Femtosecond enhancement cavities for high repetition rate HHG

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Synopsis High repetition rate high harmonic generation (HHG) has great potential as a source of XUV radiation with exceptional frequency resolution . We present progress in our ability to efficiently create this radiation within a passive optical cavity. This has enabled new tests of the temporal coherence of the harmonic radiation as well as fundamental studies of quantum paths in below-threshold harmonic generation.

Traditional methods for high harmonic generation (HHG) employ low repetition rate optical amplifiers. This low repetition rate produces a source with poor spectral resolution. To overcome this, we have pursued experiments in which broadband, femtosecond pulses are coupled into passive external cavities. This method enhances the pulse energy sufficiently to enable the HHG process without a decrease in the pulse repetition rate. The ability to conduct high repetition rate HHG ($\sim$ 100 MHz) has the potential to create a frequency comb in the XUV which possesses exceptional frequency resolution [1, 2].

To produce high harmonic radiation, we utilize a cavity enhanced 1070 nm ultrafast fiber laser. The laser supplies a train of $\sim$100 fs pulses at 136 MHz with up to 10 W of average power. Within the cavity, the average power is enhanced by a factor of 260. Curved mirrors produce a tight intracavity focal spot with a peak intensity of 4×10^{13} W/cm^2. We inject xenon gas at the intracavity focus to act as a nonlinear medium. An XUV diffraction grating written on a 1070 nm high reflector is utilized as one element of the enhancement cavity so that a portion of the generated harmonic radiation will diffract out of the cavity (efficiency$\sim$ 10%). This method allows the generation of harmonics up to the 21^{st} with individual outcoupled harmonic power of $\sim$50-1000 nW [3] (see Fig. 1).

The ability to conduct high-field studies at a high repetition rate has allowed several new studies of harmonic generation. By investigating below-threshold harmonics, we were able to discover multiple generation pathways with distinct intensity dependent optical phases. These intensity dependent phases were distinct in magnitude from those of above threshold harmonic generation and manifested themselves as oscillations in the harmonic yield as the driving intensity was varied. The high repetition rate has additionally allowed us to conduct tests of pulse-to-pulse coherence through which we were able to demonstrate that the coherence of the 7^{th} harmonic is maintained over at least 10 ns. The manipulation and control of these harmonics and their coherence properties is crucial for the future development of XUV frequency combs.

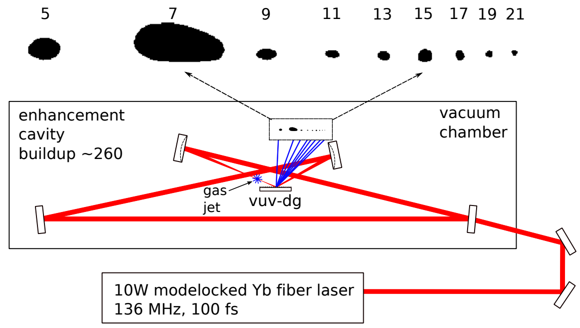

Fig. 1. Experimental setup. A cavity enhanced Yb fiber frequency comb is used to generate harmonics in Xe gas. A VUV diffraction grating (vuv-dg) is used to outcouple harmonic light. The inset shows beam profile of the diffracted harmonic orders.

We gratefully thank M. Gaarde, K. Schafer, J. Tate and J. Hostetter for theoretical support. Funding is provided by DARPA, NIST and NSF.

References

[1] R. J. Jones, K. D. Moll, M. J. Thorpe, and J. Ye, Phys. Rev. Lett. **94,** 193201 (2005).

[2] C. Gohle *et. al.*, Nature **436,** 235 (2005).

[3] D. C. Yost, T. R. Schibli and Jun Ye, Opt. Lett. **33**, 1099 (2008).

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