A novel narrow-band wavelength-tunable laser system delivering high-energy 300 ps pulses in the near-infrared

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We report on the performances of a novel powerful laser system to be used for high-order harmonic generation. The pulses are nearly Fourier transform limited, providing narrow-band radiation (~1.5GHz), with an energy of 225 mJ and 10 Hz repetition rate. The pulse duration of 320 ps covers the intermediate region between Q-switched and mode-locked lasers, and provides high peak powers. The nearly Gaussian beam profile, with a beam quality factor of 2.5, enables tight focusing, reaching intensities exceeding 5 x 10^{13} W/cm^2. The system operation is demonstrated near 780 nm, however the tunability extends over the range 700 - 970 nm. The first results of high-harmonic generation with this source are reported.

The majority of modern high peak power pulsed laser sources is based on the concept of Q-switching and mode-locking. The most commonly used Q-switched lasers, the Nd:YAG laser and a variety of excimer lasers, generate powerful pulses with typical durations of 5-15 ns. Mode-locked lasers have typical pulse durations below 50 ps. Recent developments utilize Kerr-lens mode-locking in Ti:Sapphire (Ti:Sa) producing pulses as short as 5 fs. Both types of lasers are used for harmonic generation and the production of extreme ultraviolet radiation. The Q-switched sources typically give access to the perturbative regime and only 3rd (and a bit of 5th) harmonics can be generated. The short pulse lasers give access to the non-perturbative regime and to very short wavelengths even in the x-ray regime. Our aim is to enter the domain of high-harmonic generation, for which 10^{13} W/cm^2 power density is required, but still keep the bandwidth in the extreme ultraviolet limited, so that it is useful for spectroscopic purposes.

Here we describe an alternative laser source covering the intermediate regime between Q-switched and mode-locked lasers. Its pulse duration is, with 300 ps, just in between that of the abovementioned Q-switched and mode-locked lasers. A basic ingredient in the setup is that of a pulse compressor based on Stimulated Brillouin scattering.

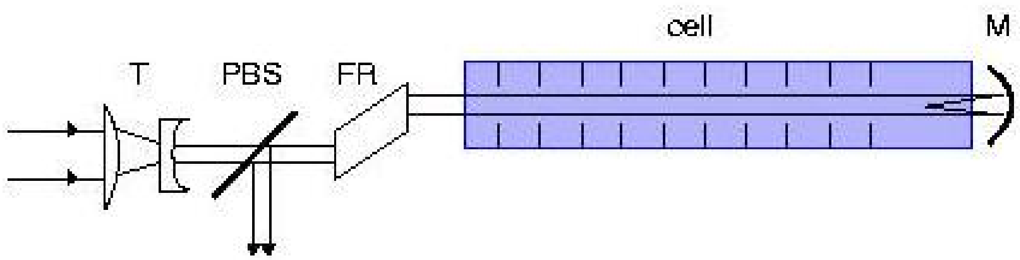

Fig. 1; SBS-compressor setup consisting of a cell of 1 m length filled with clean water, and some optics. The two lenses forming the telescope (T) bring the beam to the optimum power density, the Faraday rotator (FR) circularly polarizes the laser beam, and the mirror (M) retroreflects the beam into a focal zone where the SBS-process starts, resulting in a phase-conjugate back-reflected beam, which is separated by the polarizing beam splitter (PBS) from the incident beam.

As described in a previous publication [1] the pulses of an injection seeded Nd:YAG laser (at 532 nm) of 5 ns duration can be compressed with high conversion efficiency (90% or better) to pulses of 300 ps duration. The simple setup used to accomplish this remarkable phenomenon is shown in Fig. 1. It is built into comprehensive setup of the tunable infrared laser and is used routinely in day-to-day operation. The compressor setup is run with 120 mJ/pulse green output, obtained from frequency-doubling the residual infrared after a first doubling stage of a very powerful Q-switched Nd:YAG laser, which at the main out port delivers > 1 J/pulse green light.

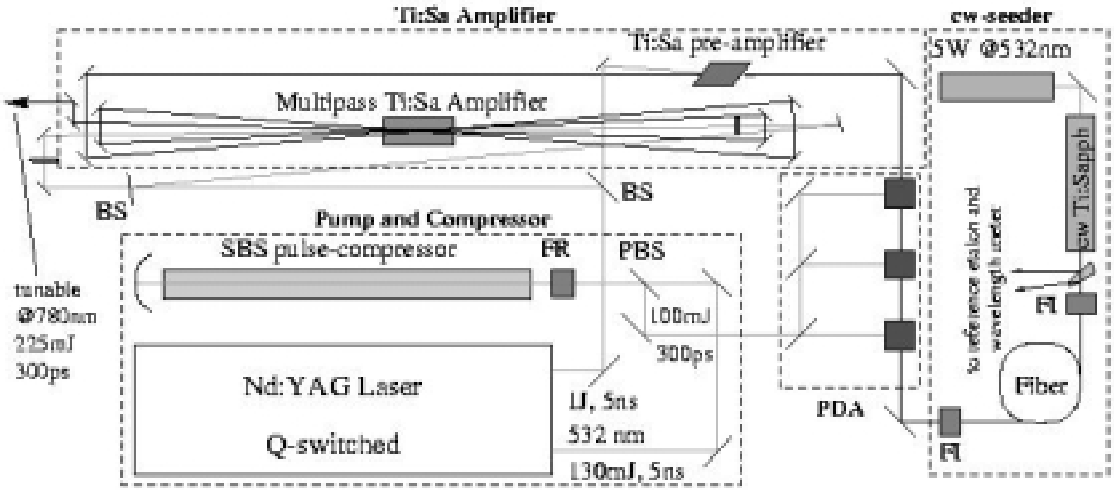

Fig. 2: Layout of the entire laser system, delivering at the output pulses of 225 mJ/pulse, with 320 ps duration, a 1.5 GHz bandwidth, an M^2 beam profile value of 2.5, and at a 10 Hz repetition rate. The subsystems are schematically drawn in boxes; the seed laser determining the frequency at the right, the pulsed dye-amplifier (PDA) section, the pump laser and the SBS-compression cell at the bottom, and the Ti:Sa amplifying stages at the top.

The output of the compressor, laser pulses of 100 mJ/pulse of 300 ps duration at 532 nm, is used for pumping a so-called traveling-wave pulsed dye-amplifier (PDA). In this way the pulse structure of a non-tunable laser pulse can be converted into a wavelength tunable laser pulse. In the range 700-900 nm the relaxation times of dyes are in the order of 150-400 ps, thereby matching the pulse lengths. The PDA is injection seeded with the continuous wave output of a Ti:Sa laser. The PDA serves to produce pulses (indeed of 300 ps duration following the pump laser), which are then amplified in Ti:Sa crystals. With the use of a single pre-amplifying stage and a four-pass amplifier pulse energies of 225 mJ are achieved. Both the pulse duration of the high energy pulses (320 ps) and the bandwidth of the output (~1.5 GHz) are measured; the resulting Fourier time-bandwidth product is 0.48. The M^2 value for the beam profile is 2.5. Further details of the laser source can be found in Ref. [2].

A preliminary investigation was performed using the highly energetic 300 ps near-infrared pulses for high-order harmonic generation, the results of which are displayed in Fig. 3. Harmonics were generated in pulsed jets of noble gases: Argon, Krypton and Xenon. Up to 19^{th} harmonic were observed in argon gas yielding a wavelength as short as 42 nm. Currently measurements of the XUV-bandwidth are conducted, where it is anticipated that these are smaller than 1 cm^{-1}, making the coherence of the source better than at synchrotron beam lines.

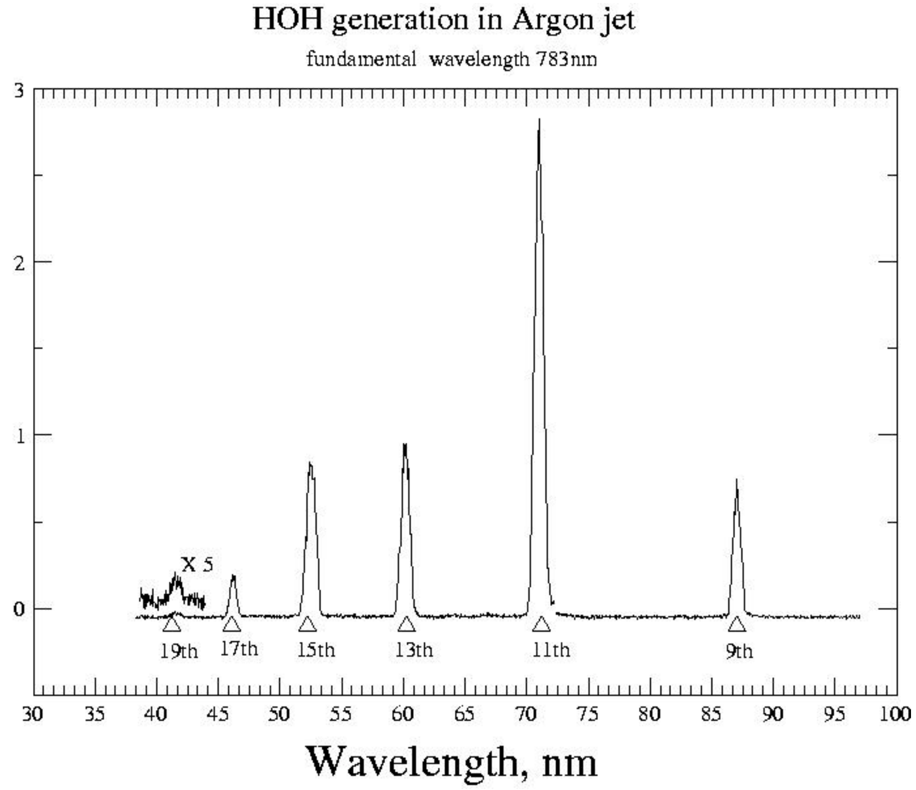

Fig. 3: Results of high-order harmonic generation in a pulsed jet of Argon gas at a fundamental wavelength of 783 nm. The input energy is 225 mJ in 320 ps pulses. Extreme ultraviolet radiation down to 42 nm is produced. Note that the width of the resonances is determined by the grating-slit setup and that it does not reflect the bandwidth of the XUV-radiation.

References

[1] D. Neshev, I. Velchev, W. Majewski, W. Hogervorst and W. Ubachs, “SBS Pulse compression to 200 ps in a compact single-cell setup”, *Appl. Phys. B* 68, 671 (1999).

[2] F. Brandi, I. Velchev, D. Neshev, W. Hogervorst, W. Ubachs, “A novel narrow-band wavelength-tunable laser system delivering 300 ps high-energy pulses in the near-infrared”, Review of Scientific Instruments, January 2003.