

Flash spectrographs for FEL diagnostics and XANES measurements at LCLS

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This proposal aims to continue the preliminary experiments using SPPS, which demonstrated the feasibility of performing XANES experiments on the femtosecond time scale. It also has the potential to provide a shot-by-shot measurement of the beam spectral profile. The instrument consists of a simple dispersive spectrometer coupled to an integrating position-sensitive detector. Experiments at NSLS and SPPS verified the operation of the spectrometer using imaging plates and a commercial CCD detector respectively. With the low intensities available from SPPS, several hundred pulses needed to be accumulated for a useable spectrum. With LCLS, a single shot should be sufficient. At 100Hz operation, 1 second should give excellent spectra, even for rather dilute systems, and would allow subtle spectral modifications to be recorded. To fully realize the instrument's potential, several enhancements need to be made, described below.

We are also investigating the possibility of a very high-resolution device for use as an FEL diagnostic. It would use a micromachined structure to allow many very thin crystal plates to be introduced into the beam with controlled misorientations on the arcsecond scale. Each plate would diffract a particular energy from the entire incident beam cross-section. This is a more ideal setup than the Bragg device, which slices the beam in both energy and space. Unfortunately, silicon is not completely transparent at 8keV, so there is a hard limit on the total silicon thickness which can be tolerated. We need to study this idea further.

Present status

The ideas for the instrument and results from a prototype were presented at the Synchrotron Radiation Instrumentation conference in San Francisco, August 2003. The basic idea is represented in figure 1.

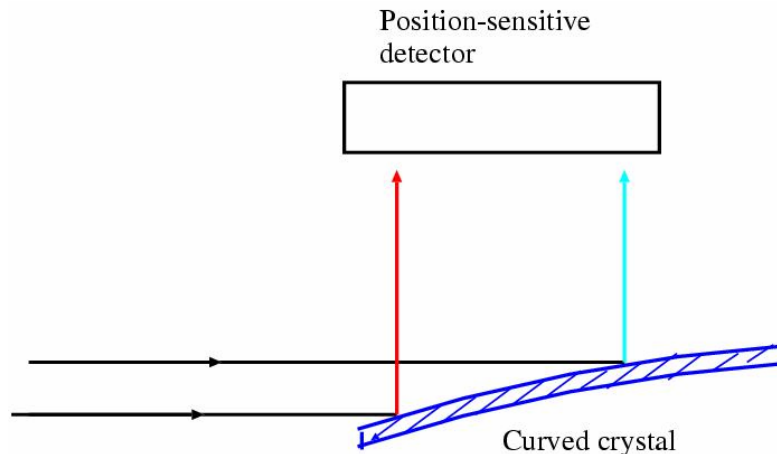


Figure 1. The geometry of the flash spectrograph. An asymmetrically cut crystal plate is bent to a circular profile. The consequent change in incidence angle (and hence Bragg angle) with ray position disperses the incident beam spectrum in the detector.

The incident beam is essentially collimated, and hence in order to force a change in Bragg angle with position within the beam, the crystal must be bent. Also, the incident beam is rather small in cross-section, so the Bragg planes must be asymmetrically cut to the surface in order to spread the beam footprint over a reasonable distance. The optimal asymmetry depends on several factors (source size and distance, crystal reflection, desired range/resolution etc). We chose the Si (4 2 2) reflection, with an incidence angle around 4 degrees. This makes the beam footprint about 15 times the vertical beam size at the crystal. Figure 2 shows a nickel K-edge Xanes spectrum extracted from image-plate data taken at an NSLS beamline. The image was formed by scanning the beamline monochromator in energy while recording the image continuously. The image on the plate was then integrated perpendicular to the scan direction. The graph shows a comparison between data collected conventionally and that generated by the spectrometer. The agreement is good, with the spectrometer showing somewhat more detail on the edge suggesting better energy resolution than the beamline monochromator (which is expected to be the case).

Data collected at the copper K-edge using SPPS is shown in figure 3. The spectrum reproduces the near-edge features quite well.

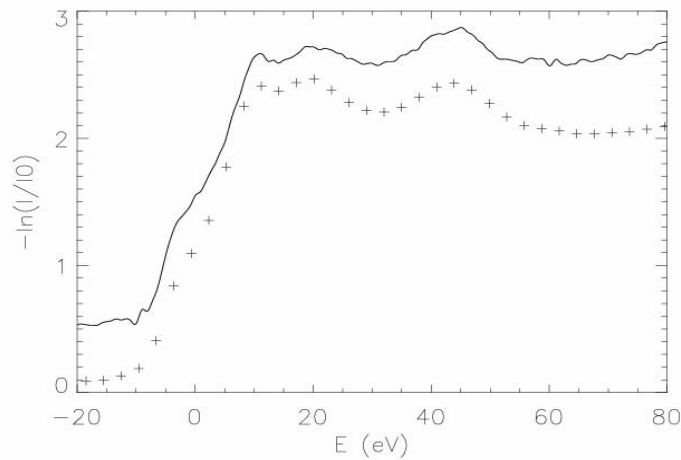


Figure 2. Nickel K-edge spectra collected using the flash spectrograph and a conventional monochromator scan.

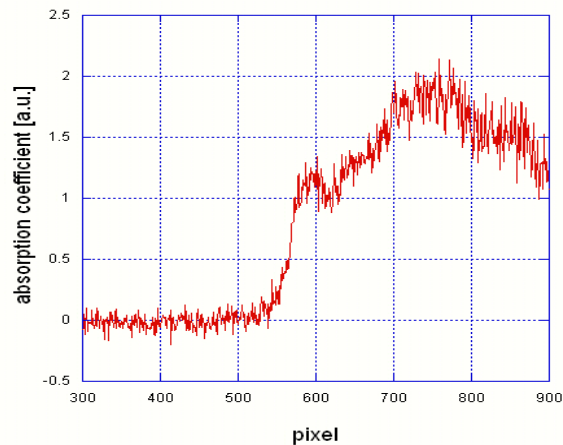


Figure 3. A copper K-edge spectrum collected using the flash spectrograph at SPPS.

Proposed enhancements to Bragg device

The bending mechanism used to provide the dispersion needs to be made remotely adjustable to permit the energy range of interest to be set at will, within the elastic limits of the diffracting element. This is largely an engineering exercise to automate the existing concept.

An on-line calibration scheme needs to be devised so that the center energy and energy range can be checked at any time. This could be based on an optical measurement of

the bending radius and mean incidence angle, or it may be possible to introduce additional Bragg elements upstream of the spectrometer to provide narrow-band lines of known energy.

A custom detector should be built which is efficient at the x-ray energies involved, and which provides adequate position resolution and noise performance, combined with a fast readout time. Such a detector would consist of an array of silicon photodiodes in the form of strips of order 0.1mm in the dispersion direction and a few millimeters in the transverse direction. Since the arrival time of the photons is precisely known, the integration time of the charge collection could be very short, determined by the charge drift time across the detector (typically a few 10s of nanoseconds). This would allow room temperature operation of the device since the leakage current integrated over this time would be a small fraction of the signal charge. A simple calculation assuming 100 resolution elements indicates that the signal charge in each detector element should be more than 10nC per pulse at 8keV. Even for a detector leakage current of 10nA, which is large for such a device, the contribution to the signal over 100ns would only be 10^{-16} C, i.e. 1 part in 10^8 of the signal. The cost of such a detector would be modest, consisting of a diode array mask set and device fabrication (BNL in-house), commercial ASICS and labor to assemble and test it.

High-resolution device for FEL physics

We are studying an idea for a Laue-case version of this instrument which might provide significantly increased efficiency and accuracy compared to the Bragg-case device. There are two problems with the Bragg device. First, it introduces a spatial correlation between position within the beam cross-section and energy, requiring normalization to generate a correct spectrum. Second, this spatial correlation implies that the efficiency of the device is low, since each piece of the incident beam only contributes to the signal at one energy. An ideal instrument would use all energies from all of the beam simultaneously. In principle a strongly bent crystal operating in transmission would achieve this, but it is practically very difficult, if not impossible, to make such a device. The curvature needed is beyond the yield strength of most materials, and the angular dispersion is small, requiring a long flight path to the detector. Our idea relies on micromachining technology to generate a set of thin lamellae supported by a thick substrate, spaced an appropriate distance apart along the beam direction (see fig. 4). The substrate would be bent so that each lamella presents a different angle to the incident beam. The lamella spacing would be chosen so that the spectrum is spatially dispersed without requiring long flight paths, similar to the Bragg arrangement. The advantage of this scheme is that each lamella sees the same incident beam cross-section. The disadvantage is that the beam is successively attenuated by each lamella. For realistic lamella thicknesses of around 5 micrometers, 40 lamellae would only transmit 5% at 8keV. The practical details and the technology for fabricating the device need to be developed.

Since this device would use the same elastic bending technology and detector as the Bragg device, all of the improvements mentioned above would apply to this one also.

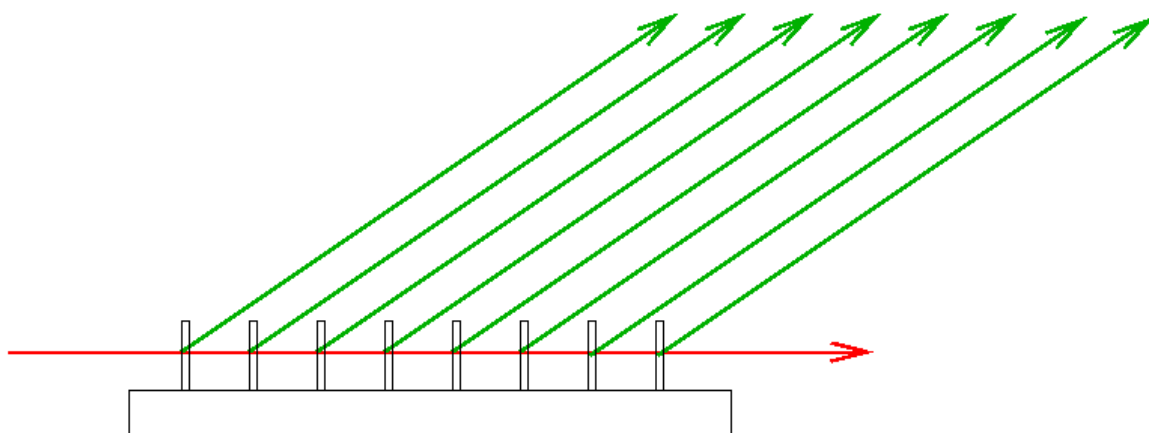


Figure 4. An array of thin crystal plates arranged to intercept the beam and disperse it by having each plate make a slightly different angle to the beam. This is achieved by elastically bending the substrate.