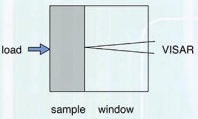
Dynamic Compression of Synthetic Diamond Windows

LDRD
LABORATORY DIRECTED RESEARCH & DEVELOPMENT

Sandia National Laboratories
Primary Investigator: D.H. Dolan, Project Manager: T. Mehlhorn

Dynamic compression research

- Rapid material loading
  - <10-1000 ns time scales
  - Nearly adiabatic
  - Extreme conditions
    - 1-1000 GPa (1 GPa=10,000 atm)
    - RT to many eV
  - Reveals a wide range of material phenomena
    - Elastic-plastic deformation
    - Phase transformations
    - Chemical reactions



Loading methods:
Impact
Explosives
Electromagnetic (Z)
Laser

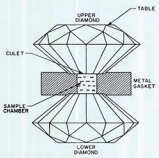
Duvall and Graham, Rev. Mod. Phys. 49, 523 (1977).

Problem: windows needed to maintain stress

- Windows must be:
  - transparent (primarily visible, emerging infrared and x-ray applications)
  - robust to chemical, thermal, and mechanical stresses
    - example: NaCl is not a particularly good choice
  - easily understood and modeled
    - No time dependent phenomena
- Other considerations:
  - Mechanical impedance
  - Thermal conductivity
  - Cost (relative to experiment)
    - Typically need to be <$1000 per piece
- Strong need for high impedance windows in the 10-100+ GPa domain

Diamond is a great window material

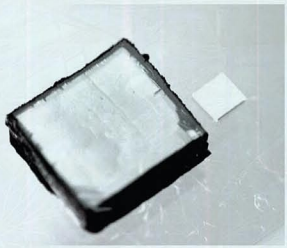
- Many useful properties:
  - Transparent (visible, infrared, x-ray)
  - Large elastic range
    - 50-100 GPa, possibly higher
  - Very robust
  - High mechanical impedance
  - Large thermal conductivity
- Nature diamond is too expensive
  - Typical impact window (1" O.D. X 1/4" thick):
    - 3.2 cc weighs in at 57 carats (11.3 g)
  - Waves travel at roughly 18 km/s
    - 50 ns experiment requires 4 X 1 mm (0.2 carat) window
    - Mass scales as t_3 (100 ns requires 1.6 carat)
- Diamond Prices are artificially high
  - http://www.edwardjayepstein.com/diamond/prologue.htm



The diamond anvil cell revolutionized static high pressure research. Schematic from A. Jayaraman, Rev. Mod. Phys. **55**, 65. (1983).

Approach: investigate synthetic diamond

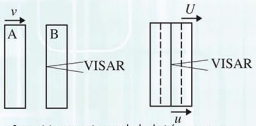
- CVD diamond:
  - Single crystals
  - Colorless
  - Large windows possible
  - Can be more perfect than natural diamond
    - Harder
    - Higher thermal conductivity
- Limited number of sources
  - Carnegie DOE Alliance Center (CDAC)
  - Apollo Diamond



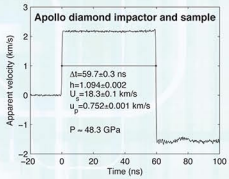
Left: 7x7x2 mm CDAC diamond (>$4000 market, ~$200 to produce)

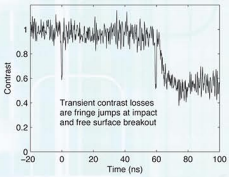
Right: ~2 mm square, < 1 mm thick commercial diamond plate (~$200 market)

Results: shock compression



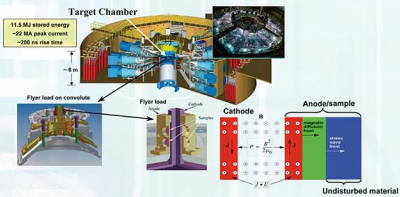
- Symmetric impact experiments probe the elastic/transparent range
  - Elastic response observed to 48 GPa
  - Very large window correction (2.7-2.9)
  - Consistency study and HEL under investigation
- Technical challenges
  - Sample variability
  - Multiple optical reflections
  - Sub-nanosecond rise times





Work planned (FY 2008)

- Shock/isentropic compression studies of diamond beyond 100 GPa (1 Mbar) using ZR



Significance: dynamic compression and beyond

- Dynamic materials campaign applications
  - Immediate impact: high impedance window for shock and isentropic compression
    - High pressure liquid isentropes (deuterium, water)
    - Dynamic strength measurements
    - Diamond melt studies (NIF capsule material)
  - Future impacts
    - Dynamic pyrometry and x-ray diffraction measurements
    - Combined static-dynamic compression experiments
- Broader applications
  - Novel diagnostics (disposable neutron detectors)
  - Micro-electronic/mechanical systems
  - Other possibilities??

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND2007-3564P CreativeArts 98429.LW.8.07

NNSA National Nuclear Security Administration

Sandia National Laboratories