THE XeCl LASER SYSTEM WITH HIGH SPECTRAL BRIGHTNESS

N.G. Ivanov, S.E. Kovalenko, V.F. Losev, and Yu. N. Panchenko

Institute of High-Current Electronics,
Siberian Branch of the Russian Academy of Sciences, Tomsk
Received May 18, 1995

We present here some experimental results on the laser system of XeCl *molecules comprising a master oscillator and an injection seeded laser with a supergaussian unstable resonator. In the experiments we have obtained laser pulses of* 80 mJ *energy at a pulse duration of* 100 ns. *Beam divergance reached in this system is close to the diffration limited, and the spectral width of the emission is as narrow as* 0.01 cm^{-1}.

Rare gas halide lasers are the most high-power and efficient sources of the UV radiation. However, low quality of the output laser beam (divergence of 10^{-3}–10^{-2} rad, line width of 1–10 cm^{-1}) limits their use in practice. In the problems of nonlinear optics, laser spectroscopy, holography, and atmospheric sounding, lasers with high spectral brightness exhibiting narrow linewidth and diffraction-limited divergence simultaneously are urgently needed. Spectral and spatial selectors are usually used for improving laser beam quality. However, this results in a substantial reduction of the laser output being, as a rule, on the order of 10–100 μJ (Refs. 1–4).

Further increase in the laser output can be reached with a system of two lasers, the second one operating in the amplification[1,4,7] or injection seeded mode[5,6]. Injection seeding enables one to obtain output energy 10^3–10^5 times higher as compared to the simple amplification mode and to control the output pulses being longer than that of a master oscillator.

In this paper, we present data on a XeCl laser system with high spectral brightness comprising a master oscillator (MO) and a controlled laser (CL). Block diagram of the experimental setup is shown in Fig. 1.

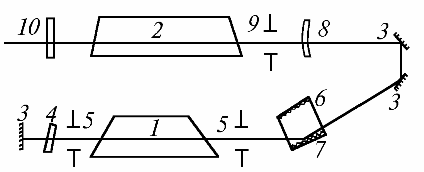

FIG. 1. Block diagram of the optical arrangement: laser active volumes 1 and 2, totally reflecting mirror 3, solid state etalon 4 with a base of 10 mm, *diphragm 5* 1.4 mm *in diameter, gratings 6 and 7, semitransparent meniscus 8, a diphragm 9* 10 mm *in diameter, and a supergaussian mirror 10.*

Laser system consists of two discharge XeCl lasers. The first one serves as a master oscillator and the second one operates in the injection seeding mode. The first one is pumped by a storage capacitor of 100 nF charged to 30 kV. This capacitor is coupled to laser gap via six spark gaps. A peaking capacitor of 6 nF is connected in parallel to the laser gap. Active volume is $0.7 \times 2 \times 60$ cm^3. Preionization is provided with a surface discharge on a dielectric that serves as one of the electrodes. When equipped with a plane parallel resonator, the laser provides 100 ns, 0.3 J output pulses at Ne:Xe:HCl = 800:10:1 mixture and a total pressure of 4 atm.

Windows of the MO laser chamber are assembled at the Brewster angle. Transverse modes are selected with two diaphragms 1.4 mm in diameter. Line narrowing is provided by two gratings with 2400 grooves/mm and an etalon with 10 mm base (its sharpness equals 12). One of the gratings is set at the grazing-incidence angle (the first order of diffraction) whereas the second one was set in retroreflection position. Zero-order diffraction on the first grating is used for laser emission escape from the cavity.

The output beam of the master oscillator exhibited nearly diffraction-limited divergence, linewidth of 0.01 cm^{-1} and 50 ns pulse of 1 mJ energy[8].

The second laser has two active volumes of $1.5 \times 3.5 \times 32$ cm^3 located in the laser chamber along its optical axis[9]. Excitation of one volume can be delayed with respect to the excitation of another one. This enables one to widen the laser output pulse. Preionization used was the same as in the master oscillator. The windows of the chamber are mounted at an angle of 3° to the optical axis. Output pulses of 120 mJ were obtained with a gas mixture Ne:Xe:HCl = 1500:5:1 at a total pressure of 4 atm with a plane parallel resonator. At a time delay of 40 ns the total pulse duration reaches 110 ns (FWHM).

Unstable resonator with $M = 7$ was composed of a convex surface of a meniscus with reflectance of 80%

0235-6880/95/11 873-03 $02.00

and curvature radius of 134 cm and a supergaussian mirror on a quartz plate. This mirror is 3.8 mm in diameter. Its maximum reflectivity is 37% and supergaussian factor $n = 4.3$. A diaphragm of 10 mm diameter is set near a convex mirror to suppress the background. Such a resonator configuration provided an output energy of 80 mJ in a pulse of 100 ns (FWHM) duration.

The beam of master oscillator is injected into the resonator of the second laser through the semitransparent meniscus. The two lasers were synchronized within ±5 ns.

The shape of laser pulse was monitored using a FEK–22 SPU photodiode and a 6 LOR oscilloscope. Output energy is measured by means of an IMO–2N calorimeter. Spectral characteristics are measured using an IT 28–30 etalon with a 70 mm spacing and a home–made spectrograph with the resolution of 0.1 cm^{-1}. The beam divergence is measured with a set of calibrated apertures placed in the focal plane of a lens with $F = 15$ m.

To provide for an effective control of the second laser output, the following conditions are to be satisfied.

First, to fill the cavity with the injected radiation between the beginning of excitation pulse and the beginning of lasing. Second, to provide the intensity of injected radiation in excess of the intensity of amplified spontaneous emission. In our experiments, these conditions were met by variation of the time delay of the initiation of the second laser and by changing the intensity of the injected beam.

Injection locking is checked by monitoring the output spectrum.

Figure 2 depicts densitograms of the output spectrum obtained in free–running operation mode and in the case of injection locking. First spectrum contained 0–1 and 0–2 bands of the XeCl molecules. Their intensities are approximately equal, band width being 0.25 Å (FWHM). Injection into 0–1 or 0–2 transition led to dominating of the injected line with a weak noise on the second line. Since line width of the injected beam was limited by resolution of the spectrograph used, its intensity can hardly be compared with the background power. Analysis of spectrograms with different attenuation showed that the signal–to–noise ratio is 1/40 when the injected beam corresponded to the peak of 0–1 or 0–2 band. When the master oscillator is tuned to minimum of the gain curve between the bands the signal-to-noise ratio measured is 1/4.

In the case of injection locking, the line width of the output radiation is determined by means of etalon. Figure 2*d* presents an interferogram of radiation that demonstrates line width of 0.01 cm^{-1} corresponding to that of the master oscillator.

Figure 3 depicts energy directional pattern of the laser beam in the free running and injection seeded operation mode (curves *1* and *2*, respectively). A theoretical curve for a beam diameter of 15 mm is shown there for a comparison. It is seen that the injection seeding mode results in a lower fraction of the energy contained in the directional pattern lobes.

FIG. 2. Densitograms of the output spectra in the free-running mode (a) and injection seeded mode with the injection into 0–1 transition (b) and 0–2 transition (c). Interferogram of the output spectrum of the laser emission in the injection seeded mode (d)

More than 50% of total energy is concentrated in the diffraction limited angle. Nevertheless, the lobes contain more energy as compared to the value calculated.

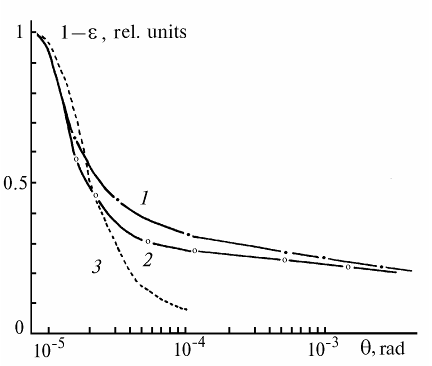

FIG. 3

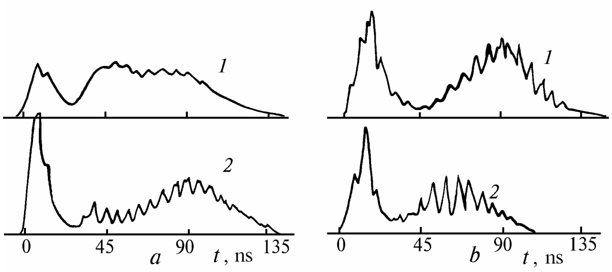

FIG. 4. Pulse shapes of laser operating in free-runnung mode (1) and injection seeded mode (2): Ne:Xe:HCl = 1000:10:1 *mixture at a total pressure of* 4 atm *(a) and* Ne:Xe:HCl = 2500:10:1 *mixture at a total pressure of* 3.5 atm *(b).*

The shape of the laser pulse under control is shown in Fig. 4. The first peak in the pulse is due to the discharge of the peaking capacitor and the second one is related to the discharge of the storage capacitor. One can see that modulation of the output power takes place. Its depth depends on the experimental conditions. When a probe beam is injected (see curve *2*) or signal gain of the active medium is low (Fig. 4*b*) this modulation is more pronounced. The modulation period is equal to the travel time of light within the resonator (about 6 ns). Hence, we can assume that modulation is related to the transverse mode formation[10,11] and its depth is determined by the ratio of the photon avalanche rise time and excitation rate. When a diffraction-limited beam is injected, the time of mode formation decreases with increasing modulation depth.

Thus, a XeCl laser system (λ = 308 nm) with the spectral brightness of $2\cdot10^{16}$ W/cm^2·sr·Å has been $2\cdot10^{16}$ developed, and a possibility of efficient output control is demonstrated for a laser with a supergaussian mirror operating in the injection seeded mode. This system can be used for different applications when high-quality UV laser beam is required.

REFERENCES

1. M. Sugii, M. Okabe, A. Watanabe, and K.Sasaki, IEEE J. Quant. Electr. **24**, No. 11, 2264–2269 (1988).
2. M.C. Cates, SPIE **24**, No. 11, 2264–2269 (1988).
3. I.A. Kudinov, V.T. Platonenko, and E.V. Slobodchikov, Kvant. Elektron. **17**, No. 5, 543–547 (1990).
4. M.S. Dzhidzhoev, S.V. Dolgii, I.A. Kudinov, et al., Kvant. Elektron. **17**, No. 6, 697–703 (1990).
5. J. Goldhar, W.R. Rapoport, and J.R. Murray, IEEE J. Quant. Electr. **16**, No. 2, 235–241 (1980).
6. I.J. Bigio and M. Slatkine, IEEE J. Quant. Electr. **19**, No. 9, 426–1436 (1983).
7. V.I. Belash, V.A. Kartazaev, and V.A. Naumovich, Kvant. Elektron. **16**, No. 6, 1135–1138(1989).
8. V.F. Losev and Yu.N. Panchenko, Kvant. Elektron. **21**, No. 1, 55–56 (1994).
9. S.E. Kovalenko, V.F. Losev, and M.R. Perrone, Appl. Opt. **33**, No. 18, 4082–4086 (1994).
10. G.J. Simonis, Appl. Phys. Lett. **19**, No. 1, 42–44 (1976).
11. V.P. Borisov, S.D. Velikanov, D.D. Kvachev, et al., Kvant. Elektron. **8**, No. 6. 1208–1214 (1981).