Below Threshold Harmonics Beams Characterization Using the Knife-Edge Technique

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Abstract: Using the knife-edge method we have measured gas generated BTH beams sizes in the VUV region and calculated their divergences, geometrically characterizing this light source.
OCIS codes: (140.7240) UV, EUV and X-ray lasers; (140.7090) Ultrafast lasers.

Introduction

The generation of harmonics below the ionization threshold in gases by ultrashort laser pulses has been widely studied due to its enormous potential for coherent light generation in the VUV region, being of fundamental interest for time resolved spectroscopy [1] and to study the electronic dynamics close to the gas ionization energy[2].

In our laboratory, Below Threshold Harmonics (BTH) are being generated in order to provide a light source in the UV and VUV regions for future applications. For this, it was decided to geometrically characterize the BTH beams, besides other characterizations of the harmonics. In this work, we report the generation of BTH in argon flowing through a nozzle inside a vacuum chamber. Were generated the 3rd (centered in 255.5 nm), 5th (152.5 nm) and 7th (108.0 nm) harmonics, and here we describe these harmonics beam characterization using the knife-edge method.

Experimental Setup

BTH (3rd to 7th harmonic) were generated using up to 650 µJ, of 25 fs pulses centered at 785 nm, at 4 kHz repetition rate (Femtolasers Femtopower Compact Pro HR/HP). The laser pulses were focused, by a f=50 cm lens, on a glass gas nozzle with a 2.7 mm gas interaction length, through which Argon flowed at a 100 mbar pressure, placed inside a vacuum chamber with a background pressure under 10^{-6} mbar. The harmonics were separated by a VUV monochromator (McPherson 234/302) and detected by a scintillator and a photomultiplier tube, as shown in Figure 1. To determine the harmonics beams sizes and divergences, it was assumed that they were TEM_{00} Gaussian beams, and two knife edges (KE1 and KE2) were mounted inside the vacuum chamber on displacement stages with vacuum compatible computer controlled actuators (Newport NSA12V6), at 65 and 221 mm from the nozzle. The monochromator entrance slit was 820 mm away from the second knife-edge, and its aperture was set at 2 mm, larger than the beams at its position. The exit slit aperture was also set at 2 mm.

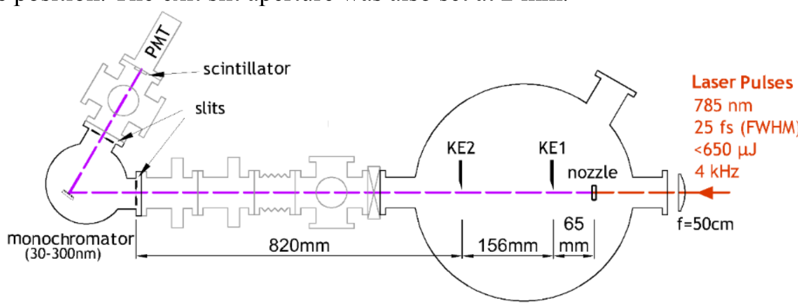

Figure 1. scheme of the experimental setup in which the harmonics beams were generated and measured.

Knife-edges measurements were performed reading the PMT signal in a lock-in amplifier triggered by the pulses. The obtained data were then fitted by[3]:

$$f = amp\frac{1}{2}\left\{1 + erf\left[\frac{\sqrt{2}}{w}(x - x_0)\right]\right\} + bg \tag{1}$$

where w is the beam spot size defined in the usual way (radial distance where the intensity drops to $1/e^2$ of the peak), x_0 is the peak position, *amp* is the function amplitude and *bg* is a background value. The measured values of w at the

KE1 and KE2 positions, w_1 and w_2, respectively, were used to calculate the beam divergence, harmonic beamwaist position relative to KE1 and beamwaist size for each harmonic. Two measurements were done for each harmonic and the values obtained are the average of the measurements[3].

Results

Figure 2 presents 2 knife-edges measurements for the 3rd harmonic, with the spot sizes obtained from fittings by eq. (1). Knowing w_1 and w_2 values and positions, and using the beam propagation law $w(z)=w_0[1+(z/z_0)^2]^{1/2}$, where z is the position relative to the beamwaist and z_0 is the beam Rayleigh length, is possible to calculate the beamwaist size w_0, its position relative to KE1 and the geometric reconstruction of the harmonics beams, and the results are shown in Figure 3, for each harmonic.

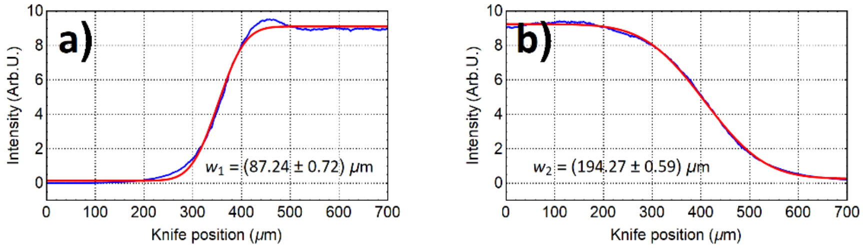

Figure 2. Knife-edge traces measured at a) KE1 and b) KE2 positions, for the 3rd harmonic (255.5 nm). The spot sizes obtained from the fittings by eq. (1), in red, are shown.

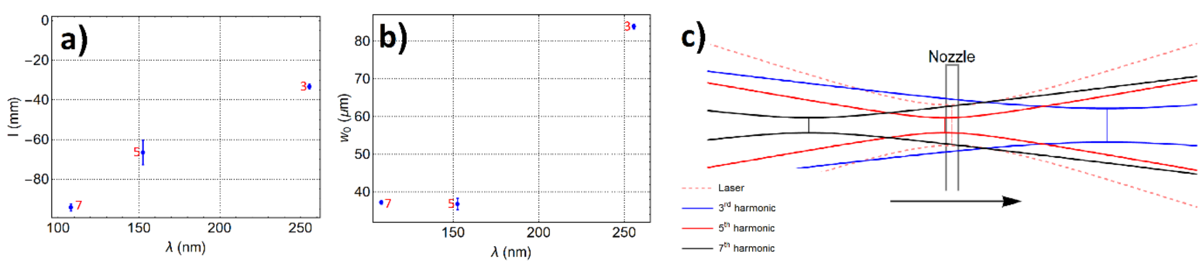

Figure 3. a) distance between beamwaist position and KE1 b) beamwaist size for the generated harmonics and c). geometric reconstruction of harmonics beams

Figure 3 shows that the beamwaist size is reduced as the harmonic order grows (wavelength increases), meaning that, as the harmonic order increases its generation is more confined to higher intensities regions, as expected. Although the beamwaist positions are do not coincide with the nozzle, there are a decreasing ratio as the harmonic order grows. Additionally, from the w_0 values the beam divergence can be calculated for each harmonic, $\theta_0=\lambda/(\pi w_0)$, which are 0.97 ± 0.01, 1.32 ± 0.08 and 0.92 ± 0.01 for the 3rd, 5th and 7th harmonic, respectively.

Conclusions

We have generated BTH beams from 100 to 260 nm and this technique has been fundamental to characterize the harmonics beams geometrically. As for the limitations of the technique, we are working to improve it.

References

[1] Y. Nabekawa, Y. Furukawa, T. Okino, A. A. Eilanlou, E. J. Takahashi, K. Yamanouchi, and K. Midorikawa, "Sub-10-fs control of dissociation pathways in the hydrogen molecular ion with a few-pulse attosecond pulse train," Nat. Commun. **7**, 1-11 (2016).

[2] P. C. Li, Y. X. Jiao, X. X. Zhou, and S. I. Chu, "Role of quantum trajectory in high-order harmonic generation in the Keldysh multiphoton regime," Opt. Expr. **24**, 14352-14361 (2016).

[3] A. A. Almeida, A. V. F. Zuffi, R. E. Samad, P. S. F. de Matos, and N. D. Vieira, "Harmonics Beams Characterization Using the Knife-Edge Technique," in High-Brightness Sources and Light-Driven Interactions, OSA technical Digest (online) (Optical Society of America, 2016), paper ET4A.1..

Acknowledgements

The authors thank the financial support from FAPESP, CNPq and SAE, and a CAPES scholarship to one of us (Zuffi).