

# Influence of Gas Pressure on High Harmonic Generation on Argon

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**Abstract:** Generation of high-harmonics using femtosecond laser pulses has remarkable feature in various applications. A Ti:Sapphire laser was employed to generate harmonics in argon gas flowing through a nozzle. We present here the current results of high-harmonic generation at different gas pressure and discuss phase matching.

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## Introduction

Generation of coherent extreme ultraviolet (EUV) by focusing femtosecond laser pulses into gasses is a well-known method [1-4]. High pulse intensities, greater than  $10^{13}$  W/cm<sup>2</sup>, are required for the High Harmonics Generation (HHG) nonlinear conversion process. These high pulse intensities are not directly attainable using only the output power of a femtosecond oscillator. Chirped Pulse Amplification (CPA) enables the pulse intensity to exceed this threshold by incorporating several regenerative and/or multi-pass amplifier cavities in tandem [5].

The HHG process depends on a high density of atoms leading to coherent buildup of light as it propagates through the nonlinear medium, the length of the nonlinear medium, the absorption of harmonics by the nonlinear medium and phase matching between the fundamental and the harmonic field. In addition to medium dispersion, the presence of free electrons can lead to a phase mismatch, which limits coherent buildup to short interaction lengths. The HHG efficiency is optimized by a delicate balance of these competing processes [6, 7]. Gas jets are common source of high harmonics with typical medium lengths and on-axis pressure on the range of few millimeters and tens of mbar, respectively.

There are two reasons for phase mismatch: the first one is the nonlinear medium dispersion that is due to the phase difference between the fundamental light and the generated field. The second one is the laser beam focusing that also leads to an effective phase mismatch. The effect of dispersion increases with the atomic density (by increasing the medium pressure) and is very sensitive to the presence of resonances. In contrast the effect of focusing is purely geometrical. There will be no harmonics if the laser is not well focused and if the gas pressure is above or below the correct range. The situation becomes more complicated when harmonics are generated in thin gas nozzles. This introduces another length, the medium thickness, which can be comparable to the laser confocal parameter.

In this paper HHG in an argon gas nozzle at different gas pressure has been carefully studied, and the phase matching was observed at an optimized gas pressure.

## Experimental set up

Pulses from a Ti:Sapphire laser (Femtopower Compact Pro HP/HR, from Femtolasers), centered at 785 nm, in a 4 kHz train, with 29 fs and 800  $\mu$ J of maximum energy were employed to generate harmonics in an argon gas nozzle. The pulses were focused by a 50 cm focal length lens to intensities in the  $10^{15}$  W/cm<sup>2</sup> range to generate harmonics in the gas nozzle, which was placed inside a vacuum chamber. A turbomolecular vacuum pump was used to evacuate the chamber and an attached monochromator (McPherson 234/ 302, 30-300 nm range) to a background pressure of  $10^{-6}$  mbar. Harmonic radiation produced in the nozzle passed into the monochromator where the beam was spectrally dispersed by grating and then imaged onto a PMT with a Sodium Salicylate scintillator.

The gas nozzle used was only 2.5mm thick to minimize the possibility of phase mismatch and re-absorption. Argon gas was injected through the nozzle, which was placed just after the focus point for the short trajectory, with different back pressures and it. Only odd harmonic orders were generated due to selection rules. The measured spectrum was recorded in a digital oscilloscope and then processed in a computer. The experimental setup is depicted in Figure 1.

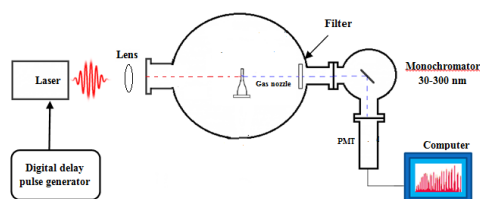


Fig. 1. Experimental setup for High Harmonics Generation in the gas nozzle.

## Results & Discussion

We have studied the pressure dependence of different harmonics and phase matching pressures. In order to have harmonic spectra, we first needed to find the best location of the gas nozzle within the confocal range of the laser beam. The gas nozzle was placed at  $\sim 2$  mm after the focus to get properly phase match and harmonic spectra. Figure 2 depicts the harmonic signals at 140 mbar argon gas pressure, and the odd harmonics between the 11<sup>th</sup> and 19<sup>th</sup>, in the 50 nm spectral region ( $\sim 25$  eV), can be clearly seen.

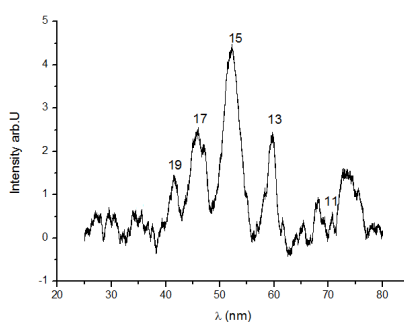


Fig.2. High harmonic signals at 140 mbar pressure at  $\sim 2$ mm nozzle position after the focus.

Figure 3 shows the harmonics spectrum dependence on the argon pressure. As expected, the pressure plays a large role in the harmonic yield as it contributes to both the plasma density and neutral atom response mechanisms of the phase matching. Through increasing pressure, we found optimal signal strength near to 140 mbar of backing pressure.

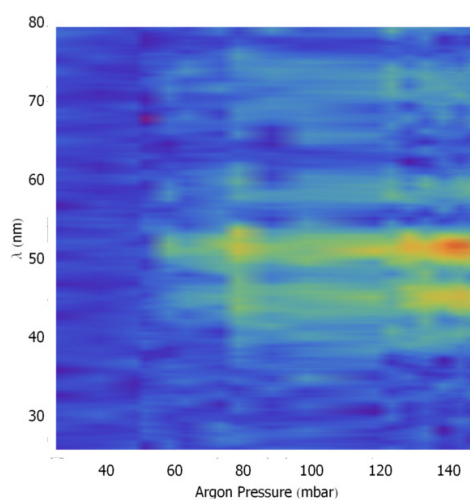


Fig.3. Argon pressure dependence of harmonics spectrum in the pressure range from 40 to 140 mbar. Phase matching peaks can be observed.

The interplay between absorption and phase matching is clearly observed in Figure 3. This indicates that the gas pressure, atomic density and laser focusing play an important role in phase matching. In the case of high harmonics in argon, phase mismatch takes over at high pressures, resulting in a strong decrease in the harmonic signal due to destructive interference in the medium. Harmonics are generated in the pressure range from 10 to 250 mbar, and Figure 4 shows the different harmonic intensities dependence on the gas pressure. The emissions are weak for low pressures, increasing with the gas pressure, decreasing for pressures above 150 mbar. The optimal signals for the 13<sup>th</sup> and 15<sup>th</sup> harmonics are obtained at 140 mbar, and for the 11<sup>th</sup>, 17<sup>th</sup> and 19<sup>th</sup> harmonics they peak at 80 mbar.

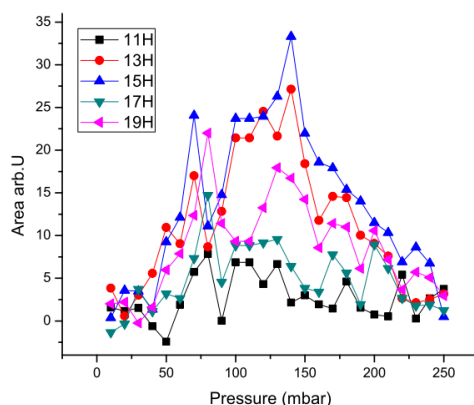


Fig.4. Area of high harmonics signals versus gas pressure

Each harmonic signal is optimized at a different gas pressure. The phase matching is determined by different dispersion terms, and then compensates at a particular pressure for each harmonic. The harmonic signals increase together with the medium gas density due to increasing gas pressure. However, one could not always expect an increased harmonic emission by applying higher density gas target. There is a critical value beyond which the production of high harmonics has a very weak dependence upon the dense gas target. It is shown that at high pressures, due to atomic density, a phase mismatch occurs and the signals drop.

### Conclusions

In summary, we have examined the behavior of the harmonics signals in the argon pressure, and optimized them using a 2.5 mm length nozzle. We have successfully generated from the 11<sup>th</sup> to the 19<sup>th</sup> harmonics using Ti:Sapphire laser pulses with intensities around  $10^{15}$  W/cm<sup>2</sup>. Optimized signals were observed at 140 mbar for the 13<sup>th</sup> and 15<sup>th</sup> harmonics, and at 80 mbar for the 11<sup>th</sup>, 17<sup>th</sup> and 19<sup>th</sup> ones.

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