EXCIMER LASERS FOR THE AERODYNAMIC FLOW DIAGNOSTICS

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We discuss here some results of the development of two-pulse excimer lasers intended for use in diagnostics of high-speed aerodynamic flows. In so doing we present the electric circuitry of the laser pumping and performance parameters of two types of lasers. One of such lasers delivers two pulses of 4 *to* 5 ns *duration in a* 1 μs *to* 2 ms *interval in time while the second one is a compact pulse-periodic laser that delivers paired pulses at a repetition rate of up to* 100 Hz.

Many applied problems that deal with the study and use of pulsed nonstationary turbulent flows need for determining quantitatively instantaneous fields of the flow velocity. Recently, the methods of tracking anemometry, namely, the particle image velocimetry (PIV) and particle tracking velocimetry (PTV), have been being more and more widely used for this purpose. The main idea of these methods is in measuring the drifts of a moving optical inhomogeneity, such as, for example, a light scattering particle, using two or more its images taken in a succession, the time intervals between the images being known.

The main technical problem of implementing these methods to diagnostics of high-speed flows ($V \sim 10^2$ to 10^3 m/s) is to develop high-power light sources that are capable of delivering a series of pulses (at least two pulses) with a single pulse duration 1 to 10 ns and time intervals between them of 0.1 μs to 1 ms set highly precisely. One may find in the literature reports on the researches where two separate Q-switched lasers, synchronized in operation, are used as light sources for this purpose. Thus, Ref. 1 describes the experiments with two ruby lasers delivering 25-ns-duration single pulses in an interval that may be varied from 1 μs to 10 s, while in Ref. 2 the experiments are described that used two Nd:YAG lasers delivering pulses of 4 to 6 ns duration at 532 nm wavelength in an interval shorter than 1 μs. At the ITAM SB RAS there is a stroboscopic light source developed based on a ruby laser that is capable of delivering series of pulses, starting from a single pulse to a series of 30 pulses, with the duration of 30 ns and time intervals between the pulses being varied from 5 to 500 μs in a step of 1 μs.[3,4]

Normally, in the tracking anemometry, the flow region under study is illuminated by a slit shaped plane laser beam, the so called laser blade, and radiation scattered from such a beam by the flow inhomogeneities is then recorded. As known, the scattering cross-section of a gas medium essentially depends on the incident radiation wavelength, being much higher for a short-wave radiation. For this reason a short-wave radiation is much more efficient for use in such an optical diagnostics of moving media.

In this connection, excimer lasers capable of emitting 4 to 20-ns-duration pulses of the UV radiation could certainly be useful in such studies. Besides the enhanced scattering cross-section, one may use photographic materials and photodetectors of much higher sensitivity while, at the same time, having a decreased intensity of the background noise and spurious light. It is also important that using excimer lasers enables one to make diagnostics based on laser induced fluorescence. Besides, the small coherence length of radiation and short pulse duration provide for obtaining high-quality shadowgraphs that may bear information on the peculiar features of the aerodynamic flows. So, one can acquire information on acoustic and shock waves, compression and rarefaction regions in the flow, as well as on other inhomogeneities of a transparent medium using excimer-laser radiation.[5]

At present excimer lasers are used in the studies of aerodynamic flows not so widely. This is caused by the absence of commercially available and reliable devices as well as by limitations in the pulse repetition frequency of such lasers.

In this paper we present a two-pulse source of UV radiation developed based on an excimer laser that has two active volumes excited by one and the same current pulse.[6] We place special value in this paper on the use of simple circuits for the laser pump. We also present in the paper a description of a developed small-size, pulse-periodic excimer laser capable of delivering paired pulses at a high repetition rate.

1. TWO-PULSE EXCIMER LASER

The primary goal of developing such a laser was to provide generation of paired pulses with a regulated time interval between the pulses within the pair. To make up such a device we have built a laser with the electrodes configured so that they form two active volumes. We have also added to this configuration a return conductor connected with the intermediate

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plate.[7] Thus configured two pairs of electrodes are connected to two separate pump power supplies. The electric circuitry of the laser pump power supply is depicted in Fig. 1, while the photo of the two-pulse excimer laser designed being shown in Fig. 2*a*. The upper part of the laser set up is the emitting laser head and the bottom one contains two excitation systems. The sliding caliper spaced at ten centimeters shows the scale of the overall size of the laser.

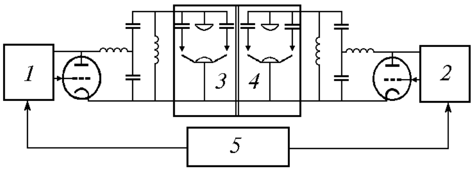
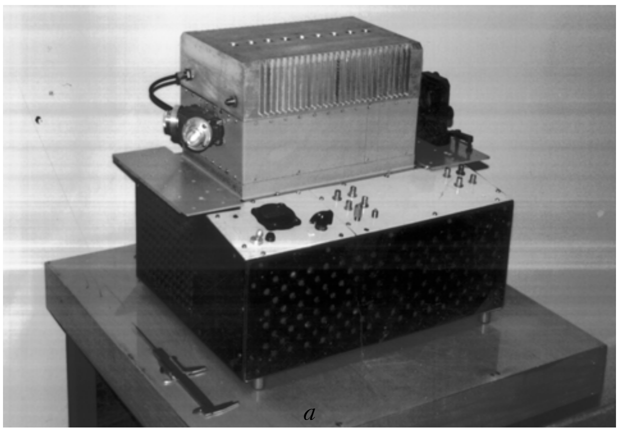


FIG. 1. Electric circuitry of a power supply for a two-pulse excimer laser. 1 and 2 are the electric circuits for charging the energy storage of a pulsed-voltage generator; 3 and 4 are the laser discharge cavities; 5 is the generator of the triggering pulses.



a

b

FIG. 2. Photographs of the two-pulses laser (a) and of the small-size pulse-periodic, high-repetition rate laser (b).

The pumping of active medium in two volumes is performed with the pulsed-voltage generator (PVG) based on LC inverter and the commutation by thyratrons. Each generator is capable of accumulating up to 4 J energy at the voltage of 16 kV. The operation of PVGs is controlled with a complicated thyristor based trigger generators. Time lag between the pulses produced by these PVGs could be varied from 1 to 1000 μs. The operation of this two-pulse laser may be performed in two modes. In the first one two volumes of active media are placed in two independent resonators. In that case the output beams are brought together with the help of additional mirrors that resulted in unwanted additional losses of energy. The energy parameters of the excimer lasers operated in this mode in different gases are given in Table I.

TABLE I.

Molecule	KrF	XeCl	N_2
Wavelength, nm	248	308	337
Energy per pulse, mJ	20	15	5
Pulse duration, ns	5	4	4

The instability of time interval between the pulses, within a pair of pulses produced, is about 0.5 μs that is mainly due to the spread in time of the dischargers firing.

In the second mode of operation the two volumes are placed into the same common resonator. In this configuration no additional mirrors are needed to bring the output beams of the lasers together since the beams are exactly coupled by the resonator mirrors. However, as preliminary investigations of such a laser showed, in this case the output energy of lasing essentially decreases. Evidently, this is caused by two times increased length of the cavity and, as a consequence, by an increased time of the lasing pulse formation that becomes comparable to time of the active medium inversion existence. This clearly shows the necessity of providing conditions for a longer lifetime of the medium inversion.

2. SMALL-SIZE PULSE-PERIODIC LASER OPERATING AT A HIGH REPETITION RATE

The primary goal of developing such a laser is to provide a possibility of studying the nonstationary flow dynamics. To met certain requirements of that type of studies one has to built up a laser that is capable of emitting paired pulses at a high repetition rate.

Note that commercially available excimer lasers normally operate at the repetition rates about 100 Hz, and only special excimer-laser installations are capable of delivering pulses at the rates up 2.5–3 kHz.[8] One can also find in the literature[9] description of experiments on obtaining paired pulses in an active medium within a single working volume. In that case the spacing between the pulses within the pair was about 100 μs.

Below we present a description of the pulse-periodic laser capable of delivering paired pulses. The view of this laser is shown by a photo in Fig. 2*b*. The electric circuitry of the laser power supply is depicted in Fig. 3. This laser differs from the laser presented in Fig. 2*a* by an additional fan mounted inside the active volume to provide for the gas pump through the discharge gap between the electrodes.

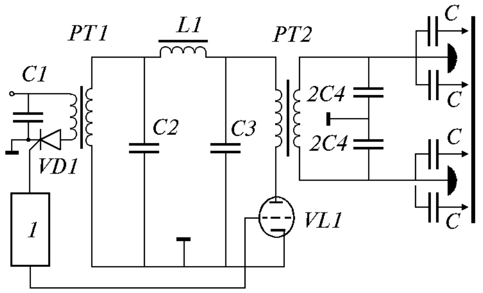


FIG. 3. Electric circuitry of a power supply for a small-size pulse-periodic, high-repetition rate laser: 1 is the generator of triggering pulses; VD1 is a TChI–100 thyristor; VL1 is a TGI1–1000–25 thyratron; PT1 and PT2 are pulsed transformers; L1 is a saturation choke coile; C1 are K50–17, 500 V, 200 μF *capacitors; C2, C3, and C4 are KVI3,* 16kV, 1000 pF *capacitors; C are KVI2,* 10 kV, 47 pF *capacitors.*

The pump-through rate of 5 m/s achieved in this laser provides for a stationary mode of operation at a repetition rate of up to 100 Hz. The active volume of this laser has the size of $2\times(0.8\times0.6\times20)$ cm^3. The pump electric pulse bears 2.2 J energy at the voltage peak of ± 12 kV. The primary capacitative energy storage *C1* used in the power supply provides for large amount of energy stored. The magnetothyristor pulse shaper built up from *PT1, VD1, C2,* and *L1* provides for charging the capacitor *C3* during about 5 μs at only insignificant discharge of the energy storage *C1*. The whole circuit is ready to produce the next pulse in a 100 μs interval. This enables obtaining pulse series (2 to 4 pulses) with the time spacing of 100 μs.

The final stage of the excitation pulse shaper consists of a thyratron *VL1*, pulse transformer *PT2* peaking capacitor *C4*, and an automatic pre-ionization circuitry with the limiting capacitors *C*. This part of the circuitry does not limit the operation of the entire device by the pulse repetition rate up to several tens of kilohertz. It is a peculiar feature of this electric circuitry that it uses a matching transformer that has low losses and fast response. This transformer enables obtaining bipolar voltage, that is needed for this laser operation. Simultaneously, its use helps one to resolve the problem of creating high pump power at low commutation losses in the thyratron. The power of the primary power source loaded by the capacitative energy storage *C1* enables obtaining series of paired pulses at a repetition rate up to 200 Hz. Parameters of such a laser are given in the Table II.

TABLE II.

Molecule	KrF	XeCl	N_2
Wavelength, nm	248	308	337
Pulse repetition rate, Hz	100	100	100
Energy per pulse, mJ	8	5	2
Mean power, mW	600	400	150

Let us now present some preliminary results on production of paired pulses in the active medium of XeCl. In the case when no pump-through of the mixture has been used we could observe a stable emission of paired pulses that differ in amplitude by no more than 30%, the time lag between the pulses being 300 μs. The mixture pump-through, when switched on, did not affect the paired pulses lasing.

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