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Chapter 24

Pico–Femto–Attosecond Metrology for Advanced and XUV Photon Sources



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Abstract We present a new Velocity Map Imaging (VMI) spectrometer based on the thick-lens configuration to be implemented at different XUV source beamlines to realize the measurements of the pulse temporal structure using the technique of laser-dressed photoionization.

24.1 Introduction

The temporal characterization of ultrashort XUV pulses generated from seeded plasma-based XUV lasers [1], high-order harmonics from plasma mirrors [2], or free-electron lasers [3] is a crucial challenge for both the ongoing development of these advanced sources and for the interpretation of their interaction with matter in various applications, such as ultrafast dynamics in atoms and molecules, or multiphoton processes [4, 5]. There is thus an important worldwide effort toward establishing adapted, reliable, and easy-to-use techniques of temporal metrology in the femtosecond to attosecond range, possibly on a single-shot basis, using different approaches [6–8].

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In the frame of a collaborative project led by ISMO and LCF and gathering several XUV source developers within Paris-Saclay University, we are currently developing a new portable instrument, based on a home-made Velocity Map Imaging (VMI) spectrometer. This device was designed following the thick-lens configuration proposed by Kling et al. [9] to allow higher resolution of the photoelectrons over a broader range of kinetic energy compared to standard VMI designs. This VMI spectrometer will be implemented at different laser-based XUV source beamlines to conduct measurements of the pulse temporal structure using the technique of laser-dressed photoionization, already demonstrated elsewhere. Depending on the relative timescale between the duration of the ionizing XUV pulse and the period of the dressing laser field, both the sidebands [10] and the streaking regime [11] will be investigated. The main advantage of using a VMI spectrometer rather than other types of photoelectron spectrometers [(time-of-flight (TOF), magnetic bottle (MB))] is the higher collection efficiency and the access to angularly resolved distributions of photoelectron velocities, from which temporal information could be extracted.

In this paper, we discuss the first step of our ongoing project devoted to the construction and commissioning of our new VMI spectrometer. We have used two types of sources, (i) a conventional helium lamp, (ii) an ASE plasma-based XUV laser operated at 32.6 nm available at the LASERIX facility. Tests with different rare gases were performed to characterize the performance of the spectrometer in terms of sensitivity and resolution. The measurements were compared with numerical simulations using the SIMION code.

24.2 VMI Spectrometer

The principle of the VMI spectrometer consists in projecting the expanding sphere of photoelectrons produced by the interaction of a gas jet with a XUV beam onto a 2D detector with an intense electrostatic field applied across the electrodes as shown in Fig. 24.1. The photoelectrons with the same velocity vector are projected onto the same position on the detector, independently of their point of emission in the interaction region. Focusing effect is produced by the thick-lens configuration involving 11 electrodes including a repeller, extractor, and focusing electrodes [9]. This configuration allows optimization of the spectrometer resolution over a broad kinetic energy range $E \sim 0\text{--}100$ eV at the detector plane with full angular information. The gas is injected by the polarized needle going through the \varnothing 3 mm hole in the repeller. Then, the photoelectrons are detected by a single multichannel plate coupled to a phosphor screen to convert the electron signal into luminescence which is observed by a CCD camera.

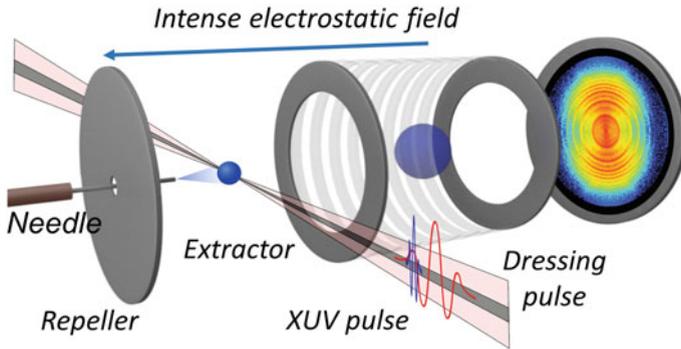


Fig. 24.1 Scheme of VMI spectrometer with thick-lens configuration

24.3 Numerical Simulations

Numerical simulations of the trajectories of photoelectrons in the electrostatic field were performed using SIMION code to determine the expected resolution and range of electron’s kinetic energy as well as to optimize the voltages of the electrodes. The photoelectron trajectories were calculated for different relevant kinetic energies and voltages of repeller. Their positions and radius R on the detector plane are presented in Fig. 24.2. The resolution of the spectrometer is estimated between 2 and 5%, depending on the applied voltages and energy range.

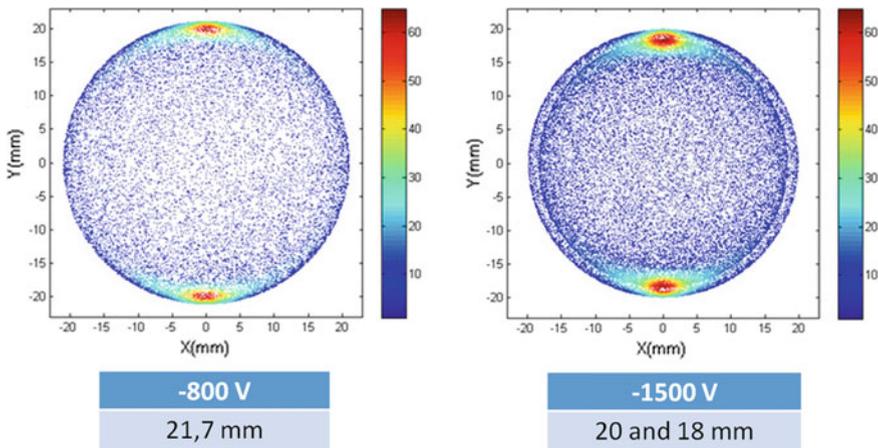


Fig. 24.2 Simulated images of photoelectrons for $E_k = 5.45\text{ eV}$ (left side) and $E_k = 9.08$ and 7.77 eV (right side) and the radius R

24.4 VMI Experiments

24.4.1 Helium Lamp

First tests were realized with a DC photon source, namely helium lamp with energy $E_{hv} = 21.21$ eV. Valence np^6 -photoionization produces an unresolved electron line of 5.45 eV in the Argon case ($n = 3$) and of 9.08 and 7.77 eV in the Xenon case ($n = 5$) corresponding to the $^2P_{3/2,1/2}$ thresholds. Raw and inverted photoelectron images for relevant kinetic energies are shown in Fig. 24.3. The doublet states of Xe^+ can be distinguished in the both raw and inverted images. Comparison of the measured R with simulated results for both gases and different voltage settings shows good agreement.

The photoelectron spectra obtained from the inverted images allow to determine the resolution of the VMI spectrometer. Each peak of these spectra was fitted with a Gaussian profile. The energy resolutions $\Delta E/E$ are 8.3 and 10% in the Ar case and 8.4 and 9.6% in the Xe case for the mentioned voltages of the repeller. The experimentally found energy resolution is lower than was predicted by the simulation due to a larger size of the interaction zone (1.5×4 mm) given by an intersection between the gas jet and the diaphragmed diverging photon beam since the light was not focused in the VMI, but more than satisfactory for future tests.

The calibration curve of the VMI spectrometer is given by following expression: $E_k = V_{rep} \frac{R^2}{C^2}$, where C is the VMI constant and R is the measured radius, and illustrated in Fig. 24.4 [13]. A linear fit to the measured results provides a good representation of the $E(R^2)$ dependence and the coefficient of the linear fit k gives the value of the VMI constant C : $k = 1/C^2$. The constant C is equal to 25.9 for the experimental data and 25 for the SIMION simulations for the current geometry.

24.4.2 XUV Plasma-Based Laser

Experiments with the plasma-based XUV laser were performed with Ne target. Photons of energy of 38 eV produce an unresolved electron line of $E_k = 16.4$ eV asso-

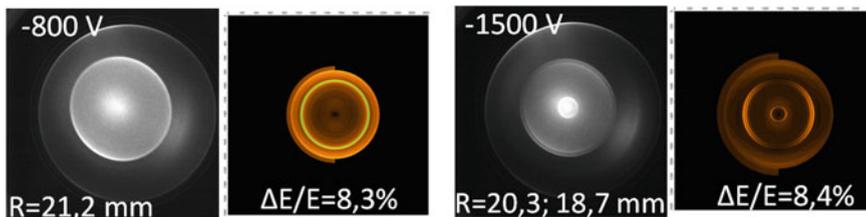


Fig. 24.3 Raw and inverted images of photoelectrons of $E_k = 5.45$ eV (left side) and of $E_k = 9.08$ and 7.77 eV (right side)

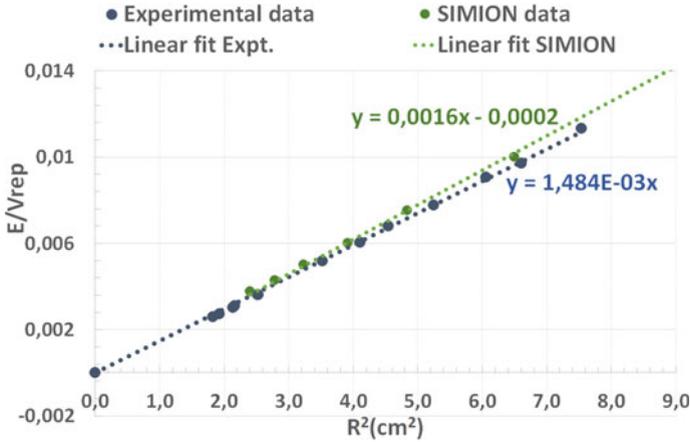


Fig. 24.4 Experimental (blue) and simulated (green) energy calibration curves $E_k/V_{rep} = f(R^2)$ as well as its linear fit

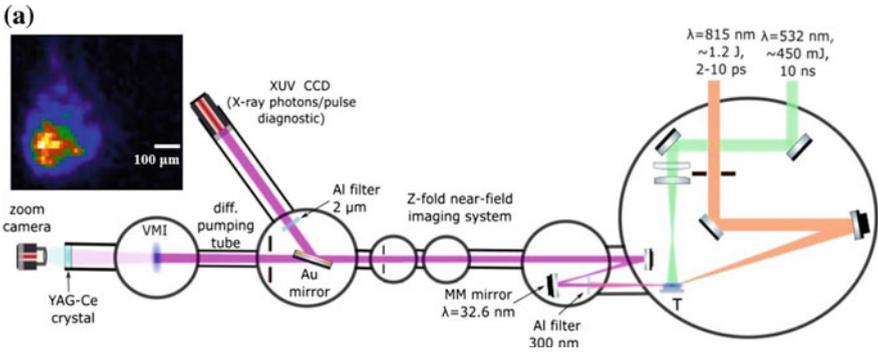


Fig. 24.5 Schematic of the setup of the plasma-based X-ray laser. Inset figure **a** depicts XUV laser focused at the VMI center

ciated with the ${}^2P_{3/2,1/2}$ thresholds. The experimental scheme of the solid target plasma-based soft X-ray LASERIX source is shown in Fig. 24.5 [12]. The exit of Ne-like Ti X-ray laser plasma is imaged with a magnification of ~ 10 into VMI spectrometer. For diagnostics of the X-ray source size, position, and energetic characteristics, an X-ray CCD was placed approximately at the same path-length as for the center of the spectrometer. The X-ray spot size into the VMI spectrometer is $190 \times 260 \mu\text{m}$ with a standard deviation of 11% between two X-ray laser pulses.

The left and right halves of Fig. 24.6 show the measured raw and inverted images. The energy resolution $\Delta E/E$ found from the photoelectron spectra for different voltages is 8–10%. Despite the smaller size of the interaction zone, the found resolution is lower than predicted by the SIMION simulations and need further optimizations. The single-shot capability of VMI spectrometer was also successfully tested. The raw VMI image taken in single-shot at 38 eV is shown in Fig. 24.6.

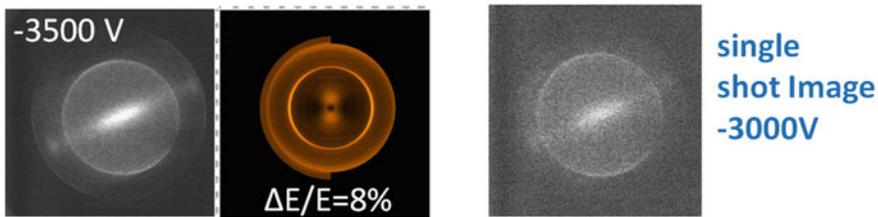


Fig. 24.6 Raw and inverted images of photoelectrons of $E_k = 16.4$ eV

24.5 Conclusion

Our new VMI spectrometer has been implemented and characterized at LASERIX (LUMAT, Université Paris-Sud, France) for commissioning with a helium lamp and a plasma-based XUV laser pulse. The SIMION simulations were performed to confirm the reliability of the spectrometer. The found energy resolution is actually lower than was predicted by the numerical simulations but satisfactory for the realization of the future program. Further, the spectrometer will be implemented at the UHI100 facility (CEA-Saclay, France) for the characterization of high-order harmonics generated from plasma mirror, using an IR laser dressing field.

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