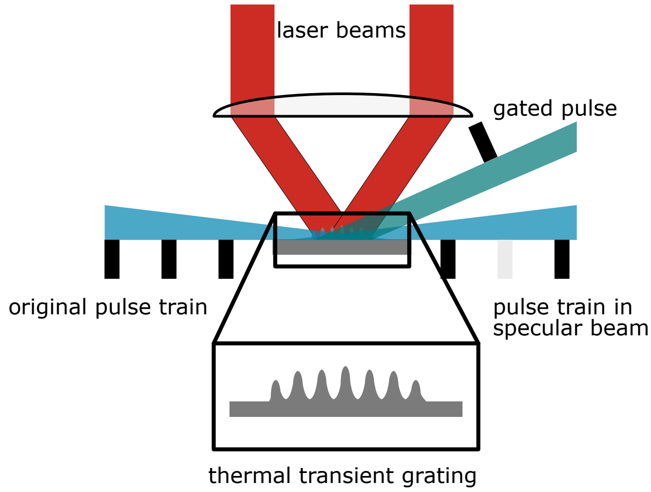
IT'S ALL A MATTER OF TIMING

A new method for the temporal gating of X-ray pulses

Synchrotron radiation is a powerful tool for the study of small structures, with applications in physics, biology, nanotechnology, and many more. In storage rings, synchrotron radiation is produced as electrons moving at relativistic speeds are forced on a curved path by bending magnets, undulators, or wigglers. These electrons are injected in so-called bunches. The time structure of this filling pattern is consequently also inherent to the emitted light. However, for certain time-resolved experiments, one might desire to be able to control the time structure of the X-ray beam. This can be facilitated with thermal transient grating.

Thermal transient grating is realized with two crossed laser beams, which generate thermally induced surface distortions in a sample. Where the laser beams constructively interfere, the material expands and forms small "bumps". This surface modulation is transient and decays when the laser pulse recedes. Differently put, the presence of the grating in the sample can be switched on and off with the laser pulses. One thus has a dynamic optical element allowing for the tailoring of the time structure of the X-ray beam.



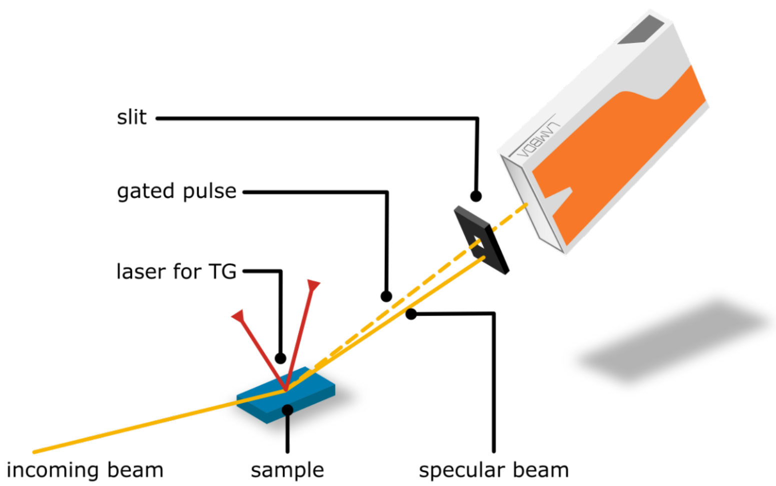
Principle of thermal transient grating. The red beams represent the crossed laser beams used for optical excitation.

adapted from CC BY 4.0 Schmidt et al. (2021)

EXPERIMENTAL SETUP

The team of researchers who developed this approach tested their setup at the in situ and nano-diffraction beamline P23 at PETRA III, DESY, Germany. The synchrotron was running in 40 bunch mode, which means that the X-ray pulses were 192 nanoseconds apart. Their sample was a thin film heterostructure consisting of a substrate, an opaque layer of lanthanum strontium manganite and a transparent layer of lanthanum aluminate. The excitation pulses ($\Delta t = 7$ ns) for the transient grating were realized with a Q-switched laser synchronized with the synchrotron bunch marker. The X-ray beam hit the sample at grazing incidence, meaning it would be reflected unless the transient grating was switched on, in which case it would be diffracted. While the specular beam was blocked, the diffracted light was detected with a LAMBDA 750k detector in electronic gating mode synchronized with the laser pulses. **"As a consequence of the timing mode, the count rate on the detector is reduced by more than three orders. This is substantial even at synchrotrons.**

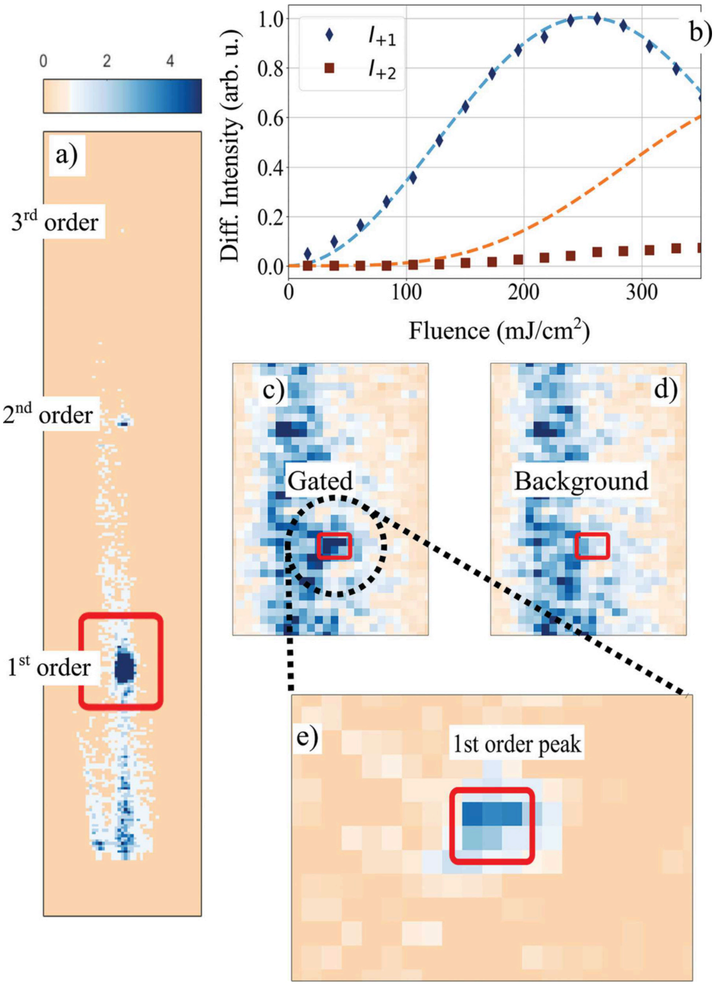
Setup	PETRA III, DESY (Germany), P23 beamline
Camera	LAMBDA 750k Si detector
Resolution	786,432 pixels with 55 µm
Electronic gate	100 ns to 50 µs
Photon energy	9.5 keV



Thus, high quality data can only be acquired with detectors that are highly sensitive and robust", explains Peter Gaal, who led the study. **"In addition, the detector must provide the necessary timing capabilities to isolate single bunches from the emitted pulse train. The LAMBDA detector available at beamline P23 combines all these properties and was a key element in our experimental setup."**

RESULTS

The researchers succeeded in singling out an individual X-ray pulse, but were surprised by its low intensity. By increasing the acquisition time and resting the thermal grating, they found a comparably strong background signal from stray photons. Only in a few of the small pixels could they identify the diffraction signal. As one of the reasons why the theoretically possible intensity of the diffraction peak wasn't achieved, the researchers point out that the sample substrate accumulates heat and thus slowly deforms over time. The method could thus be improved by choosing a different substrate alongside specific cooling techniques.



a) Diffraction from a single synchrotron pulse. b) Fluence dependence of the maximum diffracted intensity in the first (blue) and second (brown) diffraction order. The dashed lines indicate theoretical predictions. Measured intensity in the second order was lower than predicted, possibly indicating that the surface deformation deviated from a pure sine modulation. c) Diffraction in the first order of a single X-ray pulse, d) Diffraction in the first order averaging 255 X-ray pulses. e) Background-corrected image of the first-order diffraction peak (c–d).

REFERENCE

- Schmidt, D., Bauer, R., Chung, S., Novikov, D., Sander, M., Pudell, J.-E., Herzog, M., Pfuetzenreuter, D., Schwarzkopf, J., Chernikov, R. & Gaal, P. (2021). A new concept for temporal gating of synchrotron X-ray pulses. J. Synchrotron Rad. 28, 375-382. https://doi.org/10.1107/S1600577521000151

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