Fast Compton

Inverse Compton produced x-rays for structural dynamics

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Energy Measurement Using K-edge

- Characterized x-rays via K-edge foil
- ICS photons have angular-energy relation (undulator eqn.):

\[
E_x = \frac{4\gamma^2}{\left(1 + \frac{a_L}{2} + \gamma^2\theta^2\right)} E_L
\]
Analyzing the photons

- 250 μm Be-window
- Insertable Ni, Fe, and Ag foils
- 1 mrad pinhole on remote 2-axis control
- Remotely insertable Si-diode detector
- 250 μm Be-window
- MCP image intensifier (CCD camera not pictured)
Lobe observation angle

ΔE_e = 1.3 MeV => ΔE_x = 290 eV

Fit simulation curve to data by adding energy offset (~290 eV)

- Energy offset could be due to absolute e-beam energy calibration or nonlinear induced red-shifting (a_L > 0) (more likely)

- Nonlinear effects would then dominate bandwidth: 4%
Circular polarization and sub-ps pulses

68 MeV, 4 ps FWHM e-beam

(2Δγ/γ=ΔE/E=1%)

X-rays are e-beam bunch length

68 MeV, 300 fs FWHM e-beam

(2Δγ/γ=ΔE/E=2%)

Measured BNL ICS source:

~2x10^6 photons over 1 mrad (1x10^8 full angle) in a modest 300 fs pulse
Dynamics: Where ICS shines...

- Pump-probe and living samples require data in a single shot
- Can’t compete with avg. brightness of synchrotrons, but...
- ICS capable of delivering high flux in single sub-ps pulse
- Tunability of energy and polarization allows for range of ultra-fast applications: lattice changes, magnetic materials dynamics, chemical processes, etc.

Melting of InSb
K.J. Gaffney, et al., PRL 95, 125701 (2005)
Is “Fast Compton” Possible?

• Need to show feasibility of Compton as ultra-fast x-ray source
• Requires a “basic” study to understand pump-probe synchronization
• Will watch non-thermal melting of Ge-layer on Si-substrate (bulk crystal won’t reveal melted surface by diffracted x-rays)
• Preferential absorption of 800 nm pump by x-ray probed Ge layer
• 1st: Static Diffraction
• 2nd: Time stamp e-beam (x-ray) arrival time = Electro-optic sampling (EOS)

Lattice Dynamics

• Compressed e-beam can (presumably) produce 100 fs x-rays
• Allows sub-ps probe of lattice changes in non-thermal melting of Ge
• Look for decrease in diffracted signal
• Recreating known experiment can put upper bounds on x-ray pulse length = temporal diagnostic
Chapter 1: Static Diffraction
(Bragg Condition : \( \lambda=2d\sin\theta \))

- Measurement of central photon energy made using Ni-foil method
- Shows \(~8.6\) keV photons on axis
- Start with Si-crystal: cheap, Bragg angle near our energy, part of exp!
- Given Si lattice spacing of \(2d=6.28\), have \(\theta=13.3\) deg.
Single-shot Static Diffraction

$\Theta = 13.4$ degrees ("8.53 keV")

$\Theta = 13.5$ degrees

$\Theta = 13.7$ degrees

$\Theta = 13.8$ degrees ("8.28 keV")
Diffraction lessons learned

• Observed diffraction signal in 250 eV window (as dictated by Bragg angle)
• Corresponds to expected bandwidth given in simulation and K-edge measurements
• Central energy not exactly right: very possibly due to non-normal incidence angle on crystal
• Higher resolution detector/camera may be needed for melting experiments
Electro-optic sampling

- Use nonlinear crystal (e.g. ZnTe <110>)
- E-field of electron bunch imprinted on crystal
- Acts as polarization gate
- Resolution: probe laser pulse length and crystal thickness
- Time window: crystal width and laser spot size
- Provocation based on measurements done at UCLA Pegasus Lab

C. M. Scoby, et al., PRSTAB 13, 022801 (2010)
Summary

• Fairly good confidence in deliverable x-ray energy using two different diagnostics
• To our knowledge, 1st observation of single shot static diffraction from a Compton source
• Use new Ti:Sa laser for pump AND time-stamping of x-ray arrival time due to system jitter
• Experience with EOS will carry to other experiments requiring tight synchronization requirements
• Will demonstrate feasibility of ATF Compton source for ultra-fast science