mization of the spectral phase, we developed a modified simulated annealing algorithm, which searches for a spectral phase that maximizes this feedback signal.

To exploit the full potential of adaptive compression of pulses obtained directly from a laser, we adjusted our mode-locked Ti:sapphire laser to produce wideband pulses (see Fig. 1b, inset). An interferometric autocorrelation measurement of these pulses, shown in Figure 1b, indicates strongly chirped pulses of 80-fs duration. These pulses were adaptively compressed down to 14 fs, using our modified simulated annealing algorithm with 1,000 iterations. We also performed a search in the 2-D space of the second- and third-order dispersion coefficients, to approximate the spectral phase of the pulses by a superposition of quadratic and cubic phase distributions. Using this search, we compressed the 80-fs pulses down to 11 fs, in 1,200 iterations, as shown in Figure 1c. Theoretically, the input pulse spectrum can support pulses as short as 9 fs.

More recently we extended the scheme of adaptive compression to adaptive pulse shaping.[3] For this purpose, we minimized the difference between a predetermined target shape and a real-time cross-correlation measurement of the output pulses, used as a feedback. With this method, a variety of shaped pulses were generated,[3] using no information about the input pulses.

The adaptive scheme removes not only the spectral distortion of the input pulses, but also any additional distortions induced by the setup, such as residual dispersion of the shaper, the mirrors, and the SLM itself. Adaptive techniques will also be used for pre-compensation of distortion induced by high-power short pulse amplifiers, where the feedback signal is taken at the output of the system. An important application for adaptive manipulations is in the field of quantum coherent control, where shaped ultrashort pulses drive a quantum system toward desired final states.[5]

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X-RAY SOURCE

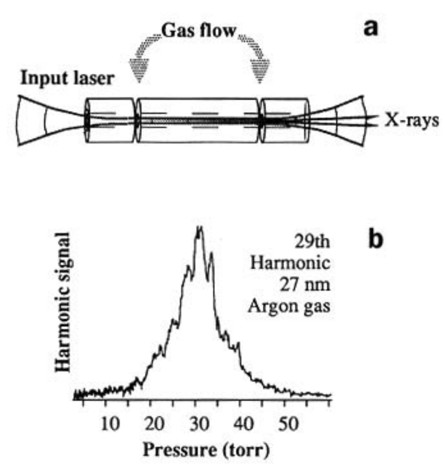
Phase Matched Generation of Coherent Soft-X-rays

A. Rundquist, C.G. Durfee III, Z. Chang, C. Herne, S. Backus, M.M. Murnane, and H.C. Kapteyn, Center for Ultrafast Optical Science, Univ. of Michigan, Ann Arbor, MI.

Nonlinear optical techniques for frequency conversion have played a pivotal role in the development of efficient coherent light sources. Most of these techniques rely on phase matching to obtain high conversion efficiency. Typically, by using birefringence, one can equalize the phase velocity of the pump light with the desired signal light, resulting in constructive interference of the signal produced through a nonlinear interaction. This allows the signal to build up rapidly. However, most techniques rely on crystals. This significantly limits extending nonlinear optics to shorter wavelengths, since no solid material is transparent to wavelengths below 110 nm. Furthermore, dispersion in solid materials makes it difficult to generate extremely short pulses at short wavelengths.

In recent work, we developed a new technique for phase matched frequency-conversion in gases rather than crystals, avoiding these limitations.[1, 2] In this technique, called guided-wave frequency conversion, instead of using the structure of the nonlinear material itself to alter the propagation velocities of the various frequencies involved in the interaction, we use a structure surrounding the nonlinear material. By propagating the light in a simple capillary tube, the effects of the capillary waveguide and of the index of refraction of the gas on the propagation speed counterbalance each other. By choosing an appropriate capillary diameter, the pump wavelengths and, by adjusting the gas pressure, phase-matched frequency conversion in a gas can be obtained. In our first work, we demonstrated extremely high (20%) frequency conversion of 20–40 fs pulses into the ultraviolet using four-wave difference-frequency generation. More recently, we demonstrated that high-harmonic generation in such a capillary can be phase-matched, resulting in a practical, small-scale, high peak-power coherent soft X-ray (17–42 nm to date) source with average power in the microwatt range. Significant improvements will be possible in the future.

The basic experimental configuration for the phase-matched high-harmonic conversion experiments is shown in Figure 1a.[2] Light from an ultrashort-pulse Ti:sapphire laser is focused into a 3-segment capillary tube, with both ends exposed to vacuum and a gas feed that maintains a constant pressure in the center section. Phase-matched high-harmonic generation occurs in the constant-pressure section. Figure 1b shows the signal level for the 29th harmonic, at 27-nm wavelength, as a function of Argon gas pressure. The signal level peaks strongly at 35 torr, consistent with our prediction for phase matching. We also observe that, at the phase-matched



Rundquist Figure 1. (a) Basic configuration for phase-matched high-harmonic generation. (b) High-harmonic output as a function of pressure, showing optimization at a pressure that balances waveguide and gas dispersion to achieve phase matching.

pressure, the spatial mode of the output changes from a diffuse spot into a clean, nearly TEM_{00} mode, as expected. In high-harmonic generation, the nonlinear interaction occurs during the process of ionization of the gas. This creates free electrons that alter the propagation of light in the waveguide and limit the phase matching. To circumvent this difficulty, we use very short (20 fs) driving pulses, so that we can reach the intensities required for high-harmonic generation before very many of the atoms are ionized.

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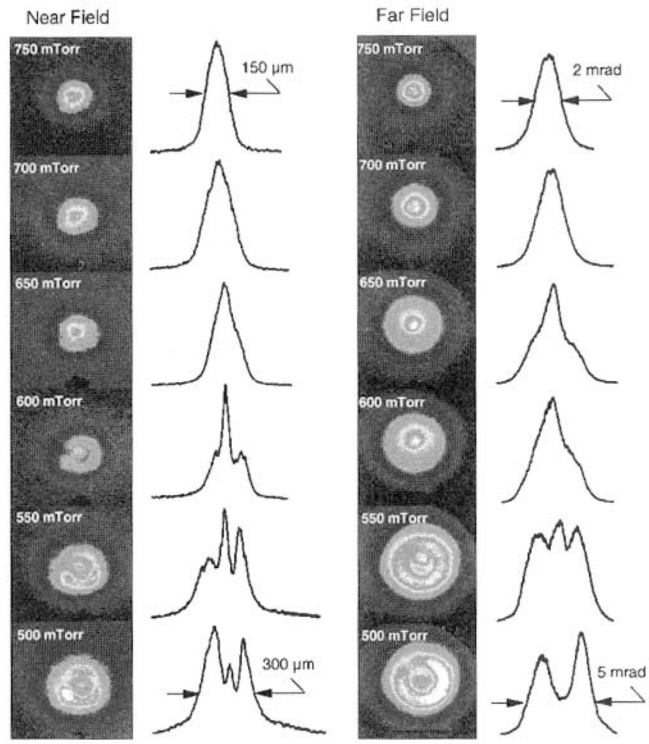
Two-dimensional Near-field and Far-field Imaging of a Ne-like Ar Capillary Discharge Table-top Soft X-ray Laser

C.H. Moreno, M.C. Marconi, V.N. Shlyaptsev, B.R. Benware, C.D. Macchietto, J.L.A. Chilla, and J.J. Rocca, Electrical Engin. Dept., Colorado State Univ., Fort Collins, CO; A.L. Osterheld, Lawrence Livermore National Lab., Livermore, CA.

The observation of large soft X-ray amplification in the plasma of a capillary discharge[1] and the subsequent demonstration of a saturated discharge pumped table-top soft X-ray laser in Ne-like Ar at 46.9 nm has established a new approach for the development of compact and practical soft X-ray lasers.[2] In these lasers the gain medium is a hot and dense plasma column with aspect ratios approaching 1000:1, generated in a capillary channel by a fast discharge current pulse where lasing is obtained by collisional electron excitation of Ne-like ions. Knowledge of the near- and far-field spatial distribution of the output of these lasers is of both practical and basic interest.

We obtained the first 2-D near- and far-field imaging of a capillary discharge-pumped soft X-ray laser.[3] The measurements were conducted in an Ne-like Ar capillary discharge laser emitting a single strong laser line at 46.9 nm.[4] The current pulse, having a peak amplitude of ≈37 kA and a first half period of 72 ns generates and compresses an elongated Ar plasma column in which lasing occurs ≈39 ns after the onset of the current. The discharges took place in a polyacetal capillary 16.4 cm long, 4 mm in diameter, filled with pure Ar gas at different selected pressures ranging from 500–750 mTorr. The left side of Figure 1 shows the near-field images. They were obtained imaging the output aperture of the capillary discharge laser using a 150-cm radius of curvature Ir-coated mirror onto a MCP-CCD detector.

It can be seen that at the higher pressures (> 650 mTorr) the laser beam distribution is a single circular peak with maximum intensity at the center and monotonically decreasing intensity toward the periphery. As the pressure decreases, the beam size at the exit of the amplifier gets increasingly larger, and finally develops into a ring structure. The FWHM beam diameter at the exit of the amplifier increases from about 150 μm at 750 mTorr to about 300 μm at 500 mTorr. The far-field images and model computations show that these effects are caused by larger refraction of the beam in the lower pressure discharges as a result of larger density gradients in the plasma.



Moreno Figure 1. Near-field (left) and far-field (right) patterns of the Ne-like Ar laser beam output as a function of pressure. Diametral cuts with normalized intensities are shown at the left of each image.

Figure 1 (right side) shows the far-field beam patterns corresponding to each of the discharge conditions of the near-field patterns, measured at 148 cm from the capillary exit. As in the case of the near-field images, a transformation is observed in the spatial intensity distribution from a beam profile with a single peak at the center to a ring profile, as the pressure is decreased. This is accompanied by an increase in the beam divergence, from about 2 mrad for discharges at 750 mTorr to about 5 mrad for discharges at 500 mTorr. These results show that refraction increases as the pressure is decreased. The images have the axial symmetry that is expected from a well-behaved capillary discharge. They are a new corroboration of the very high compression, axial symmetry, and plasma uniformity that can be obtained in fast capillary discharges.

Acknowledgment

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