Polarization measurements of odd and even low order harmonics for magnetism studies and FEL seeding

C. Alves[1,2,*], G. Lambert[1], B. Vodungbo[1,2], B. Mahieu[1], J. Gautier[1], J. Luning[2], V. Malka[1]

[1]*Laboratoire d'Optique Appliquée, ENSTA ParisTech, CNRS, École Polytechnique, Université Paris-Saclay, 828 boulevard des Maréchaux, Palaiseau Cedex 91762, France*
[2] *Laboratoire de Chimie Physique – Matière et Rayonnement, Université Pierre et Marie Curie – CNRS UMR 7614 - 11 rue Pierre et Marie Curie, 75005 Paris, France*
**E-mail: carla.da-silva-alves@ensta-paristech.fr*

Abstract: *Elliptically polarized light has a promising position in applications based on dichroism effects. Here we present a detailed study of the polarization properties of low order harmonics using a cross-polarized two-color laser field. The results show a high degree of polarization and, particularly, a significant degree of ellipticity. These, in addition, are fundamental investigations for another high potential application: the seeding of free-electron laser using harmonics.*

Recently, elliptical polarization through efficient high-order harmonic generation (HHG) in gas was observed. In this technique, highly coherent odd and even order harmonics, up to 70 eV, were generated using a cross-polarized two-color ($\omega + 2\omega$) laser field [1]. This result sets up a great outlook for various applications based on dichroism effects. Here, we present extended results to low order harmonics, which show, in addition, that a high degree of polarization is obtained.

HHG has also a high potential as a method of seeding free-electron laser (FEL) since the harmonics transfer its coherence properties to the FEL pulse. In our two-color configuration, the harmonic content is doubled and a higher number of photons is produced, which makes it an ideal source for seeding. In this regard, low-order harmonics, for which the corresponded FEL gain is considerably higher than for high order harmonics, were previously studied [2]. However, in this study, no analysis of the harmonics' polarization was performed.

The experiment was conducted at *Laboratoire d'Optique Appliquée (LOA)* using a 1 KHz laser system with a duration of 40 fs and a wavelength of 800 nm. More specifically, we investigated the degree and type of polarization of completely isolated low order harmonics, in particular the 3ω and the 4ω. Indeed, these harmonics can be spectrally isolated easily, using interferential filters, and then, their signals can be directly measured on a photodiode (without any gratings, focusing mirrors and CCD camera). To characterize experimentally the polarization properties, the Stokes' parameters [3] (S_0 to S_3) are evaluated through an entirely optical technique, for which a half waveplate, a fixed polarizing mirror and an analyzer are employed. For different rotation angle positions of the half waveplate, the analyzer rotates around the harmonic beam propagation axis, acquiring the harmonic signal on the photodiode. S_1 and S_2 give information on the linear polarization and S_3 on the degree of elliptical polarization. The analysis of the harmonics' polarization showed that the harmonics are fully polarized with a significant degree of ellipticity and that the helicity of consecutive harmonics can be different.

[1] Lambert, G. et al. Towards enabling femtosecond helicity dependant spectroscopy with high-harmonic sources. Nat. Commun. 6:6167 (2015).

[2] Lambert, G. et al. Spatial properties of odd and even low order harmonics generated in gas. Sci. Rep. 5, 7786 (2015).

[3] Vodungbo, B. et al. Polarization control of high order harmonics in the EUV photon energy range. Opt. Express 19, 4346–4356 (2011).