PULSE SHAPING AT THE MAX IV PHOTOELECTRON GUN LASER

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Abstract

A motivation for the development of a versatile, programmable source of shaped picosecond pulses for use in photocathode electron gun preinjectors is presented. We present the experimental setup for arbitrary longitudinal pusle shaping of the MAX IV photocathode gun laser. The setup consists of a grating-based Fourier-domain shaper capable of stretching the pulses directly in the UV domain. Preliminary results are presented and discussed.

INTRODUCTION AND MOTIVATION

The MAX IV Laboratory is a facility for production of synchrotron radiation. It includes two storage rings, which operate at electron energies of 1.5 and 3 GeV. The facility operates a short pulse facility, while plans to build a soft X-ray Free Electron Laser (FEL) are at an initial stage. Both rings, the Short Pulse Facility (SPF) [1], and the possible future FEL make use of a 3 GeV LINAC [2] for injection. There are two preinjectors at the LINAC, a thermionic and a photocathode electron gun. While either of the guns can be used for ring injection, the Short Pulse Facility and the possible future FEL require the short electron bunches that a photoelectrode gun can deliver. The 1.6-cell, BNL/SLAC-derived photocathode gun [3] is operated at 2.9985 GHz. The gun is followed by an emittance-compensating solenoid.

The requirement for effective emittance compensation that the RF phase does not vary significantly while the electron bunch is being created sets the upper limit on the usable laser pulse durations. The maximum variation has empirically been determined to be 10-15° and, given the RF frequency used, limits the laser pulse duration to about 10 ps. A lower limit on the pulse duration is set by the need to avoid a Coulomb-repulsion mediated expansion of the electron beam.

The laser pulses used to photoionize a machined, copper cathode come from a frequency tripled Ti:Sapphire laser system. The laser system outputs IR pulses at 790 nm, with a bandwidth of 20nm. The tripled pulses, at 262 nm, have a photon energy of 4.7 eV, and a spectral bandwidth of 1.5 nm. The pulses are normally stretched to a duration of duration of 3 or 6 ps, using a combination of a prism stretcher and pulse stacking in birefringent crystals. The pulse energy is about 100 μJ on cathode. The laser system, along with the pulse diagnostics is described in detail in [4].

While the LINAC's design normalised emittance of <1 μm meets the SPF requirements, a FEL would require a normalised emittance of below 0.4 μm, given a charge of 40 pC, at the FEL entrance. We can currently measure <0.98 μm at 50 pC and at beam energy of 260 MeV. The emittance of the photoelectron gun is currently limited by the low RF power in the gun and the poor cathode quality. An upgrade of the RF driver and the installation of a new, polished cathode are both planned for 2017. At that point, it is anticipated that the laser transversal and longitudinal profiles are going to be the emittance-limiting factors.

The temporal shape of the laser pulses generated through chirped pulse amplification is well-approximated by a Gaussian whose width corresponds to the inverse of its spectral bandwidth. However, sharp rise times are more suitable for an effective emittance compensation, and quasi flat-top pulses with a duration of several ps are commonly used at photocathode guns. However, an increase in the RF field during the creating of the electron cloud leads to an increase in Q_e during the laser pulse, suggesting that a down-ramp pulse might lead to a better emittance. Furthermore, due to screening of the cathode by the electron cloud, the emittance might benefit from an up-ramp pulse. The interplay between these effects is expected to be charge dependent.

PULSE SHAPING

A pulse shaper is a device that enables the modification of a temporal profile of an ultrashort pulse [5]. We use two pulse shaping schemes at MAX IV: pulse stacking and Fourier-domain shaping.

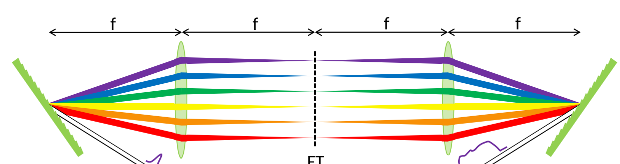

Figure 1: The principle of Fourier domain pulse shaping.

Pulse Stacking

Pulse stacking is a method of longitudinal pulse shaping that easily implemented in the ultraviolet. It relies on group velocity mismatch for different polarizations of light when passing through a birefringent crystal [6]. Thus an input pulse is turned into a pair of pulses with orthogonal polarizations. Using a number of crystals, each successive one with a thickness that is half that of the preceding one, it is possible to create a train of pulses, where the polarization changes by 90° between successive pulses. The technique is capable of producing some simple pulse shapes, including a nearly flat-top flat-top pulse and a ramp pulse. The number of control points is 2^N, where N is the number of crystals

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used. The rise time of a stacked pulse is close to that of its component pulses. Pulse stacking has the clear advantage of being a simple, cheap, and fairly efficient inline technique.

We make use of α-BBO crystals to create stacks of pulses. This strongly birefringent material introduces a delay of 800 fs per mm traversed. A prism stretcher is used to produce chirped the pulses with a duration of about 1.3 ps. Afterwards, the UV pulses are stacked using either a single 2 mm α-BBO crystal to create a 3 ps pulse, or a 2 mm and 4 mm pair, which creates a 6 ps pulse.

However, besides the limited number of pulse shapes it can produce, we have observed that stacking gives rise to an unwanted amplitude variation with a several hundred ps period due to interference between sub-pulses in the stack with the same polarization. By limiting the overlap between pulses with the same polarization through tuning the pulse duration at the output of the prism stretcher, and through choice of stacking crystals, it is possible to keep the variations to below 10%.

Fourier-domain Pulse Shaping

The most versatile pulse shpaing technique available in the ultraviolet, relies on applying a filter in the spectral, or Fourier, domain in order to modify the the temporal electrical field of a laser pulse. Fourier domain shapers are usually realized in a 4-f configuration. Figure 1 shows the operating principle of the device. The different spectral components of the laser pulse are spatially separated using a grating, and lens, placed a focal length, f, away from the grating, focuses them to different positions in its focal plane. There an optical element capable of phase and amplitude manipulation can be placed in order to shape the pulses. After the Fourier plane, a symmetrically placed lens-grating pair is used to recombine the spectral components. The programmable modulators used in the Fourier domain commonly include deformable mirrors, acousto-optics modulators and spatial-light modulators, though the latter is not available for ultraviolet wavelengths required by our gun. Of the remaining two possible shaping elements, a deformable mirror has the advantage of a very high efficiency (close to 100%), but in turn manipulating the spectral phase leads to wavelength-dependent deformations in the wavefront, which are impossible to correct after recombination. An acousto-optic modulator introduces some losses (up to 80% efficiency), but allows for independent manipulation of the spectral phase and the spectral amplitude, enabling in principle an arbitrary pulse shape at the output. We note that deviations from either the symmetric arrangement or the 4-f configuration lead to the device acting as a pulse stretcher, even in the absence of a shaping element. Such a pulse stretcher is capable of introducing both a positive and a negative chirp to the laser pulse.

In our pulse shaper, we make use of Al-coated, 3600 g/mm gratings, and fused silica lenses with a focal length f of 450 mm. These optical elements give a spatial spread of frequency components in the Fourier plane of about 2 mm per nm of bandwidth. An acousto-optic modulator with a bandwidth of 100 MHz is to be used as a shaping element, and will provide more than 10 independently controllable points per nm of laser bandwidth. The current mechanically-ruled gratings do not provide a high-quality spatial mode, and are to be replaced with 3846 g/mm transmission holographic gratings. The high efficiency of the transmission gratings (90%) will make it possible to double-pass the pulse shaper, eliminating the spatial chirp introduced by stretching femtosecond pulses into the picosecond range.

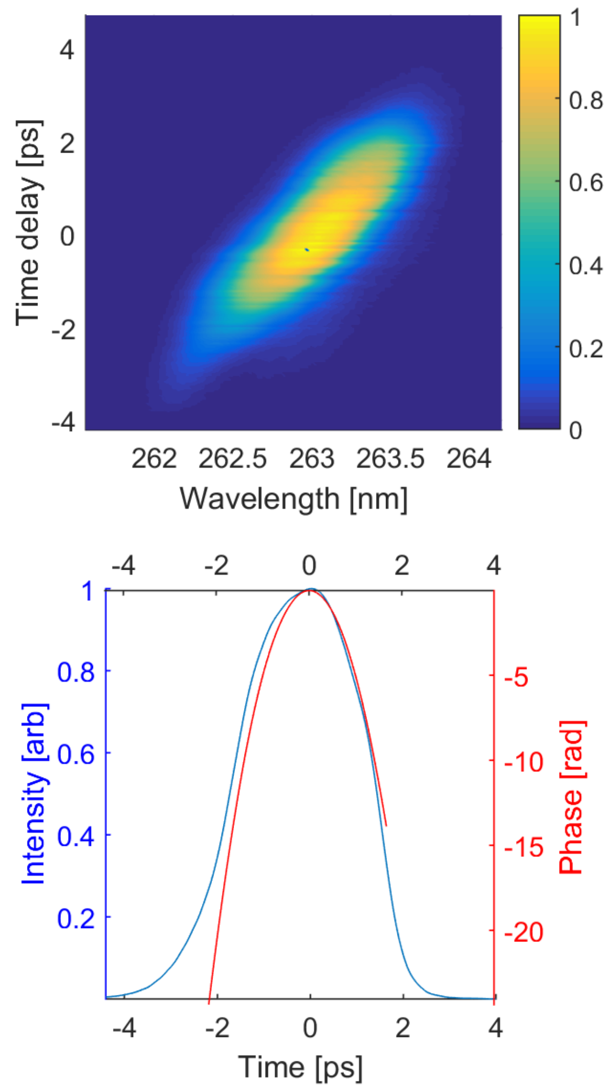

Figure 2: (top) A measure PG FROG trace of a 3 ps pulse, produced by the pulse shaper. (bottom) The reconstructed spectral intensity and phase of the pulse.

The shaped pulses have been characterized using a Transient Grating Frequency-Resolved Optical Gating (TG FROG) [7]. Figure 2 shows a measured PG FROG trace and the reconstructed spectral intensity and phase of 3 ps pulse, produced by the pulse shaper.

CONCLUSION

We built and tested a Fourier-domain pulse shaper in the ultraviolet. The advantages of a Fourier shaper over the commonly used pulse stacking are discussed.

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