Full-Field Phase-contrast Imaging and the MBA

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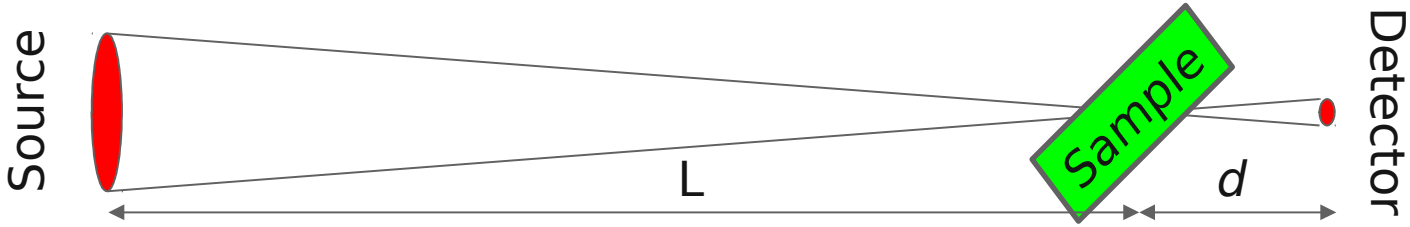
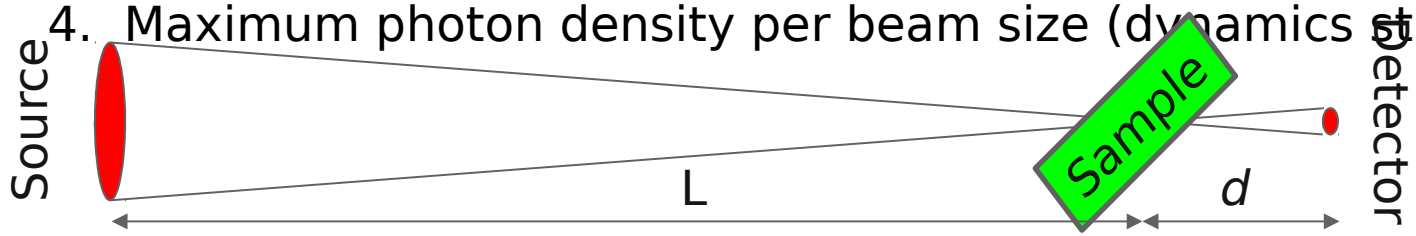
Phase-Contrast Imaging Characteristics

- Advantages of propagation-based phase-contrast imaging (PCI):
  - Powerful, versatile, high penetration, sensitivity
  - Simplicity (free propagation):
    - no restrictions on sample environment.
  - No optics required:
    - Pristine beam: wave-front and coherence preservation.
    - White beam , Large beam, All beam (photons).
  - Combines:
    - Large beam
    - High energy
    - High temporal (100 ps) and spatial (1 μm) resolution
- Fits the upgrade theme:
  Real materials in Real conditions and Real time



Phase-contrast Imaging requirements

- PCI has a **combination** of four requirements for the science drivers:
  - 1. Sufficient beam size, for realistic samples (cm scale): undulator tapering.
  - 2. Increased sensitivity:
    - Detected intensity: $I(x,y) \sim 1 - \lambda d/2\pi\, \Delta_{xy}\varphi(x,y)$, where φ is the phase of the transmitted beam wave-front, and *d* the sample-to-detector distance. Thus the contrast increases with distance *d*.
  - 3. Increased spatial resolution (µm):
    - Image blurring due to source size *σ* is proportional to the source penumbral angle $\alpha = d.\sigma/L$, where *L* is source-to-sample distance.
  - 4. Maximum photon density per beam size (dynamics studies)



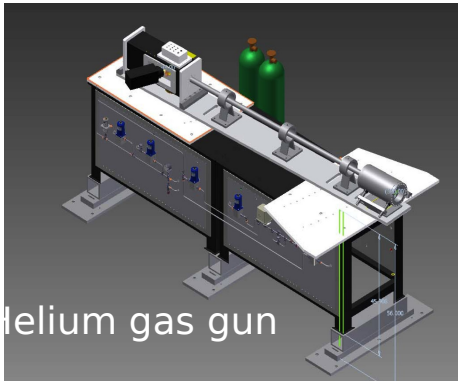
Phase-contrast Imaging with MBA

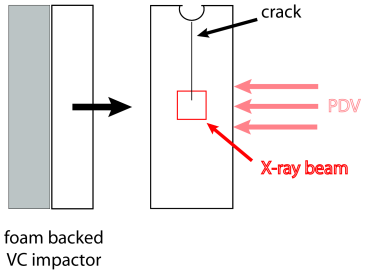
- Smaller horizontal divergence
  - Horizontal DCM, more stable, and no loss due to angular acceptance.
  - Use of optics with improved beam acceptance, central zone, and less absorption.
    - Can be used as wide-band monochromators for dynamic studies: significant increase in available photon flux.

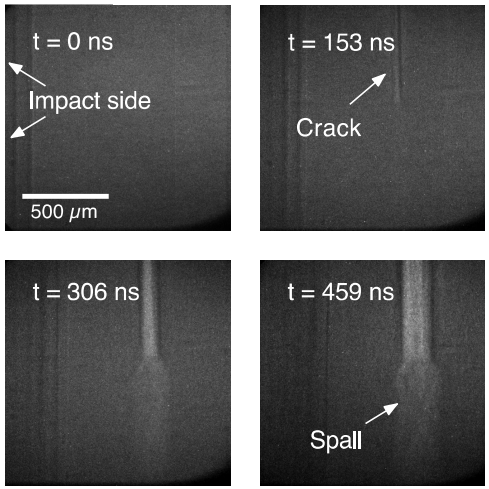
- Smaller source size
  - Longer detection distance: keep µm spatial resolution (source blurring) and improve contrast at ***high energy***.
    - Higher energy: larger and/or high Z samples, with less radiation damage/interaction for soft materials.
  - Zoom-imaging to bridge the 1 µm – 10 nm gap in full field imaging
    - Adding optics for hier

Crack dynamics using phase-contrast imaging

- Scientific opportunity
  - The development of time-resolved techniques that provide in situ spatially resolved measurements of the dynamic response of materials is a long-standing scientific need.
  - PCI is especially well suited for observing interfaces, resolve the initiation, propagation, and coalescence of cracking and spall *in situ*, something for which common shock physics and impact diagnostics are not.
  - Spall configuration was used to create plane strain from the interaction of release waves at the precise location of a fatigue crack propagated and arrested halfway into a shock loading Vitreous Carbon specimen.
- Challenges
  - Limited to low Z materials.
  - Studies of high Z and thicker samples are impossible.
  - Blurring du to the horizontal source size prevents from resolving the early stage of crack formation, or details of the cracks and voids, or the shockwave front.
- MBA strengths
  - Smaller horizontal source size
  - Use of Higher x-ray energy can be better optimized:
    - Possibility for longer detection distances
    - Better contrast







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LANL

In situ monitoring of during solidification

- Scientific opportunity
  - Solidification research is a field that is increasingly turning to phase contrast imaging techniques for ***dynamic*** *in situ* monitoring of phase transformations.
- Challenges
  - Large samples, and materials of interest with high Z (e.g. Mo, Ni, Fe, Pt, Au…).
- MBA strengths
  - Smaller horizontal source size
  - Use of higher x-ray energy can be better optimized:
    - Possibility for longer detection distances
    - Better contrast
    - No additional blurring du to horizontal source size

Proton Imaging
pRad at LANSCE at LANL

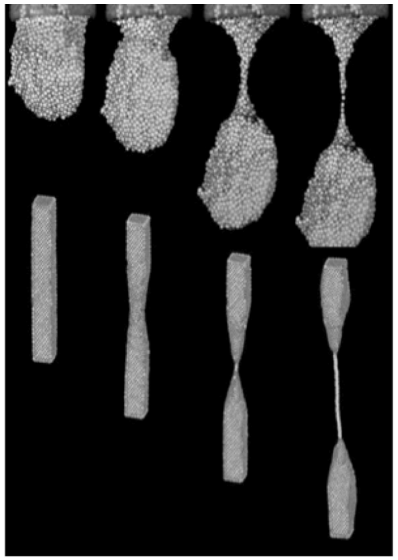
X-ray Imaging
APS at ANL

Proton (left) and x-ray imaging (right) during controlled melting and solidification of (Al-10 at.% In) alloy. Note the difference in scale (large sample size for protons) and the level of details (high resolution for x-rays).

A. Clarke et. al., Scientific Reports 3, 2020, (2013), DOI:10.1038/srep02020

Dynamics of complex and simple fluids

- Scientific opportunity
  - Dense suspensions of solid particles in a liquid exhibit behavior intermediate between ordinary solids and liquids. This gives rise to a range of unique and often complex responses to applied stresses, especially when the suspension is driven far from equilibrium.
  - Need for high resolution dynamic x-ray imaging of the particle configurations during break-up. Conversely, in densely packed systems one would detect local defects or small voids and track their coalescence.
- Challenges
  - Gravity important: need a better horizontal resolution
  - Wall (boundary) effects: need for thick samples.
- MBA strengths
  - Smaller horizontal source size
  - Use of higher x-ray energy can be better optimized:
    - Possibility for longer detection distances
    - Better contrast
    - No *additional* blurring du to horizontal source size



Dense suspension of 200 µm particles detaching from a nozzle (top), and molecular dynamics simulation of a gold nanowire being formed by ductile rupture (bottom). Courtesy of H. Jaeger (UoC)

MBA Lattice Enables Advanced Fuel-Spray Research

Opportunity

Breakup of liquid fuels is responsible for high-efficiency and low-emission engines. Fundamental hydrodynamics problems in multi-phase fluids on ms to ns time scales. Many proposed breakup mechanisms linked to in-nozzle flow: Turbulences, Cavitation

Challenge:

Through a few mm thick steel, very low contrast, and fast: 10 ns!

Efficient high-speed detectors

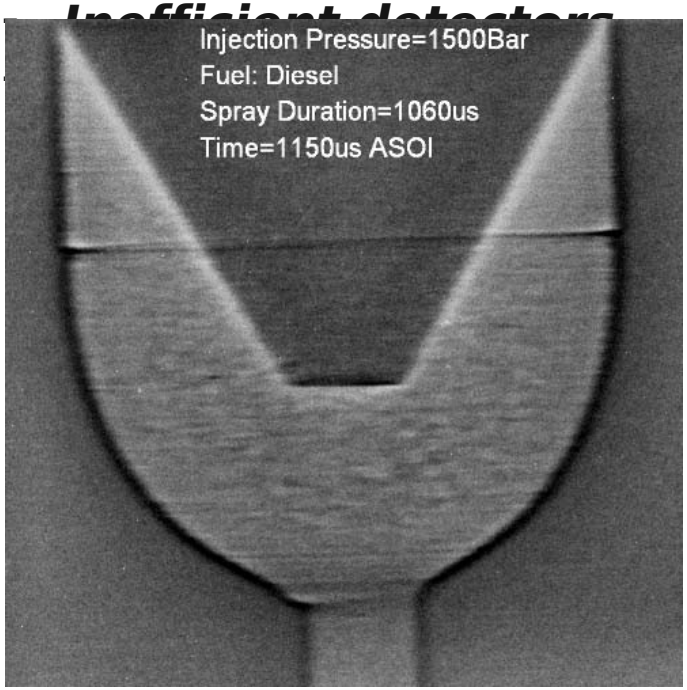
Key MBA features:

Low emittance - much smaller H-source size

Sub 1 µm spatial resolution (H & V)

Exposure time limited to 500 ns

- ***Low contrast @ high E***
- ***Lack of spatial resolution***
- ***Inefficient detectors***



Jin Wang et al. XSD, ANL.