WORKSHOP: STUDIES OF DYNAMICALLY COMPRESSED MATTER WITH X-RAYS

PROGRAMME AND ABSTRACTS

29 - 30 March 2017
ESRF Auditorium

Workshop on Studies of

Dynamically Compressed Matter with X-rays

Grenoble, 29 and 30 March 2017

ESRF Auditorium

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Dynamically Compressed Matter with X-rays

29 and 30 March 2017 - ESRF Auditorium

Wednesday 29 March 2017

8:00 – 8:30	**Registration & Welcome Coffee**	
8:30	*Welcome*	H. Reichert (ESRF, FR) S. Pascarelli (ESRF, FR)
Session I: High Power Laser Facilities: Status and Science Highlights Chair: H. Reichert		
8:40	Extreme Matters for ESRF	R. Collins (LLE, US)
9:10	High pressure produced by laser: challenges and limitations	P. Audebert (LULI, FR)
9:40	High Pressure X-ray Diffraction Experiments on the Omega and NIF Laser Facilities	R. Smith (LLNL, US)
10:00	Dynamic Compression with sub-kJ Lasers at Photon Facilities	M. Millot (LLNL, US)
10:20	**Coffee Break**	
Session II: XFELs: Status and Science Highlights Chair: K. Appel		
10:50	X-ray free electron laser studies of amorphous to crystalline phase transitions in shock-compressed materials	C. Bolme (LANL, US)
11:20	Dynamic laser compression at XFELs: pushing boundaries and identifying challenges	U. Zastrau (XFEL, D)
11:40	A Novel Setup for Transverse Diffraction at the LCLS: Shock-Compressed Silicon	E. McBride (LCLS, US)
12:00	Magnified X-Ray Phase-Contrast Imaging at the LCLS	A. Schropp (DESY, D)
12:20 - 14:00	**Lunch**	

Wednesday 29 March 2017

Session III: Synchrotrons: Status and Science Highlights Chair: S. Merkel		
14:00	Dynamic compression experiments at the APS	B. Jensen (LANL, US)
14:20	Laser shock experiments at ESRF: First results from XAS and XRD studies	R. Briggs (ESRF, FR)
Session IV: **Needs of the Users Community – Going beyond the limits of static compression** Chair: S. Brygoo		
14:40	Results on laser compression experiments for warm dense matter studies in the domain 1-10 Mbar	A. Benuzzi (LULI, FR)
15:00	Femtosecond X-ray diffraction studies of deformation in shock-compressed crystals	J. Wark (Oxford, UK)
15:20	**Coffee Break**	
Session V: Needs of the Users Community – Dynamic Behaviour of Materials Chair: S. Bland		
15:50	From quasi static to dynamic compression: A unique opportunity to study the influence of kinetics on various physical phenomena	A. Sollier (CEA, FR)
16:10	Review of progress and future opportunities for sub-surface imaging of mesoscale dynamics in heterogeneous materials at the ESRF	D. Eakins (Imperial,UK)
16:30	Dynamic material response under high strain rates: Phase transition dynamics	E. Brambrink (LULI, FR)
16:50	Dynamic Mechanics; outside the box	N. Bourne (Manchester, UK)
17:30-19:00	**Cocktail and Poster Session**	
19:30	**Bus departure for Workshop Dinner**	
20:00-22:30	**Dinner at Restaurant "La Corne D'Or"**	

Thursday 30 March 2017

Session VI: Status of HPLF-I Chair: O. Mathon		
08:30	The European Cluster of Advanced Laser Light Sources (EUCALL)	G. Appleby (XFEL,D) I. Prencipe (HZDR,D)
09:00	Laser and Interface with the ID24 Beamline	R. Torchio (ESRF, FR)
09:30	Studies of liquids of planetary interest and appropriate targets for dynamic compression at ESRF	F. Guyot (IMPMC, FR)
10:00	Diagnostics of shock-compressed matter at X-ray facilities	D. Kraus (HZDR, D)
10:30	***Coffee and Round Table Discussion*** **Expressions of Interest from potential partners** **Discussion Leader: S. Bland**	
12:30 – 14:00	**Lunch**	
Session VII: HPLF-II and Gas Gun Chair: A. Rack		
14:00	Ultra-high speed X-ray imaging of dynamic compression with gas gun(s) – The Gas Gun facility at beamline ID19	M. Olbinado (ESRF, FR)
14:30	Plans for a XRD/XRI/XES beamline for dynamic compression studies at ESRF	V. Svitlyk (ESRF, FR)
15:00	***Coffee and Round Table Discussion*** **Concrete actions by potential partners** **Discussion Leader: P. Loubeyre**	
16:30	**End of Workshop**	

SPEAKER ABSTRACTS

In order of presentation

Extreme matters for ESRF

R. Collins (LLE, US)

High pressure produced by laser: challenges and limitations

Audebert P., Benuzzi-Mounaix, A., Brambrink E., Zou J.P., Meignien L.

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Up to now only high-energy laser installations allowed the study of dynamic compression. The development of high energy lasers and the construction of end-stations or beamlines coupling high repetition x-ray radiation with lasers will open up important possibilities for studying matter under extreme conditions. In this presentation, I will focus on the experimental challenges of dynamic compression with lasers, and in particular on the very demanding laser characteristics required.

High power pulsed laser interaction with matter yields very high amplitude pressure loadings with very short durations, initiating into solids a strong shock wave. Compared to the conventional generators of shock (launchers of projectiles, explosives), these particular characteristics offer the possibility to study the behavior of matter under extreme dynamic conditions.

The study of materials subject to a large pressure wave produced by an intense laser pulse can only be done if the shock is sufficiently spatially uniform to perform measurements with enough accuracy. The intensity profile of high-power laser beams is often characterized by the presence of hot spots. Different laser intensities in the focal spot locally produce different pressures, leading to a sample which is non-uniformly compressed.
Uniform shocks have been produced using different techniques based on the introduction of optical smoothing techniques (Phase Zone Plates, PZP), which allow eliminating the laser hot spots while achieving an almost flat-top laser irradiation profile. It is also important that the plasma-laser interaction does not produce any preheating effects which can modify the shock wave propagation. These different conditions define laser and target characteristics to perform shock experiments with high intensity lasers.

The different laser characteristics needed to achieve the study of matter under extreme dynamic conditions will be discussed.

High Pressure X-ray Diffraction Experiments on the Omega and NIF Laser Facilities

Smith R.F

Lawrence Livermore National Laboratory, Livermore, CA 94550, USA **(smith248@llnl.gov)**

In this talk I will review x-ray diffraction experiments on the Omega and NIF high power laser facilities. Here, kJ of 351 nm laser energy contained within a 10-30 ns shaped laser pulse, and focused into a 1-2 mm spot, is used to shock or ramp compress materials up to TPa pressures. A synchronized source of nanosecond quasi-monochromatic He-alpha line radiation (6.7 -10.3 keV), generated by additional laser irradiation of thin metal foils (Cu, Fe or Ge), is then used to scatter off the compressed sample to provide diffraction peaks which enable us to constrain crystal structure as a function of pressure. I will show recent x-ray diffraction data from shock-compressed MgO samples. I will draw comparisons with current x-ray diffraction experiments on the LCLS XFEL and future experiments at the ESRF.

Dynamic Compression with sub-kJ Lasers at photon facilities

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Deep inside planets, extreme density, pressure and temperature strongly modify the properties of the constituent materials. In conjunction with numerical simulations, experimental constraints on phase transformations and how they affect thermodynamic and transport properties at interior conditions are crucial to determine a planet's internal structure and evolution.

Laser-driven dynamic compression can easily reach the multi-megabar range typical of the pressure existing deep inside large planets and exoplanets, but large entropy creation during single-shock compression results in large shock-heating which limits the range of pressure achievable while keeping the temperature below 5000-10000 K. The versatility of large lasers can now be exploited to design advanced shock compression schemes that allow us to probe thermodynamic states other than the pressure/temperature conditions obtained in a single-shock experiment (Hugoniot), therefore opening to the possibility of tackling fundamental questions on the behavior of planetary relevant materials at extreme conditions.

I will discuss recent experimental results on the melting line of silica, the optical properties of superionic water and the metallization of deuterium near the predicted Plasma-Phase-Transition (PPT) to illustrate the advanced dynamic compression schemes. Then I will discuss what I envision as the most interesting studies to be carried out at the new Dynamic Compression Facility at ESRF.

Prepared by LLNL under Contract DE-AC52-07NA27344. LLNL-ABS-721583.

X-ray free electron laser studies of amorphous to crystalline phase transitions in shock-compressed materials

Bolme C.A.[1], Ali S.J.[2], Bronkhorst C.[1], Brown D.W.[1], Cherne F.J.[1], Collins G.W.[3], Cooley J.[1], Eggert J.H.[2], Fratanduono D.[2], Furlanetto M.[1], Galtier E.[4], Gleason A.E.[1], Granados E.[4], Hawreliak J.[5], Jensen B.J.[1], Kraus R.G.[2], Lee H.J.[4], Mao W.L.[6], Milathianaki D.[4], Nagler B.[4], Owens C.T.[1], Sandberg R.L.[1], Yang W.[7]

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The brilliance of hard x-ray free electron laser sources is enabling a new era of dynamic compression materials science through its ability to perform *in situ* x-ray diffraction of shock-compressed materials. Using the Matter in Extreme Conditions instrument at the Linac Coherent Light Source, we have studied laser shock-driven phase transitions in silica (SiO_2) and in cerium. During these studies, we have observed amorphous to crystalline transitions in silica during shock compression and resolidification of shock-melted cerium during isentropic release. Results from these experiments will be presented.

Dynamic laser compression at XFELs: pushing boundaries and identifying challenges

Zastrau U.[1], Appel K.[1], Baehtz C.[3], Chen B.[2], Göde S.[1], Konopkova Z.[1], Makita M.[1], Nakatsutsumi M.[1], Priebe G.[1], Schmidt A.[1], Sukharnikov K.[1], Thorpe I.[1], Toncian T.[3], Pelka A.[3]

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The advent of the bright X-ray lasers (XFELs), have proven to be the most profound development in laser systems over the last decade. Significant improvements in a number of laser parameters have been achieved, which resulted in its characteristic peak brilliance values a billion times higher than that from any conventional synchrotron facilities, and triggered unprecedented opportunities and expectations in research activities worldwide.
The talk starts with an overview of the experimental capabilities of the High Energy Density Science (HED) instrument [1,2] at the European X-ray Free-Electron Laser Facility in Schenefeld, Germany. Particular details are highlighted on the recent design advancements and applied monitoring schemes at the HED instrument that allows for exploring matter in extreme conditions with advanced x-ray methods. In particular, the subset of equipment intended for dynamic laser compression, developed and contributed to a large extend by the HIBEF user consortium [3], is highlighted: the DiPOLE-100X optical laser system, its beam transport, and two interaction chambers with dedicated diagnostics will enable high-pressures studies with unprecedented precision and repetition rate [4,5].
The second focus of the talk will discuss similarities, differences and complementarity of dynamic compression using the very different X-rays provided by the ESRF and European XFEL. It will be outlined how key parameters such as X-ray photon energy and spectral bandwidth, as well as X-ray pulse energy and pulse duration enable classes of experiments at these facilities. This comprises X-ray diffraction, X-ray absorption spectroscopy, X-ray collective inelastic scattering, X-ray phase contrast imaging, and X-ray on-and-off resonance emission spectroscopy.

References

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A Novel Setup for Transverse Diffraction at the LCLS: Shock-Compressed Silicon

Emma E. McBride[1, †, *], Andrew Krygier[2], Anita Ehnes[1], Eric Galtier[3], Marion Harmand[2], Zuzana Konôpková[1], Hae Ja Lee[3], Hanns-Peter Liermann[1], Bob Nagler[3], Alexander Pelka[4], Melanie Rödel[4], Andreas Schropp[1], Ray F. Smith[5], Christopher Spindloe[6], Damian Swift[5], Franz Tavella[3], Sven Toleikis[1], Thomas Tschentscher[7], Justin S. Wark[8], and Andrew Higginbotham[9]

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Despite being the subject of numerous shock compression studies, the behavior of silicon under dynamic loading is vigorously debated [1-4]. The few studies that combine shock compression and X-ray diffraction have exclusively focused on “normal" X-ray geometry whereby X-rays are collected along the shock propagation direction, consequently sampling numerous strain states at once, greatly complicating both phase identification and studies of phase transition kinetics. Here, we present a novel setup performing *in situ* X-ray diffraction studies perpendicular to the shock propagation direction at the Matter at Extreme Conditions end station at LCLS. Combining the extremely bright microfocussed X-ray beam with a nanosecond drive laser, we unambiguously determine the character of each wave for the first time.

References

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Magnified X-Ray Phase-Contrast Imaging at the LCLS

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Current X-ray sources of the fourth generation, also denoted by X-ray free-electron lasers (XFELs), produce intense and short X-ray pulses opening up completely new scientific possibilities for the investigation of fast dynamical processes [1].

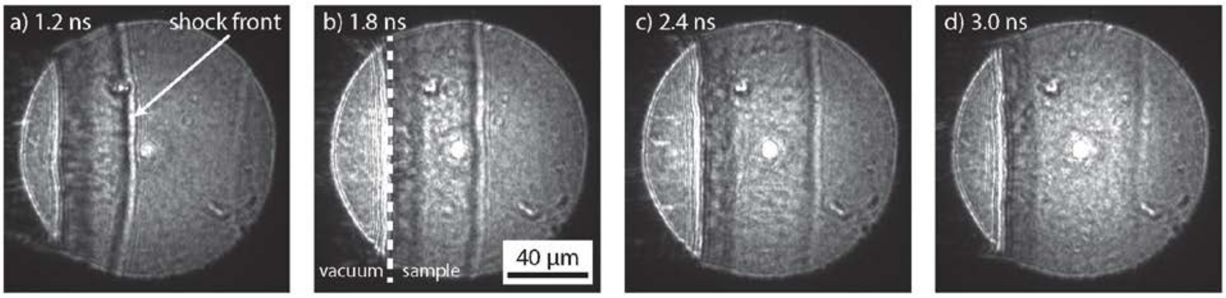

Figure 1: X-ray phase-contrast images measured with a high-resolution x-ray detector at a distance of about 4.2 m behind the sample. Specific time delays are indicated in each image.

However, some experiments require besides the high temporal resolution, which is provided by the ultrashort XFEL-pulse, addtionally a high spatial resolution to image fast physical phenomena occurring on short length scales. Therefore, we implemented the technique of magnified x-ray phase-contrast imaging (PCI) at the Matter in Extreme Conditions (MEC) instrument at the Linac Coherent Light Source (LCLS) and built a new X-ray nanofocusing setup adapted to this special XFEL environment [2,3]. The imaging setup is based on a set of Beryllium compound refractive lenses (Be-CRLs) creating a secondary X-ray source with a size of about 125 nm (FWHM) closely in front of a sample [4]. The sample is positioned in the divergent X-ray beam and a CCD detector records a magnified image of the illuminated area at a larger distance further downstream. In a pump-probe scheme a high-power optical laser hits the sample from the side, which initiates a shock wave propagating into the material, and the LCLS pulse probes the state of the material shortly after. In Fig. 1 a series of measured phase-contrast images recorded on diamond at different delay times between the optical and XFEL pulse is shown [5]. Here, we report on different PCI-experiments carried out at the LCLS and discuss these results in comparison to possibilities at synchrotron radiation X-ray sources.

References

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Dynamic Compression Experiments at the APS

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Understanding the dynamic properties of materials require experiments capable of examining their time, rate, and spatial dependencies during loading. The development in advanced X-ray sources, photon detection, and measurement techniques such as phase contrast imaging (PCI) offers unique opportunities for ultrafast, high-resolution measurements to examine dynamic materials response. Several capabilities now exist that couple dynamic compression capabilities to beam lines at light sources including the IMPULSE (IMPact system for ULtrafast Synchrotron Experiments) [1,2] capability and the Dynamic Compression Sector (DCS) both located at the Advanced Photon Source (APS) as well as the Matter-at-Extremes Conditions (MEC) end station at LCLS. A brief overview of current capabilities at the APS will be presented along with examples of on-going dynamic experiments that use LANL's novel X-ray PCI system [3,4] to examine a wide range of dynamic phenomena (see Figure 1 below). The results and capabilities presented here will show our use of these advanced X-ray diagnostics coupled with dynamic loading platforms to examine a variety of phenomena across length scales.

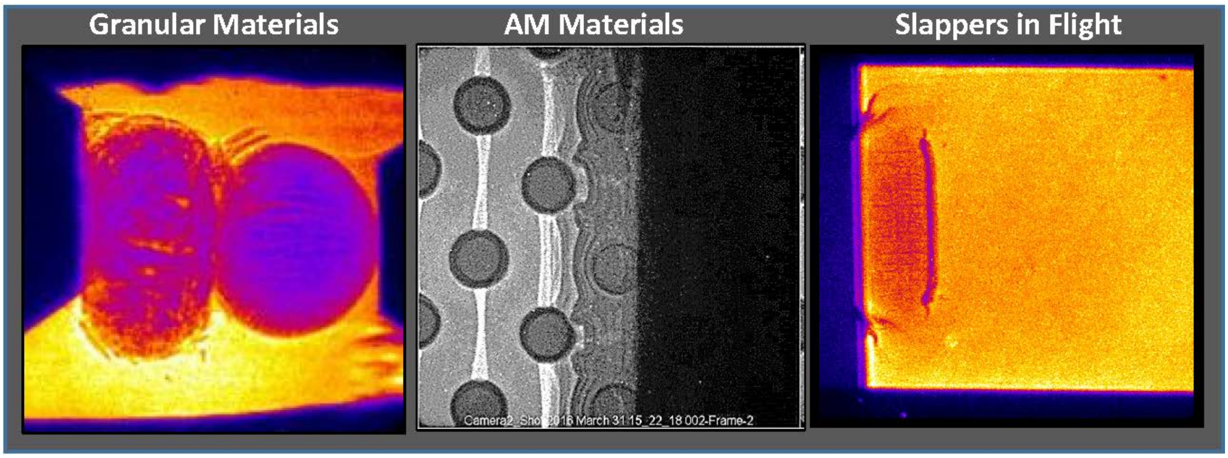

Figure 1: Examples of data obtained at the Advanced Photon Source using X-ray Phase Contrast Imaging. (Left) Compression of an idealized system of borosilicate spheres [4]. (Middle) Dynamic response of an additive manufactured material [5]. (Right) Response of detonator initiation systems [6].

References
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Laser shock experiments at ESRF: First results from XAS and XRD studies

Briggs R.,[1*] Kretzschmar N.,[1] Mathon O.,[1] Pascarelli S.,[1] Torchio R.,[1] Wulff M.,[1] Bouchet J.,[2] Lescoute E.,[2] Loubeyre P.,[2] Occelli F.,[2] Recoules V.,[2] Solier A.,[2] Videau L.,[2] Gaal R.,[3] Pepin C.[3]

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The last 5 years has seen an influx in the number of experiments that combine high energy lasers with *in situ* X-ray techniques, allowing the structural characterisation of dynamically compressed materials [1-3]. At the ESRF, some of the first experiments have been carried out using the synchrotron owned mJ ns laser (ID09b) and recently using a 30 J ns laser installed temporarily from the CEA, Paris (ID24). The first results from laser shock experiments on iron, carried out at ID24, were published in 2016 [4]. Here I will present the first results from XRD experiments on ID09b and new results from recent experiments using the 30 J ns laser installed for 4 weeks in May 2016.

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Results on laser compression experiments for warm dense matter studies in the domain 1-10 Mbar

Benuzzi-Mounaix A.[1], Ravasio A.[1], Denoeud A.[1], T. Vinci[1], Bambrink E.[1], Guarguaglini M.[1], Koenig M.[1,8] , Bolis R. M. [1], Dorchies F.[2] , Leguay P.M.[2] , Jourdain N.[2], Gaudin J.[2], Guyot F.[3], Morard G.[3], Ozaki N.[4,5], Miyanishi K.[5], Sekine T. [6], Sakawa Y. [7], Sano T. [7], Kodama R.[8,4,5] Recoules V.[9], Bouchet J.[9], Barroso P.[10], Musella R.[11], Remus F. [9,10], and Mazevet S.[11]

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The Warm Dense Matter regime, defined by density greater than the solid density and moderate temperatures (T ≈ qq 10^3-10^4 k) lies between condensed matter and plasma. The behavior and physical properties of this matter are still poorly understood, both theoretically and experimentally, and far from trivial to be numerically simulated. Major applications of the Warm Dense Matter study are in planetology. In this context, not only equations of states, but also structure changes, phase transitions and electrical properties are key parameters for modeling planets. We will present an overview of results obtained in the last few years by our team on materials of interest for planetology in the domain 1-10 Mbar, in particular the SiO_2 and SiO_2-MgO systems. These works have been supported by ANR PlanetLab. Perspectives will be presented in the context of the High Power Laser Facility (HPLF) at ESRF.

Femtosecond X-ray diffraction studies of deformation in shock-compressed crystals

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An understanding of the detailed mechanisms at the lattice level by which crystals relieve shear stress under shock compression at megabar pressures has long been sought after. Predictions of multi-million atom molecular dynamics simulations indicate that an fcc crystal such as copper could, via homogenous defect generation and motion, relax towards the hydrostat on the time-scale of a few tens of picoseconds in these pressure regimes. [1] These same simulations led to the prediction that elastic response up to the ultimate strength of the solid could be achieved if the loading were applied sufficiently rapidly. These predictions have been borne out in recent experiments at LCLS where femtosecond x-ray diffraction was employed to diagnose the onset of plastic flow in 1-micron thick samples of laser shocked copper, [2] producing results which are in good agreement with simple plasticity models. [3] In certain materials plastic deformation can occur by twinning as well as slip. This phenomena (as well as pathways for phase transitions) is particularly amenable to study with fibre-textured samples. [4] We present here recent results measuring twin fraction and significant lattice rotation in the laser-shocked samples of the bcc metal tantalum.

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From quasi static to dynamic compression: A unique opportunity to study the influence of kinetics on various physical phenomena

Sollier A., Occelli F., Lescoute E., Pepin C., Dewaele A., Loubeyre P., Brygoo S., Bontaz J., Soulard L., Videau L., Recoules V., and Bouchet J.

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With the ongoing development of various dynamic loading techniques at ESRF covering very different time scales, such as dynamic DAC, portable gas gun, and the High Power Laser Facility (HPLF), there is a unique opportunity to study the influence of kinetics on various physical phenomena. Among all the possible research opportunities, we will be able to probe with the same x-ray diagnostics, on the same platforms, a whole class of phenomena on materials under pressure: melting curves, structural phase transitions, strength properties … In this talk, we will show some examples where the application of similar X-ray techniques on samples loaded at different time scale might be of great interest. We will also discuss about the developments concerning diagnostics and samples preparation which will be required in order to perform these comparisons. To conclude, we will also talk about some industrial applications, which currently use synchrotron radiations for post mortem observations on recovered shocked samples, and could therefore greatly benefit from time resolved measurements performed with the same XR techniques.

Review of progress and future opportunities for sub-surface imaging of mesoscale dynamics in heterogeneous materials at the ESRF

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The natural and engineered world is dominated by heterogeneous materials, whose bulk properties are governed by complex interactions between their underlying phases and mesostructure. Subjected to dynamic loading, this mesostructure can give rise to a vast distribution of non-equilibrium thermomechanical states, the extremes of which are key to triggering relaxation through defect generation, structural transformation, and chemistry, for example. Our ability to predict and thereby control these behaviours relies upon improved multi-scale models, informed by details of sub-surface material interaction, deformation, and failure from the local grain/particle scale through to the bulk.

The capability for dynamic, sub-surface imaging has advanced by leaps and bounds in recent years, with researchers exploiting the brightness and coherence of 3rd and 4th generation light sources to interrogate with high resolution the vast richness of mesoscale deformation [1]. This talk reviews recent progress towards high-resolution, high frame-rate X-ray PCI applied to dynamic loading at Beamline ID19 at the ESRF. Using a portable single-stage gas gun, a range of sub-surface phenomena are studied, including the compaction of asteroidal powders [2], wave profile evolution in non-cohesive systems, and cavity collapse. Finally, opportunities for GHz imaging though improved cameras/scintillators [3], and novel research areas will be discussed.

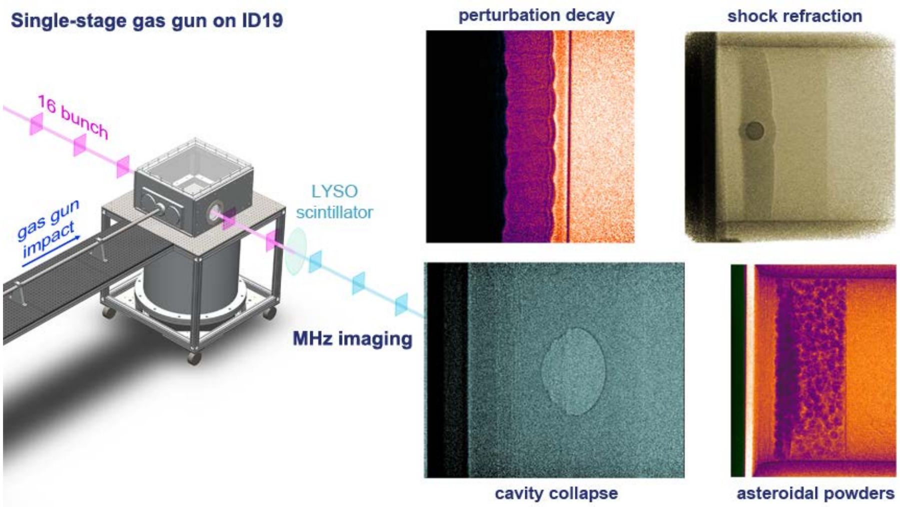

Figure 1: Illustration of the dynamic X-ray imaging experiments, showing examples of mesoscale phenomena in heterogeneous materials studied to date.

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Dynamic material response under high strain rates: Phase transition dynamics

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High strain rates produced by laser-driven compression allow studying phase transition dynamics on ns time scale. We will present results of the iron a-e transition dynamics under ramp compression with strain rates of 10^7 s^{-1}. By tracing the surface velocity history of the samples, we are able to test different transition models and deduce characteristic transition times [1]. We will discuss the further insight, which will be provided by the capability of in-situ x-ray diagnostics. We will also present the program of the GDR chocolas in the context of the future laser beam line at ESRF.

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Dynamic Mechanics; outside the box

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Few technologies have advanced faster in response to external challenges than Dynamic Mechanics. This subject now demands collaborative research to meet problems not just within physical science but also the engineering and life sciences. It is necessary to apply loads that exceed thresholds in materials and structures; strengths, hydrodynamic limits, ionisation thresholds but also reaction and the limits on conditions for life. Further there are a suite of processes that may be probed by a laser pump. We need to think forward as to how our new facility can attack not only health and industrial applications but also those of energy and the environment. How are we going to capture, and how shall we exploit, opportunities and challenges for the future?

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The European Cluster of Advanced Laser Light Sources (EUCALL)

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The European Cluster of Advanced Laser Light Sources (EUCALL) generates collaboration and synergy between large scale sources of laser-driven and accelerator-driven X-ray radiation.

The lead project partner is European XFEL, while the other partners are DESY, the Extreme Light Infrastructure (ELI) in Czech Republic, Hungary and Romania; ESRF in Grenoble, Helmholtz-Zentrum Dresden-Rossendorf, Lund University, the Paul Scherer Institute and Elettra Sincrotrone Trieste. The networks *Laserlab-Europe* and *FELs of Europe* are also involved, while representatives from the user communities of FELs and Optical Lasers are members of EUCALL's steering committee. EUCALL is the first serious effort to bring together the two scientific communities who have been using X-ray light in parallel to each other, and from different scientific and technological backgrounds.

A major part of EUCALL's output is devoted to the development of new software for simulation and processing of advanced radiation experiments, as well as for new hardware for standardised sample delivery and beam diagnostics for ultra-fast laser experiments. This presentation will outline EUCALL's objectives and its achievements at the half way point of the project.

In September 2016, EUCALL has endorsed the Target Network initiative proposed by HZDR as a foresight activity. The initiative is aimed at developing a coordinated strategy to enable high repetition rate laser experiments and establish sustainable target supply infrastructure. Here, we present the current status of this initiative.

Laser and Interface with the ID24 Beamline

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Following the success of the first laser shock experiments performed in 2014 [1] and 2016 [2,3] and the large interest from the scientific community, in 2016 the ESRF launched an ambitious project aimed at developing dynamic compression experiments using high power lasers. The science case covers the study of properties of matter under extreme conditions that go beyond those in our planet and the dynamic behavior of matter and materials under high strain rates.

The project named High Power Laser Facility phase I (HPLF-I) consists in coupling a 100-200 J, ns shaped pulse, 1053nm laser to an X-ray Absorption Spectroscopy (XAS) beamline (ID24).

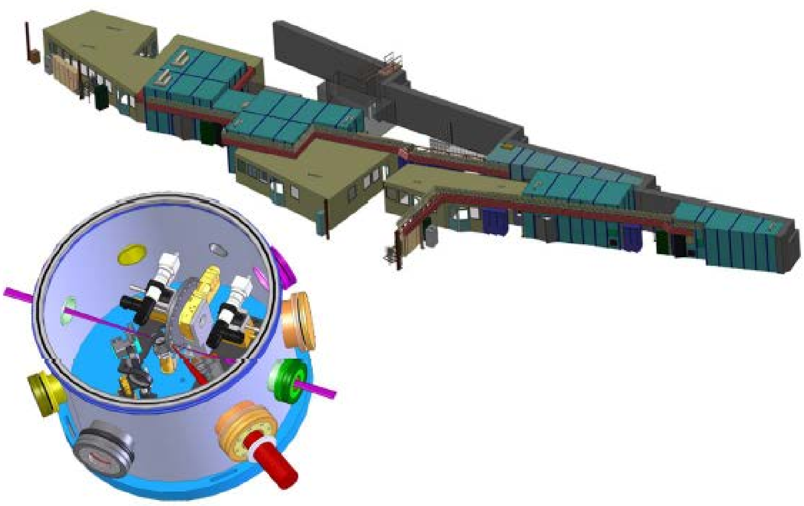

Figure 1: Scheme of ID24 beamline and of the sample interaction chamber

First tests and experiments are planned for 2018, before the ESRF shutdown for the source upgrade and further developments will follow after the shutdown in 2020.
Experiments will be performed in the experimental hutch 1 (EH1) of the beamline ID24.
In this talk we will give details about the laser parameters and implementation on the beamline.

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Studies of liquids of planetary interest and appropriate targets for dynamic compression at ESRF

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Highly compressed liquid phases play a major role in the differentiation of terrestrial planets in our solar system and beyond as well as for determining their structure and properties (e.g. generation of a magnetic field within deep electrically conductive planetary fluids). For example, in the case of the Earth, melting of iron alloys has allowed the differentiated core/mantle structure to be almost fully established 4.4 billions years ago and the Earth's core is still made of an alsmost entirely molten iron alloy under several Mbar and thousands of K in which the geodynamo generates the Earth's dipolar magnetic field observed at the surface. Moreover, giant pressures and temperatures occured during the first 100 million years of the Earth history in response to a large impact which eventually resulted in the formation of the Moon and imprinted the metal/silicate segregation thus establishing the exact chemical compositions of the planetary silicates and iron alloys.

To model such phenomena in the Earth and in other planets, including exoplanets, at the origin of the recently discovered remarkable diversity of planets and planetary systems, it is necessary to study in detail liquid iron based alloys and liquid silicates, a continuum existing between these two endmembers at high pressures and temperatures. One needs to know the phase diagrams, the equations of states, transport properties of these liquids. In order to make a link with simulations, knowing the structures of these liquids is essential.

Several methods allow to reproduce experimentally such liquids and each has its own advantages. Here we will show that dynamic compression is of great interest for generating highly compressed liquids of planetary relevance without chemical contamination by surrounding materials which occurs sometimes in diamond-anvil cell experiments as will be illustrated. Moreover, this method has a potential for reaching in a clean manner very high pressures and particularly very elevated temperatures on the Hugoniot surfaces which are essential to model the role of liquids in impact-induced tranformations in materials, such as the aforementioned Moon-forming event.

In this presentation, we will also show how elastic scattering of X-rays and X-ray absorption spectroscopy are both essential and complementary tools for studying the structure of these liquids. Particularly, the EXAFS contribution can provide unique quantitative informations about the local coordinences and environments of chemical elements such as iron in those melts. In that respect, the opportunity of coupling a high-power laser to an ESRF X-ray absorption beamline should not be missed. Premiminary results of a first campaign on the (Fe,O) system that occured in june 2016 will be shown and discussed [1].

Finally, although it is obvious to the members of the community of dynamic compression, it is important to remind that the success of such experiments is also linked to the design and quality of targets. We will provide a short presentation of the target laboratory under construction at IMPMC in Paris which is primarily dedicated to provide appropriate targets for the experiments described above.

[1] – This first experimental campaign has been made possible by the precious help and collaboration of Paul Loubeyre, Florent Occelli, Arnaud Sollier and Emilien Lescoute from CEA DIF/DPTA in Bruyères le Châtel in France and of Richard Gaal and Charles Pepin from EPFL Lausanne in Switzerland.

Diagnostics of shock-compressed matter at X-ray facilities

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The combination of pulsed high-energy lasers with highly brilliant X-ray sources has started to provide unprecedented in situ diagnostics of dynamically compressed materials. Combining various diagnostic techniques will be crucial in order to obtain an improved understanding of the extreme states of matter that are investigated in such experiments. This talk will discuss diagnostics that are planned for HPLF at ESRF in the context of other X-ray facilities that also provide high-energy laser systems.

Ultra high speed X-ray imaging of dynamic compression with gas-gun(s) - The Gas Gun facility at beamline ID19 -

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A single-stage gas gun for user operation at beamline ID19 is currently under construction in the frame of LTP MI-1252. We will present the related past, present and future activities at ID19: the development of the required fast X-ray detection schemes, first demonstration experiments as well as recently achieved results with the preliminary design of a new gun. By the end of the LTP a dynamic X-ray probe of extreme physical phenomena is available at ESRF within the general user programme: combining ultra high speed imaging by single-bunch X-ray detection and dynamic compression by gas gun impacts.

The single-stage gas gun that is being developed is one of the most widely used within the high-rate and shock physics community, and provide access to strain-rates from $10^2 – 10^6$ s^{-1} and dynamic pressures > 250 kbar. These conditions are relevant to a variety of scenarios including bird strike onto aircraft through to ballistic penetration, and thus enable study of a broad range of fundamental and applied science. The in situ subsurface probing afforded by hard X-ray single bunch imaging is essential to access the microscopic processes (such as internal damage, cracking and spall, twinning and evolving microstructures, shocked induced phase transitions, growth instabilities, void collapse and densification of porous system) which ultimately dictate the bulk behaviour of materials at extreme conditions. Reliable methodologies for synchronizing the gas gun impact system to the ESRF ring and capturing single bunch X-ray phase contrast images of rapid physical phenomena has already been developed and successfully employed in the study of 3D printed metal lattices for tailored energy absorption, spall failure in magnesium foils, and compaction of astrophysical powders to understand asteroid formation. Future activities will be directed towards multiple-frame dynamic imaging to capture the evolution of rapid physical changes in materials and exploration of strategies for dynamic X-ray diffraction.

In line with the ongoing campaign to establish a dynamic compression station at ESRF, a two-stage gas gun and its advantages and complementarities to existing gas gun at ID19 will be briefly discussed. Together, a single-stage gas gun at ID19 and a two-stage gas gun at the dynamic compression station are expected to strengthen research into dynamic/time-resolved science and matter at extreme conditions, two strategic themes of the ESRF-EBS.

Plans for an XRD/XRI/XES beamline for dynamic compression studies at ESRF

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In 2016 ESRF has launched phase one of the *High Power Laser Facility for Dynamic Compression* program (HPLF I). This phase comprises installation of a 100 J ns-shaped pulse laser on the ID24 XAS beamline. The aim of the HPLF II project is to complement the spectroscopy branch of the ESRF EBS dynamic compression facility with XRD, XRI and XES techniques.

A station hosting the XRD, XRI and XES hutches will be situated on the ID23 MX beamline (beam sharing operation mode) in order to assure the most direct access to the laser installed on the ID24 beamline. The dynamic XRD/XRI/XES facility will be composed of one optics and two experimental hutches (Fig. 1). X-ray radiation will be generated either with U18 or U12 (single harmonic) undulators allowing to cover the energy range from 20 to 70 keV. Single X-ray pulses will be isolated with a help of fast choppers and a ms-shutter. The first hutch will comprise diffraction and emission spectroscopy stations (focused beam) and the imaging will be performed in the second hutch situated at the end of the ID23 section (parallel beam). The imaging hutch has been designed to host a double-stage gas gun in the future.

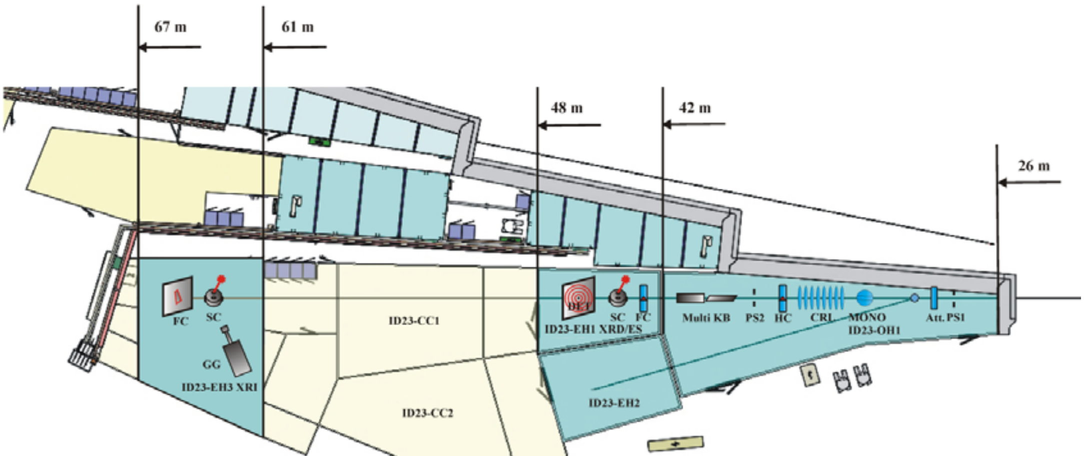

Figure 1. Schematic layout of the future ID23 beamline (PS1 – high power primary slits, Att. – attenuators, MONO – multilayer monochromator, CRL – compound refractive lenses, PS2 – bandwidth selecting slits, HC – heatload chopper, Multi KB – multilayer KB mirrors, FC –fast chopper, SC XRD/XES – sample chamber for XRD and XES, DET – detector, FC – fast camera, GG – gas gun).

The dynamic compression facility will fully exploit the increased brilliance of the EBS. A flux of 8×10^9 photons/pulse can be achieved at 25 keV with $\Delta E/E$ ~2.8%; the flux at 42, 58 and 66 keV will be equal to 9.5×10^8, 4.7×10^8 and 5.8×10^8 photons/pulse, respectively, with $\Delta E/E$ = 0.7-1.4%. The new station will enable investigation of ns-lived highly compressed/strained states of matter, including low-Z systems using diffraction/scattering/imaging/emission methods. Potential scientific fields include: high pressure physics and chemistry (new states of matter and new materials), earth and planetary science, applied engineering materials and others. This facility will have strong complementarity with other ESRF beamlines which perform studies at extreme conditions [1].

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POSTER ABSTRACTS

(Alphabetical order)

Investigation into Novel Water Window Detectors for Imaging

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X-ray microscopy of biological samples is one of the main applications of imaging which plays an important role in Life Sciences [1]. The diffusion of this technique needs the development of compact laboratory x-ray microscopy systems. Important technological issues are the reduction of x-ray source dimensions, the improvement of x-ray optics and the development of new x-ray imaging detectors.

Water window microscopy of biological samples using alkali halide detectors offers the prospect of achieving much higher resolutions than currently available with optical microscopy. In particular, LiF has many suitable properties as a detector for this purpose [2]. Typical experiments use an x-ray source such as a laser-produced plasma or plasma discharge which then illuminates the sample and produces the colour centres in the LiF. However there is much about the dynamics of the colour centre production that have yet to be investigated [3,4]. Increased knowledge of this process will help optimise the technique with a view to enhancing the resolution available and perhaps even achieving sub- diffraction limited performance. These dynamics are also relevant in developing LiF as a broadband laser.
This work will seek to investigate the dynamics of colour centre production, stability and temperature effects.

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Perspectives for dynamic compression experiments at the High Energy Density science instrument at European XFEL

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The European X-ray Free Electron Laser Facility (XFEL) is a 4th generation light source user facility coming online in 2017. The High Energy Density science instrument (HED) [1], one of the six baseline instrument stations, is dedicated for research at extreme conditions and will also offer the possibility of dynamic compression experiments [2,3]. The Helmholtz International Beamline of Extreme Fields (HIBEF) will contribute key-instrumentation to HED that enables to reach extreme conditions [4].

Dynamic compression experiments at HED can either be studied within Diamond Anvil Cells or using high-energy optical lasers (100 kHz/40 mJ/ps or 10 Hz/100J/ns). The short-lived extreme states can be probed with a FEL beam with pulse lengths of 2 -100 fs and 10^{12} photons per pulse. A very high instrument time resolution of 10 fs is planned for HED, which is based on laser–X-ray cross correlation [5]. European XFEL will operate at a burst repetition rate of up to 4.5 MHz, but 10 Hz and shot-on-demand experiments will also be feasible.

The HED science instrument is located at the SASE2 undulator, which produces hard X-rays in an energy range between 3 and 25 keV. As optical elements, we foresee mirrors, two monochromators, a split and delay unit and four positions for focussing optics in the tunnel and in the experimental hall. This leads to a variety of X-ray beam properties at the sample position, that can be selected for the respective experiment. Major X-ray beam diagnostics comprise on-line monitoring of the arrival time between X-rays and optical lasers, an in-situ single-shot X-ray spectrometer combining a diamond grating with a convex Si crystal following the concept of [6], as well as intensity and position monitors.

In this contribution we give an overview of the capabilities of the future HED science instrument with respect to expected X-ray beam properties and how these can be exploited for dynamic compression experiments. HED will be available for users from 2018 on.

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EUCALL Project – status after first year

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The European Cluster of Advanced Laser Light Sources (EUCALL) generates collaboration and synergy between large scale sources of laser-driven and accelerator-driven X-ray radiation.

The lead project partner is European XFEL, while the other partners are DESY, the Extreme Light Infrastructure (ELI) in Czech Republic, Hungary and Romania; ESRF in Grenoble, Helmholtz Zentrum Dresden-Rossendorf, Lund University, the Paul Scherer Institute and Elettra Sincrotrone Trieste. The networks *Laserlab-Europe* and *FELs of Europe* are also involved, while representatives from the user communities of FELs and Optical Lasers are members of EUCALL's steering committee. EUCALL is the first serious effort to bring together the two scientific communities who have been using X-ray light in parallel to each other, and from different scientific and technological backgrounds.

A major part of EUCALL's output is devoted to the development of new software for simulation and processing of advanced radiation experiments, as well as for new hardware for standardised sample delivery and beam diagnostics for ultra-fast laser experiments. This poster will outline EUCALL's achievements after the first year of its project period.

Portable Double-sided Pulsed Laser Heating System for Time Resolved Geoscience and Materials Science Applications

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A portable double-sided pulsed laser heating system for diamond anvil cells has been developed, able to stably produce laser pulses as short as a few microseconds with repetition frequencies up to 100KHz. *In-situ* temperature determination is possible by collecting and fitting the thermal radiation spectrum for a specific wavelength range (particularly, between 650nm and 850nm), to the Planck radiation function. Surface temperature information can also be time-resolved due to using a gated detector that is synchronized with the laser pulse modulation, and space-resolved with the implementation of a multi-point thermal radiation collection technique. The system can be easily coupled with equipment at synchrotron facilities, particularly for nuclear resonance spectroscopy experiments. Examples of application include investigations of high-pressure high-temperature behavior of iron oxides, in house and at European Synchrotron Radiation Facility (ESRF) using Synchrotron Mössbauer Source (SMS) and Nuclear Inelastic Scattering (NIS).

X-ray diffraction measurements of 'quasi'-single crystal tin shock compressed to 10 GPa

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The last 5 years has seen an influx in the number of experiments that combine high energy lasers with *in situ* X-ray techniques, allowing the structural characterisation of dynamically compressed materials. In this poster, I will present some of the first X-ray diffraction results from laser shock compression activities at the ESRF. Samples of highly textured Sn foil (45 µm) compressed up to P ~ 10 GPa. At pressures below 8 GPa, only compressed ß-Sn was observed, with compression of the Sn single crystals peaks shifting to higher 2-theta (smaller unit cell) along the same orientation; dislocations of some of the single crystals reflections at pressure were also observed. At higher energies (above 9 GPa), a phase transformation occurs to bct-Sn and a significant loss of texture is observed as the sample becomes a more textured powder (powder ring highlighted). This data marks the first time the ß-Sn – bct Sn phase transition has been observed in shock compression using X-ray diffraction techniques.

The Effect of Different Energetic Materials on the Fragmentation and Microstructure of Steel Pipe Bombs

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Pipe bombs are a form of Improvised Explosive Device (IED). Fragmentation of the pipe is affected by both the type of material of the pipe and the energetic composition used. The information gathered from this is applicable to post blast scenes where chemical trace evidence is unavailable in order to determine what explosive filler was used and hence trace it back to the supplier.

Six pipe bombs were constructed where the pipe material, a low carbon steel, was kept constant whereas the explosive was varied. The energetic fillers used were gunpowder, Bullseye, ammonal, Perunit E and PE4, thus ensuring deflagration to detonation events.

As the explosive power of the filler increased so did the number of fragments recovered, ranging from 15 (gunpowder) to 57 (PE4). However, the proportion of the total mass of the pipe recovered as fragments varied from 11.00% to 94.77% with the recovery of the detonated fragments lower than 22%, whilst the pipes which deflagrated had a recovery higher than 50%. The mean fragment size ranged from 1.23cm^2-22.06cm^2 from highest filler to lowest, this was a decreasing relationship with the exception of Pipe 3 (Bullseye with detonator) which had a mean fragment size of 1.90cm^2, lying between Perunit E and PE4.

Fragments, originating from the centre of the pipe were selected for microstructural investigation for both the radial and axial directions. Microhardness measurements ranged on average from 119Hv on the unexploded pipe to 225Hv on the pipe containing the highest explosive, PE4, an increase of 89%. The hardness of the steel was seen to increase in a linear manner with the violence of the event. The grain size was seen to reduce from 515grains/mm^2 to 837grains/mm^2, a percentage change of 63%

The FWDM confirmed the violence of the event but was limited by the fragment recovery. The changes to the steel microstructure of the pipe were proportional to level of explosive which was used, affecting both grain deformation and numbers/mm^2, a maximum change in the latter of 63%. For lower explosives, gunpowder and bullseye, grain deformation was observed in the direction of the applied strain. In higher powered explosives: ammonal, Perunit E and PE4, deformation by twinning was observed. In the case of the pipe filled with PE4, cross-slip bands were observed. The distance between grain boundaries became lower with higher powered explosive and that the number of grains per millimetre squared increased due to the plastic deformation within the steel pipe bomb. Hardness testing also gave a comparative indication of the explosive power of the energetic filler as the hardness of the metal increased by a maximum of 89%, with the explosive power.

Solid Hydrogen Targets for High Power Lasers

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Pure beams of energetic protons are of considerable interest both for scientific studies and future applications (eg cancer treatment by proton therapy). Thin ribbons of solid hydrogen have been developed at the Low Temperature Laboratory (SBT) as targets for High Power Lasers to generate such protons beams. The system was tested on different laser facilities in collaboration with ELI-Beamlines in the Czech Republic.

We will describe the cryostat [1] which can produce, with great reliability and reproducibility over long durations, such thin hydrogen ribbons (a few tens of μm in thickness). This cryostat was installed at different High Power Laser Facilities (at PALS in the Czech Republic [2] and Figure 1 below, at LULI2000 in France): the results obtained will be shown and future developments described.

Figure 1 : installation of the ELISE cryostat at PALS

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High-Pressure Synthesis of novel phases using shock waves

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The application of shock waves is an unique tool to investigate matter under extreme pressure and moreover to synthesize large amount of high-pressure phases (in gram range) for ex-situ investigations and tests.

For this purpose shock wave experiments are carried out using a detonation driven flyer-plate set-up with a special designed recovery system for the use in the Megabar range. By the use of different sample geometries, pressure/cooling media, sample holder and flyer-plate materials and material combinations a broad experimental range of pressure and temperature is accessible [1, 2].

Examples are the successful high-pressure synthesis of diamond, cBN, high pressure Sialon's and appropriate binary and ternary phases (γ-Si_3N_4, Si-O-N, rs-AlN) [3-5]. By the use of precursors (e.g. polymer derived ceramics) an adequate synthesis can be carried out.

For the understanding of processes during shock compaction including phase transitions, microscopic observation and phase analysis of the recovered samples are carried out and complemented with calculations (e.g. equation-of-state, melting curves). However, to get a better and more precise insight to phase transition (forward and backward) an in-situ observation is desirable. We believe that this can be done by fast time resolved XRD and spectroscopy using synchrotron radiation.

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AWE and LANL Detonator Research using Ultrafast X-ray Phase Contrast Imaging with LANL's IMPULSE Facility at APS

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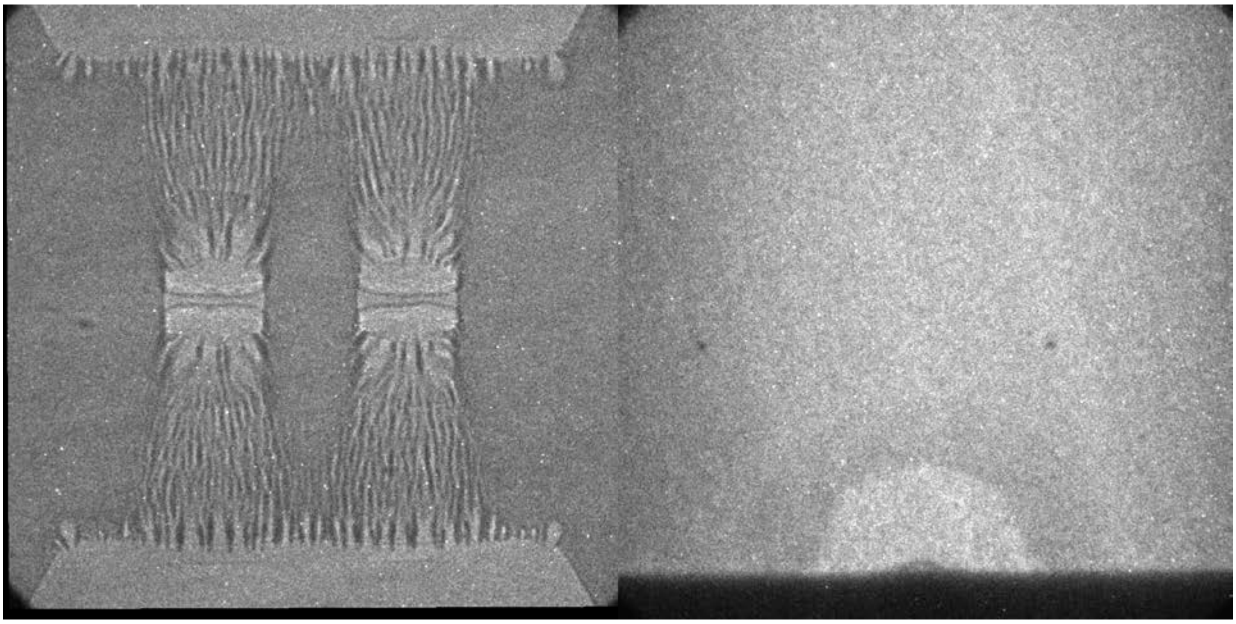
AWE is currently collaborating with LANL to conduct experiments on detonators using the IMPULSE imaging system at the Advanced Photon Source (APS). The x-ray phase contrast imaging technique used at sector 32 and 35 (DCS) is ideally suited to detonator studies due to micron resolution and 1-2 mm field of view. To date, several important advances in detonator understanding have been made. Particularly, the electrical explosion of metallic foils has been found to be heterogeneous and striated, and an explanation for this phenomena produced. This was imaged for the first time at APS on appropriate timescales and representative detonator system dimensions. Coupling this imaging technique with magneto-hydrodynamic modelling codes has enabled an understanding of surface design tolerances on the bulk electrical explosion of metal foils (see Figure 1a).



(a) (b)

Figure 1: The electrical explosion of a copper foil with two circular defects (a) and the explosion of a wire in an inert powder material showing shock-wave and gas cavity(b).

Another important breakthrough that has come from this revolutionary diagnostic technique is the ability to image the shock-wave produced during the explosion of bridgewires in optically-opaque porous beds (Figure 1b). Shock-waves are hypothesised as the critical energy transfer mechanism in the initiation of exploding bridgewire (EBW) detonators and imaging of this propagation allows determination of the energies and pressures involved in this potential shock-to-detonation transition.

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Million frames per second X-ray phase imaging at ID19

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Ultra-high-speed (UHS) hard X-ray imaging with ultra-short exposure times at up to a million frames per second has enormous potential for studies of transient dynamic processes. Particularly for processes which are impossible to visualize using just single-shot X-ray imaging and that cannot be probed, or may only be partially probed, by conventional optical shadowgraph techniques. We will present results from UHS hard X-ray imaging which exploit the high brilliance, partial spatial coherence, ~100 ps pulse width and MHz frequencies of synchrotron X-rays at the ESRF achieved using an indirect X-ray detection scheme with a burst image sensor. We will show selected examples such as an observation of electric arc ignition in an industrial fuse, crack propagation in a glass, and laser-induced dynamics such as shock wave in water, compression wave in polymer foam and ablation of aluminium.

Use of ultrafast radiography to investigate dynamic compaction of polymeric foams

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Polymeric foams are widely used in automotive, aeronautic, aerospace or defense industries, due to their energy absorption capability and light weight. In this work, we study the shock response of two polymeric foams, an expanded polyurethane foam (320 kg/m^3) and a syntactic epoxy foam (624 kg/m^3). Previous experiments under quasi-static loading highlighted both residual strain due to compaction but also viscoelasticity. The objective of the experiments conducted at ESRF was to observe the deformation of foam structures during the propagation of a laser-driven shock wave. A 5 J laser device coupled to X-rays in 16-bunch mode and a Shimadzu HPVX2 fast camera were used. The main results are the observation of viscoelastic relaxation phenomena and the compaction wave mitigation during its propagation.

Further work will consist in observing recovered samples by tomography to analyze deformation mechanisms. Besides, we intend to perform identical experiments using a VISAR in order to measure the velocity profiles and calibrate the loading.

In Situ Investigation of Mesoscale Mechanics of Energetic Materials Using X-ray Diffraction

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Weak impacts on high explosives (HE) can give rise to violent reactions or harmless fracture and material dispersal. Predicting this response or the state of damage in the material remains an unsolved technical challenge. *In situ* mesoscale insights to anisotropic dislocation-mediated plasticity, phase transitions, and damage are needed to quantify fundamental structure-property relationships, inform theory, and enable high fidelity simulations. Time-resolved, *in situ* X-ray diffraction during dynamic loading, spanning multiple orders of strain rate, using synchrotron (Advanced Photon Source) and X-ray free electron laser (Linac Coherent Light Source) radiation has been performed for single crystal and plastic bonded formulations of cyclotrimethylene trinitramine (RDX). For the first time, diffraction patterns quantify the average lattice response during elastic-plastic and phase transition and allow for direct comparison of experiments and simulations through measured and computed diagnostics.

Spectroscopic Studies of Nanostructured Topological Insulator Bismuth Telluride and Impact of Surface Oxidation

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Bismuth telluride (Bi_2Te_3) nanoparticles were prepared by wet chemical method and their surface oxidation behavior was studied by X-ray photoemission spectroscopy, Raman spectroscopy and Soft X-ray Absorption Spectroscopy. Single crystals of Bi_2Te_3 were also studied to compare the effect of nanostructuring on surface oxidation. Besides A^1_g, E^2_g and A^2_{1g} at 61.4 cm^{-1}, 101.9 cm^{-1} and 143.5 cm^{-1} respectively vibrational modes from Bi_2Te_3 nanostructures[1], two new peaks at 93.3 cm^{-1} and 121.1 cm^{-1} were observed in Raman spectra which are assigned to α-Bi_2O_3 and TeO_2 respectively [2] as shown in figure 1(a), confirmation of these peaks were done by compare it to individual Bismuth and Tellurium films which are also exposed in air. Two shoulders appear in XPS spectra along with the major peaks, which are corresponding to Bi_2Te_3 while the major peaks are corresponding to TeO_2, this indicates that most of the surface of nanoparticles get oxidized due to high surface to volume ratio and the surfaces of single crystals were not oxidized. Te-3d scan in XPS spectra shown in figure 1(b) which clearly indicates the same[3]. Overall study concluded that in Bi_2Te_3, bismuth and tellurium bonded with oxygen as Bi-O and Te-O instead of Bi-O-Te. Oxygen K-edge in SXAS results also supports the XPS and Raman studies. Oxidation mechanism of the nanostructures were presented. These oxidation studies on nanostructures will help to define a pathway towards nanostructures based devices.

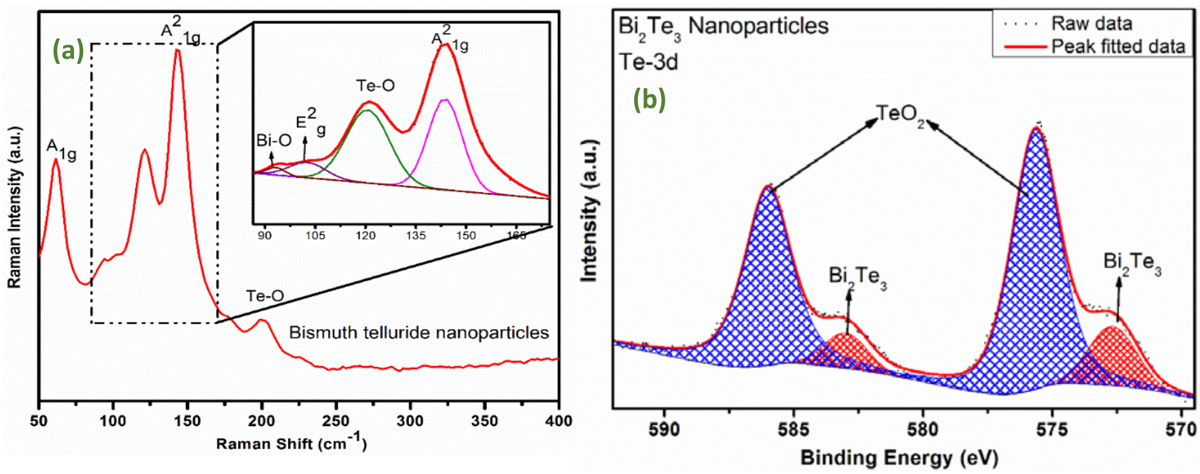

Fig. 2 (a) Raman spectra and Fig.1 (b) XPS spectra of Bi 4f scan of Bi_2Te_3 nanoparticles

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Resolving dynamic properties of warm dense matter with X-rays

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Warm dense matter (WDM), created under extreme thermodynamic conditions, like densities in the region of solids and temperatures in the region of 10^4 – 10^5 K, represents the transition state between condensed matter and hot dense plasma. This extreme material state can be found, for example, in the interior of stars, large planets or brown dwarfs but also in laboratory experiments, where solid matter is quickly transferred to a plasma state. Partial ionization, electron degeneracy, ion coupling and complex dynamic processes make the characterization of WDM very challenging. Neither methods of classical solid state physics nor of plasma physics can describe this state satisfactory and thus new models have to be developed.

X-ray facilities in the combination with high energy lasers are uniquely suited to investigate these extreme matter states and to test model predictions. This poster will show planned experiments of the Helmholtz International Beamline for Extreme Fields (HIBEF) at the HED user facility at European X-FEL using short pulse laser systems (fs-laser), focusing on the study of dynamic properties of WDM.

Probing gas gun experiments with quantitative single-bunch phase- contrast radiography on Beamline ID19

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Shock compression causes a nearly-discontinuous change in thermodynamic conditions within a system, subjecting the shocked material to extremes of pressure (GPa-TPa), temperature (1000's K) and strain-rate (10^5-10^8 s^{-1}). Shock compression is therefore a powerful tool with which to explore the high pressure-temperate states of matter that are found in aerospace, planetary, defence and nuclear fusion scenarios.

This Poster presents a state-of-the-art dynamic X-ray phase-contrast radiography method for probing dynamically compressed samples on Beamline ID19, ESRF. These experiments represent the first gas gun experiments at ESRF and demonstrate a method which is matched only by the Dynamic Compression Sector, APS. Shock-waves are driven into materials using a single-stage gas gun with a 12.7 mm or 32 mm diameter bore. A focus is given to the study of several heterogeneous granular systems with the radiographic method. The ultrafast (150 ps exposure, 176 ns interframe time), high spatial-resolution (~ 50µm), large field of view (~ 12x12mm) measurements allowed for spatially and temporally resolved measurements of wave velocity, wave thickness and density to be extracted directly from the radiographs. These results represent a significantly wider scope of data than could be collected using surface-based techniques.

Three experimental campaigns have been conducted since the first *Workshop on Studies of Dynamically Compressed Matter with X-rays* in 2015. A long-term access grant has been awarded and will see further development of loading platforms at ESRF, including a split-hopkinson pressure bar and two-stage gas gun. The unique combination of a hard X-ray flux and large beam size available on Beamline ID19, ESRF complements developing capabilities at APS, SLAC and the European XFEL.

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High Pressure Structural Phase Transition in NdX (X=P, As, Sb): A Density Functional Theory Study

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The structural and phase transition properties of NdX (X = P, As, Sb) under high pressure have been investigated using an ab-initio full potential linear augmented plane wave plus local orbitals approach within the framework of density functional theory as implanted in the WIEN2k package [1]. In this approach the generalized gradient approximation is chosen for the exchange-correlation functional energy optimization for calculating the total energy. At ambient conditions NdX stabilize in NaCl (B1 phase) structure. Under compression, it undergoes first-order structural transition from Fm-3m to P4/mmm (body centre tetragonal) phase at 30.0, 24.06 and 15.1 GPa which is found to be in good agreement with the available experimental data [2] 30.0, 24.2 and 15.0 GPa respectively. The structural properties viz., equilibrium lattice constants, bulk modulus and its pressure derivative and volume collapse are also calculated and compared with previous calculations and available experimental data.

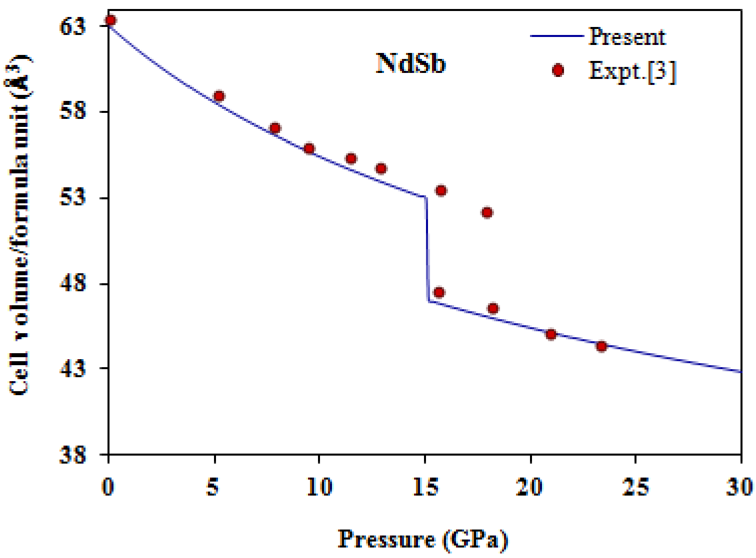

Figure 1: Variation of Cell volume/formula unit versus pressure for NdSb compound.

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Generating and recovering nanodiamonds from shock-compressed plastics

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Under the extreme conditions within the giant planets of more than a million times Earth's atmospheric pressure and thousands of Kelvins diamonds are expected to form from the present hydrocarbons. These conditions are achievable in the laboratory on a time scale of nanoseconds. In this context we aim for a better understanding of the complex interior chemistry and the evolution of these planets. Our goal comprises the generation, recovery and analysis of diamonds generated by laser-induced shock-compression of different plastics. However, nanodiamonds stand out as an interesting material for science and technology due to their mechanical and optical properties as well as their non-toxicity [1]. Thus, discoveries can have important implications for diverse applications on Earth too.

The basis of this work was set by Kraus et al. demonstrating nanodiamond generation in previous experiments. At the Linac Coherent Light Source of Stanford National Accelerator Laboratory cubic diamonds were generated by shock compression of pyrolytic and polycrystalline graphite above 50 GPa and hexagonal diamond, lonsdaleite, was detected above 170 GPa for pyrolytic samples only [2]. In a further experiment polystyrene samples were dynamically driven to 150 GPa and 5000 K yielding nanodiamonds [3]. The general experimental set-up consists of two long pulse lasers inducing the necessary two-stage shock compression and an XFEL enabling the in situ identification of diamond crystals by femtosecond X-ray diffraction.

The next step is the recovery of the shock-generated nanodiamonds by testing different recovery target designs with the focus on the survival of the structures after the release to ambient conditions. Moreover, there is potential to clarify the existence of lonsdaleite that has recently been questioned [4].

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High pressure shockwave synthesis of materials: What happens *really* at small scales?

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Although first demonstrated for diamond in the 1960ies [1], the synthesis of materials in shock waves in the multi-gram to multi-kilogram scale with the aim of their technological and industrial use still is to be regarded as largely dominated by empirical methods and phenomenological observations. This is due to the fact that in the majority of cases, the initial state of the materials subjected to the shock for this purpose is inherently heterogenic. Already in the early stages of diamond shock synthesis it became apparent that the porosity, i.e. the number and distribution of void space within the material, has a higher influence on synthesis yield than the overall shock loading parameters [2]. This is due to the fact that the shock-driven collapse of microscopic voids creates 'hot spots', where the material experiences pressures and temperatures that can be ten to hundreds of times higher than those calculated from continuous media theory of shock waves [2,3]. In a recent publication, the authors have shown that the pressure at the tip of a miniature-jet in shocked copper beads might approach 6 Mbar [4]. This sheds light on the complex role of metal powder additives first introduced in the 1960s as cooling agent and impedance modifiers to enhance the yield of shock-synthesized diamond and c-BN, which were also employed successfully in the more recent synthesis of other refractory high-pressure phases, such as rocksalt-type AlN [5] and spinel-type γ-Si_3N_4 and γ-Si/O/N [6], using crystalline nanoparticles and amorphous inorganic precursors as starting materials.
Therefore, in order to understand and model the formation processes of refractory high pressure phases in these types of shock synthesis experiments, we are seeking for means to obtain equation-of-state data on typical precursor materials up to very high pressures and temperatures, as well as to take microscopic *in-situ* snapshots of the interactions between precursor and metal additive.

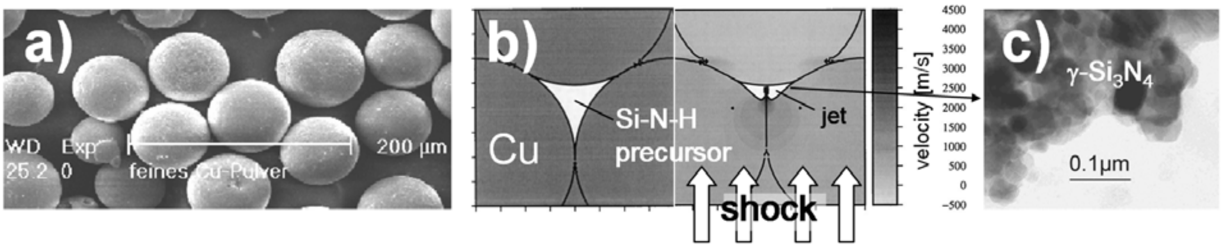

Figure 1: a) SEM image of copper beads, typically used as additive in shock wave synthesis experiments, (b) jet formation in voids between metal spheres after [3], c) TEM image of retained spinel-type γ-Si_3N_4 nanopowder

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Evolution of the structure of solid carbon clusters in high explosive detonation products

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Shock driven chemical reactions in carbon-rich high explosives yield solid carbon as a major constituent of the products and, depending on the thermodynamic conditions behind the shock front, a variety of carbon allotropes and morphologies may form and evolve. Here, time resolved small angle x-ray scattering (SAXS) was applied to study the dynamics of carbon condensation following detonation of the triaminotrinitobenzene containing high explosive PBX-9502 (Figure 1). Carbon particle growth dynamics were probed from 0.1 to 2.0 μs after the arrival of the shock front and showed rapid initial growth which ceased after 200 ns. Final carbon cluster morphologies were consistent with 8.4 nm diameter spherical particles with rough surfaces and matched particle sizes obtained from recovered products. Simulations using a reaction rate kinetic model are in good agreement with the growth phase. At longer times, the assumption of diffusion-limited condensation was found to break down, which is expected to be due to decreasing surface reactivity of the carbon particles. Detonation product densities from a Wescott-Stewart-Davis (WSD) reactive flow model[1] were compared to the electron density contrast obtained from TR-SAXS and indicated the carbon particles had an approximate composition of 80% turbostratic graphite and 20% diamond.

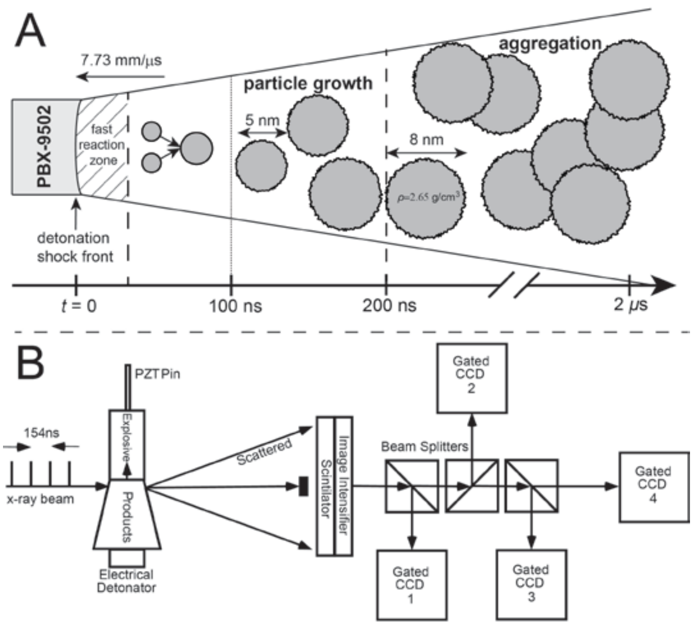

Figure 1: A) Scheme of the carbon clustering process. The shock front arrives at *t*=0 followed by chemical decomposition, growth of solid carbon particles, and finally particle aggregation. B) X-ray pulses are timed to intercept the HE sample relative to the passage of the detonation front and scattered intensity from individual pulses is measured by four gated CCD cameras

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