Structural Evolution during Exothermic Metal Combustions

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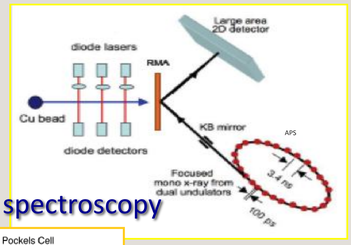
Abstract

This project is to investigate dynamic responses of reactive materials (RMs) and to understand shock/blast wave effects on materials

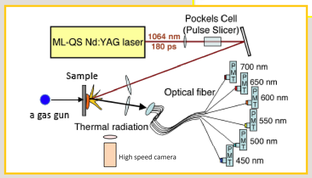
Approach

- Subject RMs under controlled mechanical (plate impact) and thermal (pulse laser/electric heating) impacts
- Measure the dynamic structural and chemical changes in real-time, using time-resolved x-ray diffraction (TR-XRD), TR-spectrocopy and high-speed microscopy

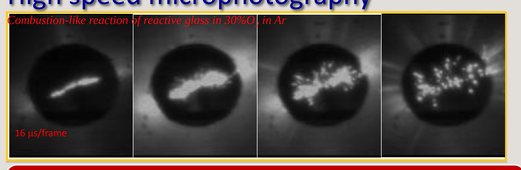
Time-resolved synchrotron x-ray diffraction



Time-resolved spectroscopy



High speed microphotography



Relevance

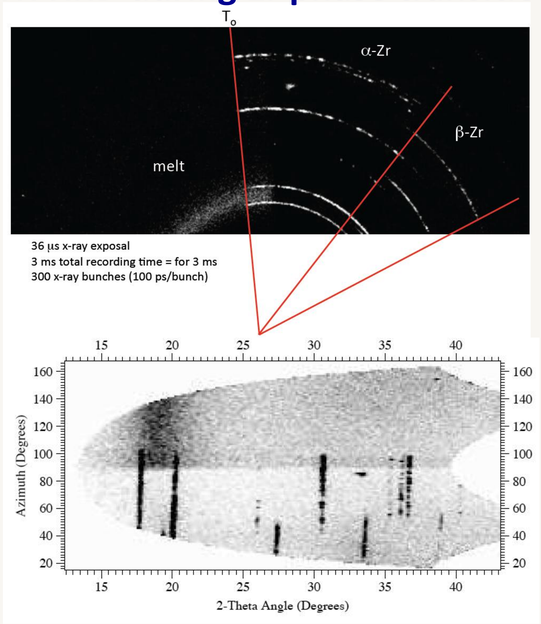
Understanding dynamic responses of materials undergoing exothermic reactions (detonation, combustions, etc.).

- Mechanical deformation
- Fracture and fragmentation
- Chemical reactions of fragments

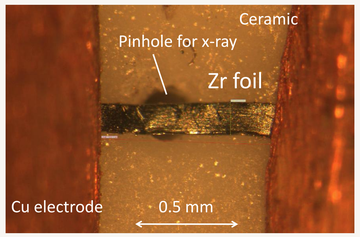
Providing fundamental data to measure the blast effects of reactive materials and thus to develop predictive capabilities

Technical Approach: Novel Time-resolved X-ray Diffraction (TR-XRD) using Third-generation Synchrotron X-rays

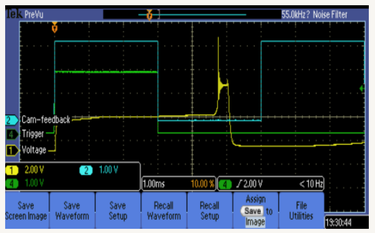
TR-XRD during Zr phase transitions



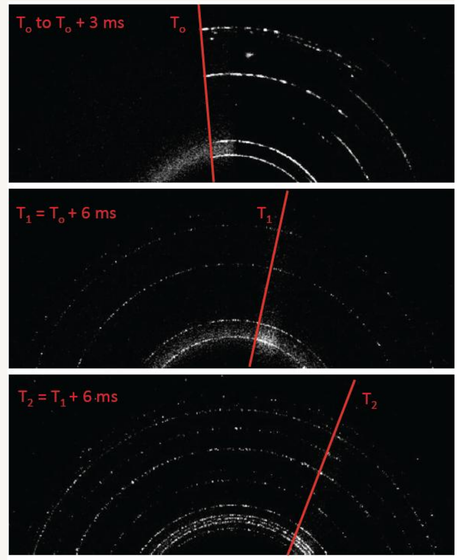
Sample configuration

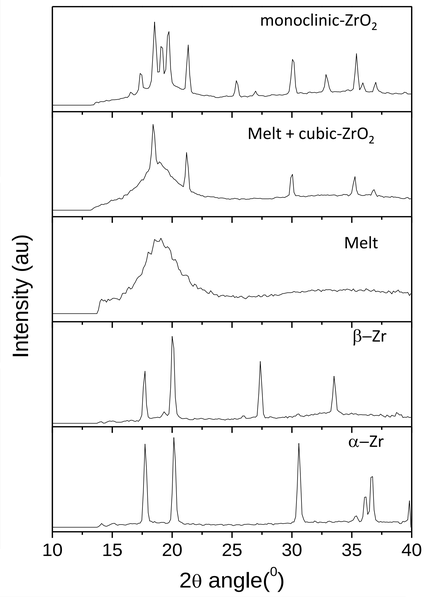


Electric pulses



TR-XRD during Zr combustion





α-Zr initially transforms into β-phase, then melts within 50-60 μs

Zirconium combustion occurs from the melt on a time scale of 2-3 ms, yielding high T cubic phase and then low T monoclinic

Accomplishments Through Current Year

- Demonstrated TR-XRD to probe structural and chemical evolutions during exothermic reactions of RMs, using the third-generation synchrotron source at Advanced Photon Source.
- This is a breakthrough development, enabling the structural and kinetic studies of energetic materials at extreme PT conditions behind detonation, deflagration, and combustions.

Future Work

- Investigate dynamic properties of RMs (thermite mixtures, nano-metallic composites, and reactive multilayers, etc) in controlled aerobic and anaerobic conditions

Opportunities for Transition to Customer

The present results are high values to understanding dynamic responses of solids subjected to strong shock/blast waves:

- Providing a quantitative method for evaluating shock/blastic wave effects.
- Enabling effective collaborations with DOE national laboratories (APS/Argonne, LANL) on DHS research interests

Patent Submissions

Via this and other related projects, we have developed several key technologies for investigation of dynamic responses of solids - leveraged by other program, including of time-resolved synchrotron x-ray diffraction and high-speed micro-photography

Publications Acknowledging DHS Support

- Minseob Kim, Jing-Yin Chen, and Choong-Shik Yoo, J. Appl. Phys. (2011) submitted
- Haoyan Wei and Choong-Shik Yoo, time-resolved temperatures to measure global kinetics of reactive metals, (2010) in preparation.
- Simon Clark, Jing-Yin Chen, and Choong-Shik Yoo, (2011) in preparation
- Choong-Shik Yoo, Novel Solids at Extreme Conditions, Pacifichem-2010, Dec. 15-19 (2010) (invited)

Other References

- Understanding dynamic responses of materials under extreme conditions has been identified as one of the basic materials research needs by DOE-BES and National Academy of Sciences.
- Time-resolved x-ray diffraction for structural studies on single event phenomena is timely with the recent emphasis at advanced light sources, LCLS, APS, NSLS-II, ERL, PETRA-III.

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