Conversion efficiency and scaling for high harmonic generation: an analytical approach

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Synopsis: Closed form expressions for the high harmonic generation (HHG) conversion efficiency are given for the plateau and cutoff regions. The results are obtained considering propagation effects, the single atom response and the single active electron (SAE) approximation. Measured absorption cross sections are used, and no parameter fitting is employed. The calculated efficiencies agree well with the experimental values published in the literature.

High harmonic generation is exciting rapidly developing field not only from the basic science enabling it, but also due to the number of promising applications involving HHG in the XUV region. Comparatively to others XUV sources, HHG is unique due to its complete spatio-temporal coherence enabling attosecond pulse generation.

In this work, applying the saddle point treatment to the dipole acceleration of the improved three step model (ITSM) [1], analytic formulas for the HHG conversion efficiencies for the plateau and the cutoff region including both laser and material parameters as well as 1D propagation effects were obtained. For fixed harmonic wavelength, a scaling for the HHG efficiency with the driving frequency of ω_0^5 at the cutoff and ω_0^6 at the plateau region were obtained. This result is in accordance with numerical simulations using the time dependent Schrödinger equation [2] which includes the single-atom response only, and with preliminary experimental results [3]. Besides the single-atom response, our derivation indicates that another major contribution to be considered in the wavelength scaling is the medium characteristics, such as, recombination amplitude, absorption cross section and phase matching. These quantities exhibit a strong wavelength dependence which has an important role if cutoff extension is the goal. As can be observed in Fig. 1(a), considering absorption limited conditions for Ne, the maximum efficiency at the cutoff shifts for different driver wavelength, but the peak does not exhibit any strong dependence with the driver wavelength, as one may expect from the scaling of the single-atom response. This behavior is also reproduced via numerical evaluation of the ITSM at constant field amplitude E_0 while varying ω_0, as shown in Fig. 1 (b). The reason for that is due to the absorption cross section of neon which decreases more than two orders of magnitude for that wavelength range.

In summary, our derived formulas simplify the HHG optimization problem and enable a complete HHG scaling analysis. Thus, we believe that the theory presented in this work can have a significant impact on the development of any HHG based EUV sources, including attosecond pulse generation.

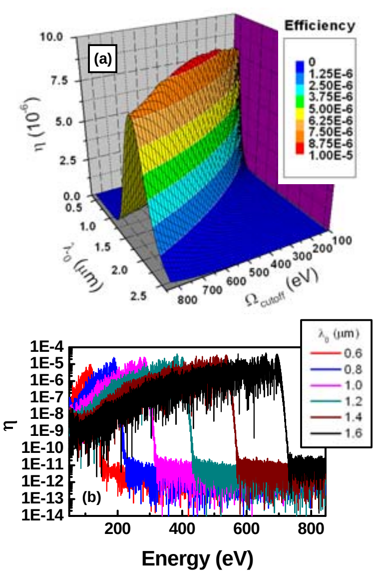

Fig. 1. (a) Neon HHG efficiency at the cutoff region, as a function of the driver wavelength, λ_0, and the cutoff energy, Ω_{cut}. (b) Full spectrum obtained considering a Gaussian pulse with $E_0 = 0.16$ a.u. for different driver wavelengths. For both cases absorption limited conditions and a 5-cycle-driver-pulse were assumed.

References

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