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THz pulses from 4th generation lightsources:

Perspectives for fully synchronized THz pump X-ray probe experiments

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A unique instrumentation is presented, based at the soft x-ray free electron laser FLASH, that provides radiation throughout the THz and in the XUV to soft x-ray spectral range. The THz pulses and the XUV/soft x-ray pulses are generated from the same electron bunch and thereby naturally synchronized. This natural synchronization between the THz and soft-xray pulses is an intrinsic property of the *cascaded-undulator* design, where a long-period THz undulator immediately follows the short-period x-ray undulators. The electric field within the THz pulse furthermore is a Lorentz transformed image of the periodicity of the THz undulator and fixed with respect to its envelope, thereby generating naturally phase stable radiation. Due to the only few micron long electron bunches the THz pulse energy scales quadratically with the bunch charge and at FLASH routinely reaches the μJ range [1] providing for THz electric fields in the experiment of up to 100 MV/m. The instrumentation has been benchmarked and analyzed by novel NIR/THz and XUV/THz cross correlation techniques [2] in the time and frequency domain. It is shown, that combination of the THz pulses with the fully synchronized femtosecond soft x-ray pulses enables a new class of experiments, that directly probe the sub cycle dynamics of e.g. highly vibrationally perturbed molecules and solids.

Based on these results the general potential of science with THz radiation from ultra short electron bunches will be discussed in hindsight that these electron bunch forms are typical for all currently developed or already operating so called 4th generation X-ray lightsources.

A perspective on the most promising fields of research is given and possibilities for transfer of the novel conceptional design of the FLASH THz beamline to other 4th generation x-ray light sources are outlined.

[1] M. Gensch et. al., *The new infrared undulator beamline at FLASH*, Infrared Phys. Technol. 51, 423 (2008).

[2] M. Gensch et. al., *submitted,* U. Fruehling et. al., *submitted.*