

Wave-Mixing and Amplification in Extreme Ultraviolet Region

Lap Van Dao, Peter Hannaford

*Quantum Centre for Quantum and Optical Science, Faculty of Science Engineering and Technology,
Swinburne University of Technology, Melbourne 3122, Australia*

**E-mail: dvlap@swin.edu.au*

Abstracts: *We report the investigation of the wave-mixing and optical parametrical amplification process in extreme ultraviolet region. Using a non-collinear scheme for the two beams, which helps to spatially separate the extreme ultraviolet field according to the mixing condition, we study the properties of the high-order frequency mixing field. When very high intensity is used as pump pulse of parametrical amplification we are able to enhance the flux of the coherent extreme ultraviolet radiation in the photon energy range around 80 eV by more than an order of magnitude compared to the generation with a single-wavelength pulse.*

When atoms or molecules interact with an intense laser field, high-order harmonics (HHG) of the incident radiation may be generated. This process provides methods to produce short pulses of coherent radiation in the extreme ultraviolet (XUV) and soft x-ray region. From the point of view of fundamental research, high-order harmonic generation is an example of nonlinear physics, where simple pictures can be used to describe strongly non-perturbative processes with the time-dependent Schrödinger equation. On the other hand, the observation of nonlinear optical wave-mixing [1] and parametrical amplification [2] in XUV region suggest the possibility to treat the physics in the XUV range with a perturbative nonlinear optics theory although perturbative and non-perturbative nonlinear optics seem conceptually very different.

In our experiment an 800 nm, 9 mJ, 30 fs, 1 kHz repetition rate laser beam is split into two beams, with pulse energies of 4.5 mJ. One of 4.5 mJ beams is used to pump a three-stage optical parametric amplifier system to generate an infrared (IR) driving pulse at 1400 nm with energy of ~ 2 mJ and duration 40 fs. In the wave-mixing experiment the 1 mJ 800 nm beam is used to mix with the 1400 nm field. The 1400 nm IR pulse is used for phase-matched generation of XUV pulses and the 800 nm pulse, which is used to control the HHG output, is aligned at a very small angle (< 10 degree) to the direction of the 1400 nm beam by a dichroic mirror. For parametrical amplification high intensity 800 nm beam, which propagates in same direction of 1400 nm pulse, is used for pumping. When the 1400 nm and 800 nm pulses are overlapped, i.e., for zero time delay the intensity of the XUV radiation is much higher (by more than an order of magnitude) because of the presence of parametrical amplification. We confirm that a perturbative formalism can be developed around the amplification process, up to ultra-high orders of nonlinearity, even though the HHG is a highly non-perturbative process. This result is important for the application of IR and near-IR driving pulses for the generation of high order harmonic radiation and in strong field physics. When an IR driving pulse is used for generating high order harmonics, the parametric amplification can be used to enhance the efficiency.

References:

1. L. V. Dao, K. B. Dinh, H. V. Le, N. Gaffney, P. Hannaford, Wave-mixing with high-order harmonics in extreme ultraviolet region, *Appl. Phys. Lett.* 106, 021118 (2015)
2. L. V. Dao, Kh. B. Dinh, P. Hannaford, "Perturbative Optical Parametric Amplification in the Extreme Ultraviolet", *Nature Communications* 6, 7175 (2015).