**Design of an X-Ray Thomson Scattering Imaging Spectrometer**

E.J. Gamboa, D.S. Montgomery, R.P. Drake

1. University of Michigan, Ann Arbor, Michigan 48109
2. Los Alamos National Laboratory, Los Alamos, New Mexico 87545

**X-ray Thomson scattering diagnostics**

- X-ray Thomson scattering (XRTS) is a powerful technique which can provide information on the density, temperature, and ionization state of a dense plasma.

- A spatially-resolved XRTS diagnostic allows us to extract this information along a propagating shock.

- The small Thomson scattering cross section necessitates diagnostics with high throughputs.

**Spatially resolved spectra**

- The detector must resolve better than 25 μm spatially and 4 eV spectrally. An energy range of > 300 eV is desired.

- This leads to an optimization problem for the choice of crystal, probe beam, and optical mount in the design of an XRTS diagnostic.

- Diagnostic development is taking place on the Trident laser with future integration on OMEGA.

**Integration of the spectrometer into a TIM**

- With the higher photon flux available at OMEGA, considerations for high throughput can be relaxed in favor of robustness and technical constraints on alignment.

- The spectrometer must be made as compact as possible along the z-axis. This favors high energies (Zn) and therefore low Bragg angles (θv < 16°).

- A large-format hybrid CMOS imaging sensor would allow for lower magnifications and ease shot-to-shot alignment.

**Choosing the crystal and probe beam energy**

- Maximizing Rv will yield the greatest throughput.

- For photon energies < 9 keV, the (111), (220), (311), and (400) planes of Ge are available.

- The 90° scattering geometry means that the crystal will see only π-polarized photons.

- Rv = Cos(2θv) > Rv > 0 for θv = 45°

- Large θv leads to decreased astigmatism (Ge(400)), flatness of Rv across the energy range ensures linearity of intensity (Ge(111)).

**Spatial resolution for TIM design**

- The spectral range of the spectrometer as determined by the crystal length in the dispersion direction Sv and the magnification M.

- The length of the detector in the dispersion direction is limited by defocusing as the flat detector moves off the Rowland circle.

- Shown is a plot of the spectral range for a Ge(400) crystal aligned to Ti He ν with Rv = 15 cm and Sv = 5 cm.

- The spectral range of a curved crystal may be expressed in terms of the range of a flat crystal as

\[ ΔE(M, S_v) = ΔE_{(M, S_v)}(S_v, R_v, \theta_v) \]

**Spatial resolution for TIM design**

- The detector must resolve better than 25 μm along the z-axis.

- The spectrometer is fairly insensitive to rotations along the y and z axes. Rotations about the x-axis are similar in effect to z-displacement. The crystal must be aligned to better than 0.01 degrees about the x-axis.

- The x-displacement and x-rotation will necessitate precise post-insertion alignment.

**Toroidally curved imaging spectrometers**

- A toroidal crystal is defined by a horizontal radius of curvature Rv and a vertical radius Rv. The spectrometer has dispersion along the horizontal axis and spatial focusing along the vertical axis.

- An image is formed at the detector which is spectrally resolved along one direction and spatially resolved along the other. The spatial axis at the detector corresponds to the direction of the propagation of the shock in the source.

- We use perfect crystals that are grown and bent in such a manner to create a lattice that is almost completely free of defects. This allows for spatial resolutions that are not possible with mosaic crystals.

**Spectral range**

- The spectral range of the crystal is determined by the crystal length in the dispersion direction Sv and the magnification M.

- With the higher photon flux available at OMEGA, considerations for high throughput can be relaxed in favor of robustness and technical constraints on alignment.

- The spectrometer must be made as compact as possible along the z-axis. This favors high energies (Zn) and therefore low Bragg angles (θv < 16°).

- A large-format hybrid CMOS imaging sensor would allow for lower magnifications and ease shot-to-shot alignment.

**Tolerances to misalignment**

- Misalignments defocus the spectrometer and reduce the spatial resolution.

- With the crystal and detector fixed relative to each other on an optical mount, the greatest cause of misalignment comes from positioning the spectrometer relative to the source.

- The uncertainty in the positioning of the TIM is 200 μm along any axis.

- Ray tracing was used to calculate the spatial resolution of the spectrometer in response to displacements of the source along the TIM axes. The alignment tolerances are defined as the displacements that will cause the spectrometer to fail to meet the required spatial resolution (∼25 μm).

- The tolerances along the y and x axes are within the TIM positioning uncertainty.

- The source must be aligned to better than (-169, +66) μm along the z-axis.

- The spectrometer is fairly insensitive to rotations along the y and z axes. Rotations about the x-axis are similar in effect to z-displacement. The crystal must be aligned to better than 0.01 degrees about the x-axis.

- The x-displacement and x-rotation will necessitate precise post-insertion alignment.

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Publications

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