WB4
11:30am - 11:45am

Phase-matched Generation of Short Wavelength, Ultrashort-pulse Light in Capillary Waveguides

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In recent work[1], we demonstrated a new technique for phase-matched frequency conversion of ultrashort laser pulses in a gas-filled capillary waveguide. Here we present several major new developments that demonstrate that this technique can be used to efficiently upconvert light into the deep-UV and the XUV. This technique is particularly well suited to the generation of very short 10-20fs pulses, making it possible to leverage recent advances in near-infrared ultrashort-pulse lasers[2]. In the past, third harmonic generation by sum-frequency mixing in nonlinear crystals has been the primary means for the generation of μJ-level light in the deep-ultraviolet[3]. However, maintaining reasonable efficiency along with ultrashort pulse durations (≤100fs) has proven difficult. In contrast, frequency conversion in gases exhibits a dramatically lower group velocity walkoff, making it possible to generate much shorter UV pulses[4, 5]. However, due to poor phase matching in a simple focused beam configuration, the conversion efficiency is relatively low (0.1%).

In our novel phase-matching technique[1] light is generated in the deep-UV through nonlinear parametric amplification ($\omega_{signal} = 2\omega_{pump} - \omega_{idler}$) in a gas-filled capillary waveguide. Phase-matching is achieved through a balance between the waveguide dispersion of the lowest order mode with the pressure-dependent gas dispersion. This results in near-Gaussian beam quality and high conversion efficiency. In these new results, by using a larger-bore capillary, we have increased the conversion efficiency from the 400nm pump light into 267nm to 18%, with a pulse energy of 10μJ at 1 kHz. This pulse energy can be generated using only ~0.5mJ at 800nm. Using self-diffraction frequency-resolved optical gating, we have measured the 267nm pulse at <40fs, with a linear chirp that would allow compression to < 25fs. Due to the nonresonant nature

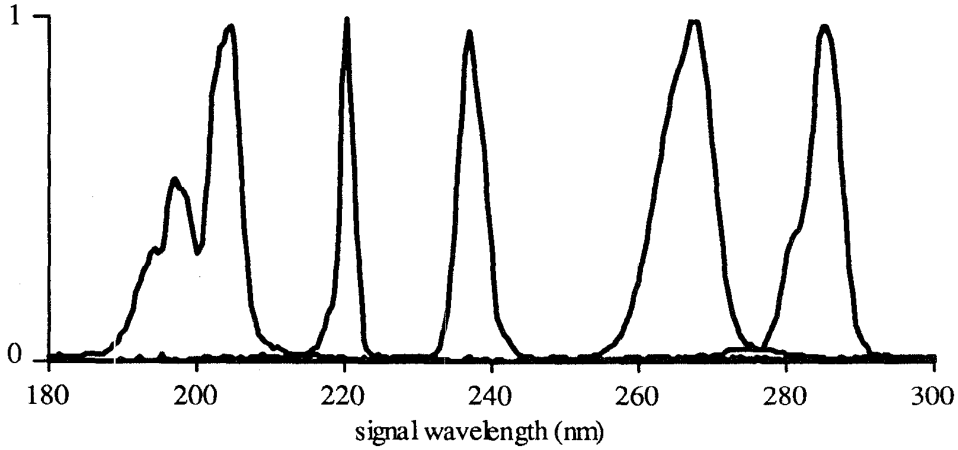

Figure 1: Normalized spectra of mixing signal with 400nm pump and various idler wavelengths.

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of the phase matching in this configuration, and small degree of group velocity walkoff, we expect to obtain sub 10-fs pulses by optimizing the chirp and energy of the input pulses.

We have also demonstrated that this technique can generate light tunable throughout the ultraviolet, by mixing 400nm output with the light from an infrared optical parametric amplifier. A 300μm BBO crystal was used to frequency double the kilohertz multipass amplifier[6-8] output, with 20% conversion efficiency. After separation of the two colors, the blue light was combined with the output (signal, idler or their second harmonics) of a two-pass BBO OPA (Spectra-Physics) in the gas-filled capillary. Representative spectra from the output are shown in Figure 1. The full tuning range for this four-wave mixing process is 217 to 305nm. Also shown is a spectrum at 200nm resulting from a phase-matched $\chi^{(5)}$ process ($3\omega(400)-2\omega(800)$). Similar higher-order mixing processes promise to allow efficient ultrafast conversion throughout the VUV, up to 50eV photon energy.

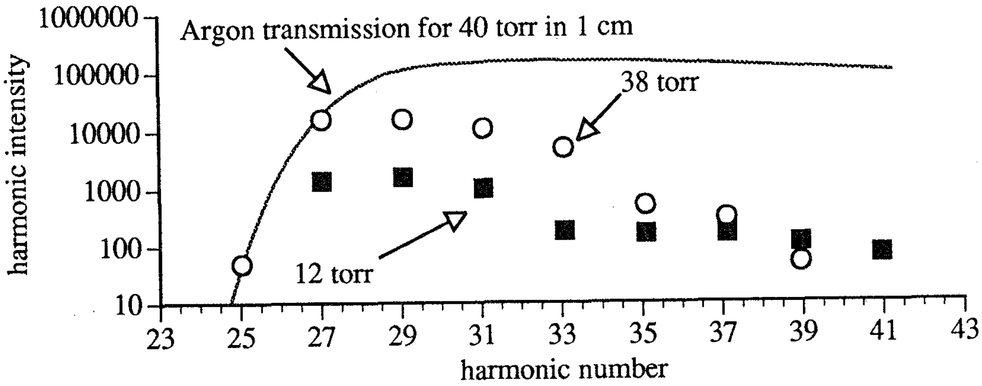

Figure 2: Harmonic spectra from a capillary waveguide filled with 12 and 38 torr of argon. Transmision curve for argon is also shown (solid line).

Finally, we have evidence for phase matching of high-order harmonic generation in a capillary waveguide. For photon energies well above the ionization potential, the refractive index of neutral or partially ionized gas is very close to unity. Phase matching of high-order harmonics is therefore possible by making $k_{fund} \approx k_{vacuum}$. Pressure tuning allows the gas dispersion to balance that of the waveguide. This can be achieved with up to a few percent of ionization, so we expect phase-matched HHG to be possible for those mid-plateau harmonics that are generated before strong ionization occurs. The capillary cell used in the experiment is of a novel design that allows a relatively high gas pressure within the capillary while greatly restricting the flow of gas into the vacuum regions at either end. Three sections of capillary were held in a V-groove with ~1 mm spacing between the segments. This allowed a guided laser beam to pass from one section to another with minimal loss. Figure 2 shows the harmonic spectrum generated in argon in a 150μm core diameter capillary. At low pressure, the harmonics show the typical plateau structure seen with gas jet targets. At higher pressure, there is a strong increase in the mid-range harmonics, in contrast to the lower harmonic orders that are dominated by gas absorption and the higher harmonics which are more affected by strong ionization effects such as dispersion. The output beam in these experiments showed no effect of defocusing found at high density in gas jet experiments. In very recent experiments, we have obtained a significant improvement in the harmonic yield in this manner [9].

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