L.4: Ultrastable high harmonic generation from a semi-infinite gas cell with a thermally insulated exit endcap

High harmonic generation (HHG) is well known technique for generation of coherent and ultrashort extreme-ultraviolet (XUV) radiation. These unique characteristics enables the source to be used in wide areas of scientific research application. HHG is a highly nonlinear process, in which the characteristic of the radiation is crucially dependent on the interaction of ultrashort intense laser pulse with atoms in a nonlinear medium. Several nonlinear media, such as gas jets, small length cells, gas filled waveguides and semi-infinite gas cell (SIGC) etc., has been explored to achieve high flux, high coherence, good spatial profile along with small pulse width, which may extend to tens of attosecond. The study of source stability remains least explored. Several applications of this source, such as pump-probe experiments (for time resolved studies of ultrafast phenomena) need high source stability, together with high flux, however the source stability remains a prime criterion. We present our study on HHG from a SIGC with a prime focus on achieving ultrahigh stability (rms stability ⩽ 1%) together with high photon flux. Due to high nonlinear nature of HHG, this criterion is difficult to achieve. We have selected SIGC for HHG and carefully optimized parameters like gas pressure, cell position relative to laser focus and more importantly the design of exit endcap plate. We have used two plate configurations a) the aluminium endcap (0.5 mm thick), called SIGC(M) and b) thermally insulated endcap SIGC(I) for the study.

Fig. L.4.1 shows the experimental setup used for HHG using a 450 mm long SIGC. In SIGC, the cell is vacuum shielded with a glass window at laser entry and with a thin aluminium (0.5 to 1 mm) sheet at the exit. For HHG, the laser pulse is focused in the cell using 600mm focal length plano-convex.

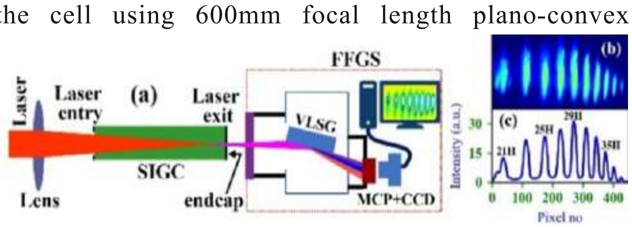

Fig. L.4.1: Experimental setup for generation and detection of high order harmonic radiation from SIGC

The laser pulse drills orifice in the endcap plate (marked in Fig. L.4.1), through which the high-harmonics and laser pulse comes out. The high-harmonics are dispersed and detected using in-house developed flat field grating spectrograph (FFGS). From the recorded FFGS spectra of high-harmonics, the vertical binning was performed to get the intensity profile. For estimation of root-mean-square (rms) intensity stability, we recorded ten consecutive spectral images of same exposure time. A separate background frame was recorded under the same condition (except without laser pulse) and was subtracted from these spectra before further processing. The integrated high-harmonic intensity (I_i) was calculated by summing the intensity of all the harmonic orders present in the spectrum recorded using FFGS. The coefficient of variation (CV) is calculated from the ratio of standard deviation (σ) and mean value (μ) of integrated high-harmonic intensity and given by

$$CV\ (\%) = \sqrt{\frac{1}{N}\sum\left(\frac{I_i}{\bar{I}}-1\right)^2} \times 100 \qquad (1)$$

In Eq. 1, $\bar{I}$ is the mean value of intensities I_i, and N is the number of data points. A smaller CV value indicates better rms stability. We have first used SIGC (M) and optimized parameter to achieve minimum CV. Figure L.4.2 a) shows the CV and intensity of high-harmonics at optimum pressure (20 mbar). The CV is smaller on laser defocusing regime (cell position > 0) and is very localized, whereas the intensity peak is close to zero. This shows that the CV minima and intensity maxima are not coinciding. We have performed numerical simulations to understand the observation and found that during self-drilling of laser pulse in SIGC exit endcap, full beam is not able to transmit and the blocked laser part heats the endcap plate, which increases its temperature. This affects the gas flow through the exit end cap and creates density fluctuation, which is detrimental in deteriorating the source stability. To overcome this, we have used thermally insulated endcap plate.

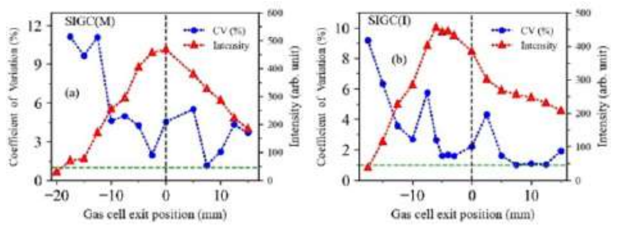

Fig. L.4.2: a) Variation of CV (left) and intensity (right) of high-harmonics in SIGC (M) with cell position, and b) variation of CV and intensity with cell position in SIGC(I), at optimum gas pressure of 20 mbar

Fig L.4.2 b) shows the CV and high-harmonic intensity at 20 mbar in SIGC(I). It can be seen that the CV improves to ~ 1% and it is not localised as in SIGC(M). The high-harmonic intensity also slightly increases as compared to Fig L.4.2 a). This shows an improvement in source stability as well as high harmonic intensity in SIGC(I). In this condition, the photon flux of > 5×10^{10} photons/laser shot in ~20 – 40 nm range (23rd to 39th harmonic order) was measured. The intensity stability was continuously monitored over duration exceeding 12 hours and average CV ⩽ 1% was maintained. The high stable HH source will be extremely useful for applications such as study of thermal transport, ultrafast demagnetization etc., where the source stability is very important to observe small changes.

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