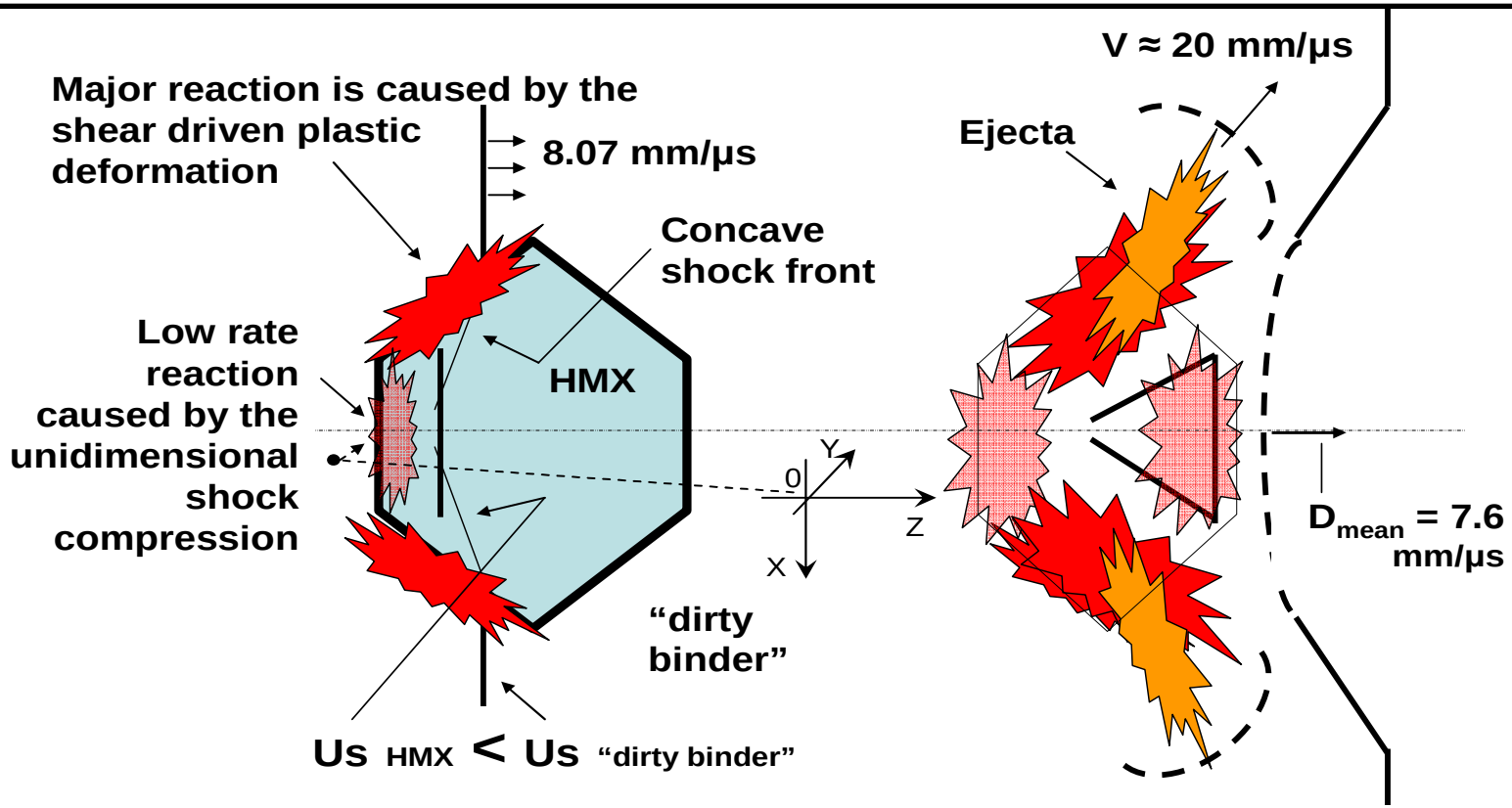


Reaction localizations in β-HMX coarse crystal subjected to the PBX_b detonation

Attenuation of P(t) field in the KSM 5x135 μm



Scenario of reaction localizations in β-HMX crystal subjected to detonation of the "dirty binder" PBX_b



Shear-driven plastic deformation plays a dominant role in the origin of the detonation conversion of HMX grains

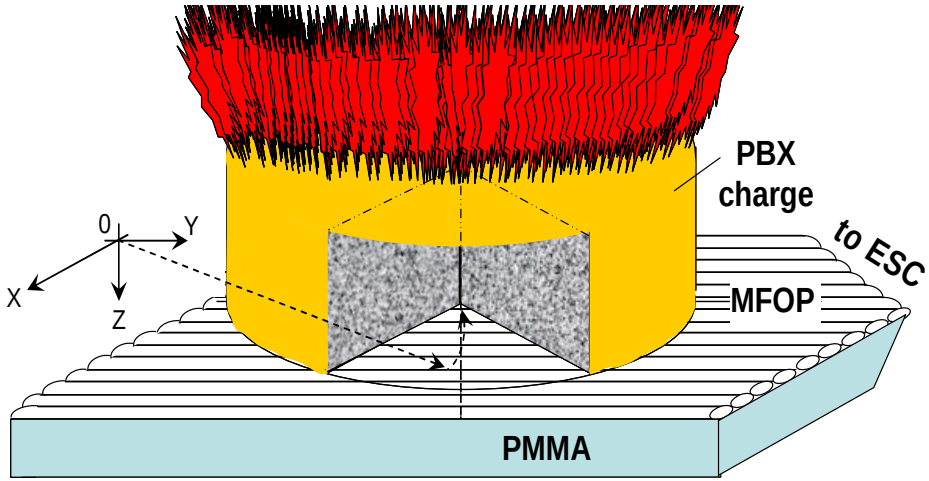
Significant kinetic disequilibrium occurs at the interface "HMX grain -"dirty binder""

Shear-driven plastic deformation is a major trigger to origin the detonation conversion; however it plays also a main part in origination of kinetic non-equilibrium in the DRZ.

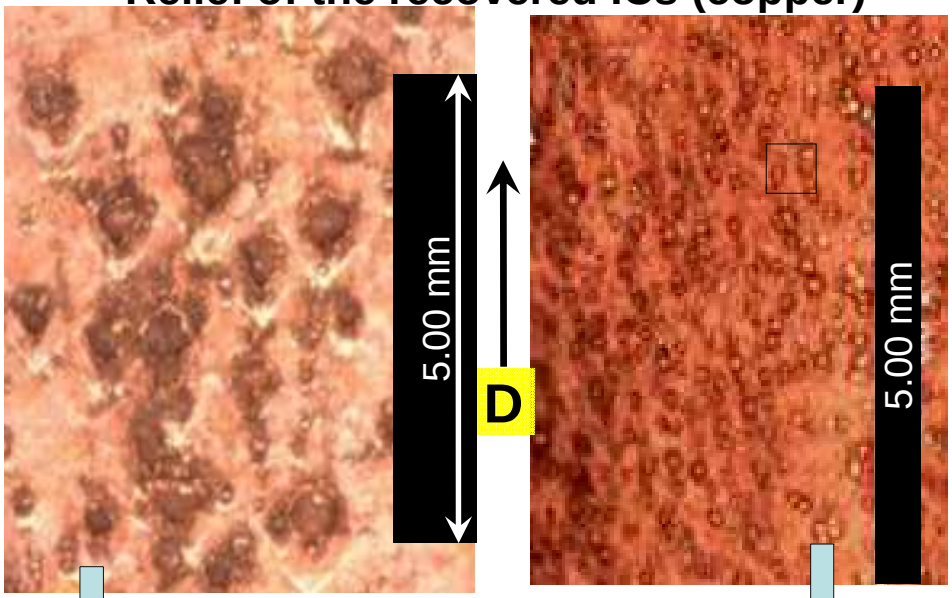
Equalizing between the kinetics of the coarse HE particles and the "dirty binder" provides a way to increase a quality of the DRZ, and by these means, to attain a better performance of the explosively-driven IC and finally the higher effectiveness of the detonation action.

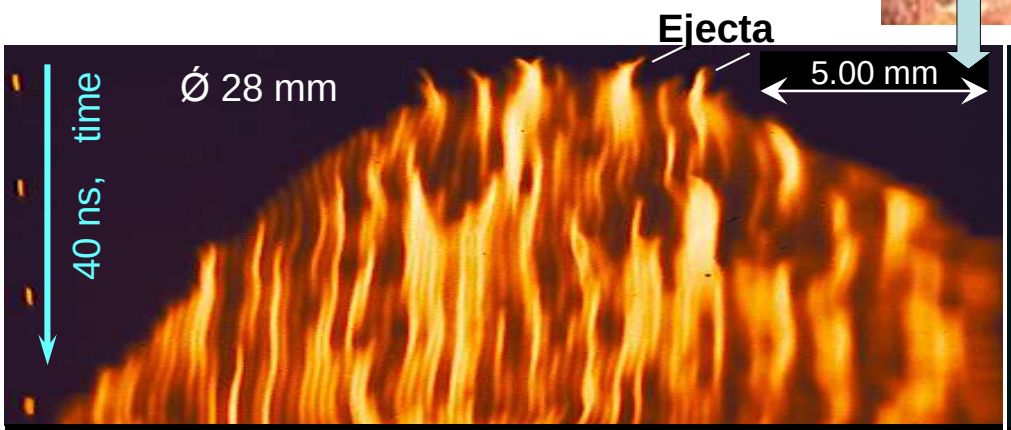
IC deterioration caused by reaction localizations in the DRZ surface & ejecta

Scanning reaction localizations & ejecta in the DRZ surface

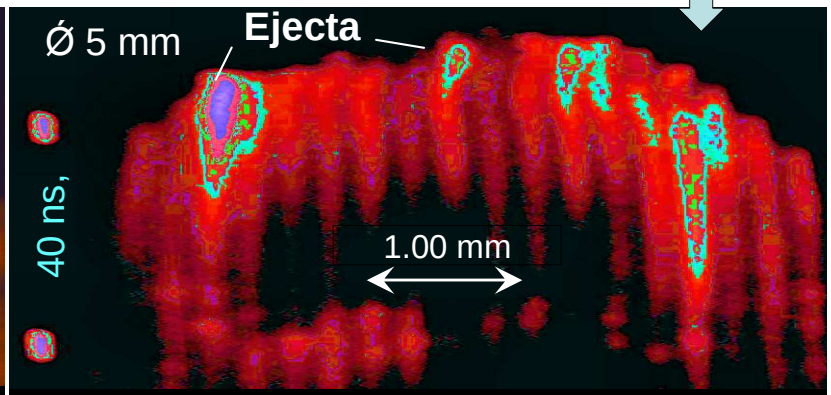


Relief of the recovered ICs (copper)





$HMX_{Class\text{-}3}/HMX_{Class\text{-}2}$/GAP 65.6/16.4/18



$HMX_{Class\text{-}2}$ 82/18 GAP

PBX having the poorly equalized DRZ kinetics causes large, 0.8-1.2 mm-dia., craters in the IC surface.

The PBX with the well equalized DRZ kinetics causes in 6-8 times smaller craters in the IC surface (0.1-0.2 mm)

IC deterioration caused by reaction localizations in the DRZ surface & ejecta

►Deterioration of the PBX-driven IC is caused by reaction localizations and ejecta [4-6] occurring in the DRZ due to the non-equilibrium between kinetics of coarse HE particles vs. “dirty binder”

►The cast-cured PBX-3 ≡ “HMX $_{Class\text{-}3}$ (d_{50} = 203.7 μm) / HMX $_{Class\text{-}2}$ (d_{50} = 16.46 μm) / energetic binder GAP 65.6/16.4/18 wt. % composed with application of the *“Maximum Packing criteria”:*
ρ_0 =1.704 g/cm^3 (0.974 TMD) and a VoD = 8.56 mm/μs;
► Strongly pronounced detonation cells and ejecta ⇨ the DRZ is poorly equalized in kinetics. Approximately 20% of energy, released at detonation conversion of the PBX-3, is localized in the multiple ejecta.

►The PBX-4 was a cast-cured material “HMX $_{Class\text{-}2}$ 82/18 wt. % GAP”;

►ρ_0 =1.759 g/cm^3 (0.998 TMD) and a VoD = 8.07 mm/μs ⇨ well equalized DRZ

►The DRZ-induced perturbations in copper IC (μ-craters) are in 6-8 times lesser in case of PBX-4 than PBX-3 (0.1-0.2 mm vs. 0.8-1.2mm-diameter). The micro-perforation is attended with the over-heating and swelling of the IC-boundary layer that is causing the compressibility losses at the mechanism of convergent IC motion

IC deterioration caused by reaction localizations in the DRZ surface & ejecta

►Spatially-resolved measurements of shock field attenuation process in the copper-IC:

In case of PBX-3, local perturbations penetrate in the IC up to ≈1.5 mm-thickness;

In the case of the convergent motion, local perturbations lead to the origination and growth of the grater scale oscillating instability [9].

►Performance of the shaped-charge jet might be enhanced through the improvement of the DRZ homogeneity.

The PBX-4 explosive material will conduct a better cumulation and will produce more stable (less perturbed) cumulative jets than the PBX-3, because it has a better equalized DRZ.

Conclusive remarks

►Controlling the spatially localized kinetic instabilities in the Detonation Reaction Zone (DRZ) 3D-structures provides a new way for designing the ***reduced sensitivity (RS)*** or ***insensitive (IS)*** PBX formulations allowing improving the performance ***of the explosively-driven inertial confinement (IC)***.

►The RS-PBXs having the homogeneous DRZ structure, are of considerable interest for application in precise ***IS-munitions,*** such as the ***or RS/IS-shaped charges*** and other **RS/IS** ***devices using the cumulation energy of convergent detonation,*** because they allow for minimization of the DRZ-induced local perturbation in the IC and further elimination of instabilities growth in the IC at its convergent motion.

►Novel, physically justified concept for designing the high performance RS/IS-PBXs implies in assembling the selected by size *coarse RS-HE particles* with the *fine-grained RS/IS HE particles in binder*, which formulation is pre-determined on the criterion of minimum kinetic disequilibrium in the DRZ between the coarse and fine crystalline fractions in binder.

►Experimental evidences provide argumentation of the criterion of ***Minimum Kinetic non-Equilibrium in the DRZ Structure*** as alternative to the principle of ***Maximum Packing Density*** of crystalline constituents conventionally applied for designing PBXs.

►Novel concept is currently under the extensive study by researchers of Coimbra University (PO), Fraunhofer ICT (DE), ISL (DE/FR) and MBDA ITALIA (IT), conducting in terms of the EDA Research Project *"The Reduced Sensitivity Energetic Materials for the Higher Performance of the Inertial Confinement",* ***RSEM-HPIC***.

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