IR LASERS WITH ACTIVE MEDIA BASED ON EXTENDED OPEN INHOMOGENEOUS ELECTRICAL DISCHARGES IN NOBLE GASES

A.G. Gridnev and I.I. Murav'ev

V.D. Kuznetsov Siberian Physicotechnical Scientific-Research Institute at the Tomsk State University, Tomsk

Received March 2, 1992

The lasing effect in the IR spectral region and the spontaneous emission within the visible spectral region were studied. The active media were open pulsed electrical discharges in noble gases. Four types of discharge tubes were analyzed.

Extended open inhomogeneous pulsed discharges (EOIPD) can serve as an active medium for lasers.[1] An investigation of lasing in such active media promotes for better understanding of the inhomogeneity and relaxation development.

To study the EOIPD we used several types of a gas discharge device (Fig. 1).

The first type consists of the alundum discharge tube *1* with the slit *2* which is cut through along the generating line. The plasma of the pulsed discharge localized in the tube flows out through the slit into the chamber *3* (see Ref. 1). The gas in the chamber is illuminated by the discharge light through the slit and constitutes, together with the plasma flowing out of the tube, the active medium. The processes developing in the chamber and tube are well separated in a such device, which is attractive by its simplicity, long lifetime, and resistance to powerful pulses. However, the long discharge gaps require high voltage hold–off capability, sometimes the discharge is localized in the tube in an improper way, and its stability and reproducibility are insufficiently high.

The second-type device (see-Fig. 1*b*) differs from the first only in that the thin molybdenum vitreous bar *5* lies on the inside wall of the discharge tube. The end of the bar on which there is no glazed surface is connected with the electrode *4* (Ref. 2). As a result, the breakdown voltage decreases, the discharge is localized in the tube in a proper way, and stability and reproducibility of the parameters become satisfactory.

The base of *the third-type device* (see Fig. lc) are two curved vitreous molybdenum bars *6* and 7. The bars are arranged horizontally, soldered together, and placjed into the gas-filled chamber. The ends of both bars are not vitrified. The inside opposite ends of the bars form a discharge gap. The outward-projecting ends *8* and *9* are the leads connected with the source of pulses.[3] Low breakdown voltage, satisfactory spatial localization of the discharge column, high stability and reproducibility of the parameters can be considered as the device advantages. One can easily obtain a necessary gas purity in this device because of the absence of ceramics usually prone to gas release. The gas in the chamber is strongly irradiated because the current filament is not covered.

Insufficient capability to hold off pulsed voltages in comparison with the previous types of gas-discharge devices can be considered as disadvantage of the device.

The fourth-type device (see Fig. 1*d*) is a simple chamber in which the current filament creeps along the wall between two electrodes *4* and the plasma expands toward the chamber axis. For this purpose the electrodes are pressed to the inside wall of the chamber while a foil strip connected with one of the electrodes is attached to the outside wall (along the line between the electrodes). The device design is simple for production, it ensures high stability and reproducibility of operation. The breakdown voltage is comparatively low.

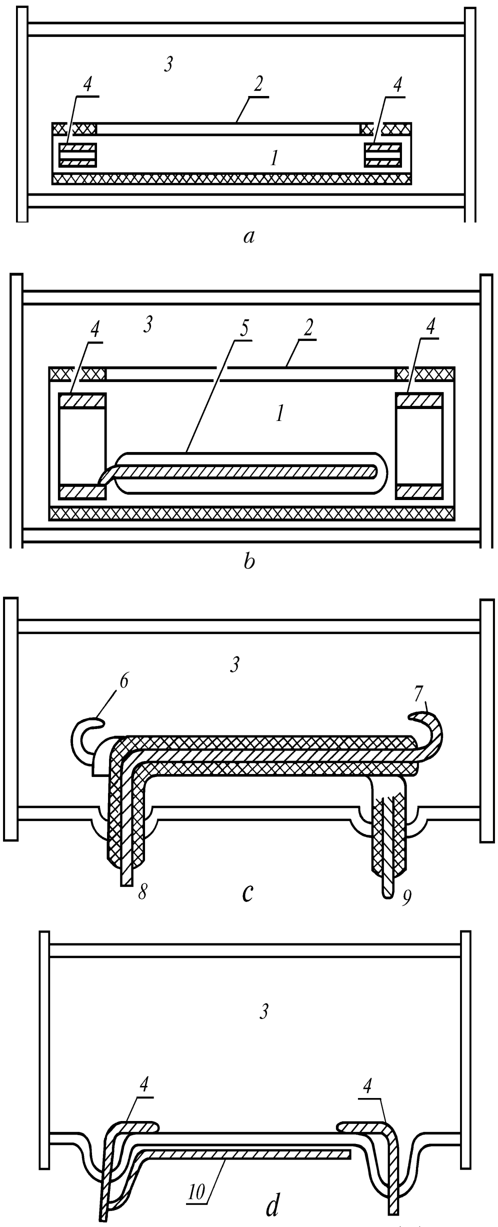

FIG. 1. Gas–discharge devices of the first (a), second (b), third (c), and fourth types (d). 1) ceramic tube, 2) slit, 3) chamber, 4) electrodes, 5) vitrified bar, 6 and 7) inside ends of electrodes forming the discharge gap, 8 and 9) outside ends of electrodes (leads), and 10) foil strip.

0235-6880/93/06 396-04 $02.00

The first and second types of the device are suitable for investigations, because the processes in the chamber and discharge tube are well separated. The third– and fourth–type devices make it possible to irradiate the gas in the chamber with high intensity light.

The source of electrical pulses was a capacitor bank switched by a three–electrode spark gap onto the gas discharge device. More often a self-breakdown of the spark gap was used because it is more advantageous. In some experiments the TGI1–1000/25 thyratron was employed. The capacitance of the capacitor bank could be changed by steps of 0.1 up to 0.7 μF. The charge voltage reached 25 kV. The discharge current was measured by a shunt.

We used also a S1–74 oscillograph, ZMR–3 monochromator (in some cases the MDR–23 monochromator), FEU–62 photomultiplier as well as photoconductive cells to indicate the radiation. The photoscans of the glow were recorded by a VFU–1 photomultiplier.

The above––mentioned instruments were used to investigate the electrical discharges in noble gases (essentially, in mixtures). The lasing lines that we observed and the respective transitions are shown in Table I.

For the 2.026–μm line of neutral xenon the main results were obtained with the help of a "discharge tube – slit – chamber" device (the first and the second types). We present the results obtained for this line and brief comments in the course of expounding the material. Xenon-containing mixtures (mainly, for a pressure of 1 Torr) and helium-containing mixtures (0–150 Torr) were studied.

1. A lasing effect is observed in both the tube and chamber.

2. In the tube the lasing effect is particularly dependent on the first half–cycle of the discharge current, while for other time intervals it does not appear. The most probable mechanism of excitation seems to be a predominant electron impact.

3. A lasing effect can be observed in the chamber as pulses: (a) dependent on the half–cycles of the discharge current, (b) appearing just after current pulse decay, and (c) occurring within the interval of 40–50 μs after the current pulse.

4. The intensity of the spontaneous lines in the tube is considerably higher than the intensity of the same lines in the chamber. As to the lasing effect, it is more pronounced in the chamber.

5. In the discharge tube the spontaneous radiation pulses have comparatively short rise times. They peak at the end of the first current half-cycle.

6. The spontaneous radiation in the chamber has an intensity maximum which starts to develop 7–10 and more microseconds after termination of the current pulse. Before this the intensity increases continuously, sometimes there is a bump, sometimes – some intermediate maxima connected with the second and third half–cycles of the discharge current.

7. Pulses of lasing in the chamber can be related to the first, second, first and second, second and third, first, second, and third half-cycles of the discharge current. Other combinations were not observed for any variations of the experiment conditions.

8. The lasing pulse occuring after termination of current disappears as the energy stored in the capacitor bank increases.

9. Lasing effect near the 40th–50th μs appears only when the mixture is renewed.

TABLE I.

λ, μm	Transitions	Gas
1.27	$3\,d'\left[\frac{3}{2}\right]^0_1 - 4\,p\left[\frac{1}{2}\right]_1$	Ar I
1.35	$5\,s\left[\frac{3}{2}\right]^0_2 - 4\,p\left[\frac{3}{2}\right]_2$	Ar I
1.44	$6\,s\left[\frac{3}{2}\right]_1 - 5\,p\left[\frac{3}{2}\right]_1$	Kr I
1.45	$5\,d'\left[\frac{3}{2}\right]^0_1 - 4\,p\left[\frac{1}{2}\right]_0$	Ne I
1.73	$5\,d\left[\frac{3}{2}\right]^0_1 - 6\,p\left[\frac{5}{2}\right]_2$	Xe I
1.79	$4\,d\left[\frac{1}{2}\right]^0_1 - 4\,p\left[\frac{3}{2}\right]_2$	Ar I
2.03	$5\,d\left[\frac{3}{2}\right]^0_1 - 6\,p\left[\frac{3}{2}\right]_1$	Xe I
2.39	$3\,d\left[\frac{3}{2}\right]^0_0 - 4\,p\left[\frac{1}{2}\right]_1$	Ar I
2.52	$4\,d\left[\frac{1}{2}\right]^0_1 - 5\,p\left[\frac{3}{2}\right]_2$	Kr I
2.65	$5\,d\left[\frac{3}{2}\right]^0_1 - 6\,p\left[\frac{1}{2}\right]_0$	Xe I

Figure 2 shows the photoscan schematic, current, lasing effect in the chamber, and spontaneous emission from the chamber for the common time scale.

Analysis of wave forms of the spontaneous radiation from the tube and chamber gives reason to suppose that photoplasma is generated in the chamber illuminated by the discharge light. Then the plasma flowing out from the discharge tube mixes with photoplasma in the chamber. However, this occurs at that time when the lasing effect has already ceased.

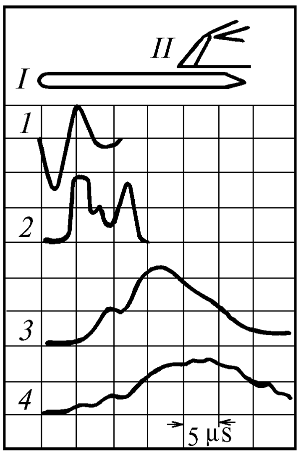

FIG. 2. Dynamics of the processes developing in the chamber of the first-type device. I is a photoscan schematic in tube and II is a photoscan schematic in the chamber. 1) Current, 2) losing at the 2.026 μm *neutral xenon line in chamber, 3) spontaneous emission in chamber* (588.9 nm *neutral helium line), and 4)* 840 nm *neutral xenon line. Helium pressure is* 150 Torr. *Xenon pressure is* 1 Torr, *capacitance is* 0.4 μF, *and voltage is* 14 kV.

The lasing at the 2.026–μm line of neutral xenon can be accounted for by a direct electron impact (discharge tube), direct optical excitation (chamber, low helium pressure), the processes of photoplasma generation and relaxation in the case of gas illumination with the discharge light (chamber, high gas pressure), the recombination of the photoplasma (peak after the current pulse), the recombination of the discharge plasma flowing out of the tube slit (pulse in the range 40–50 μs).

The lasing effect in a gas exposured to a resonant light can be considerably more pronounced than in the case of direct electron excitation or recombination under similar conditions (pressure, composition of the mixture, and energy contributed into the discharge).

When using the third type of discharge device the lasing wave forms are qualitatively identical to those which were obtained in the devices of the tube–slit–chamber type. The lasing signal outgoing from the photomultiplier intensified as the charge voltage is increased up to 11–12 kV after which saturation is observed.

As to the maximum lasing intensity, it decreases as the helium pressure is increased up to 120 Torr (for a voltage no more than 15 kV) and then started rising.

The lasing effect on the neutral xenon spectral lines at wavelengths of 1.73 and 2.65 μm differs considerably from that at $\lambda = 2.026$ μm. The latter can be observed with both aluminum and dielectric mirrors. As to the 1.73 μm line, no lasing is observed with aluminium mirrors but it appears when replacing one of the mirrors by a selective dielectric mirror reflecting near 1.73 μm. Under the same conditions one can observe lasing at the wavelength 2.65 μm (the 2.026–μm line cannot be suppressed by such a resonator).

The lasing at $\lambda = 1.73$ and 2.65 μm begins under comparatively high helium pressures (100–150 Torr for the 1.73 μm line and 75 Torr for the 2.65 μm line). We used the fourth type of gas-discharge device with the electrode separation being as short as 180 mm because of the high breakdown voltage under elevated pressures. The laser oscillations at $\lambda = 1.73$ μm do not disappear under the xenon partial pressures up to 4 Torr.

The dependence of the maximum lasing power at $\lambda = 1.73$ μm on the storage capacitance has a maximum at 0.4 μF (for the xenon pressure 1 Torr, helium pressure 720 Torr, and voltage 9.5 kV). When the capacitance is 0.7 μF the lasing intensity is a factor of three lower and for the capacitance 0.1 μF no lasing occurs. The maximum lasing power as a function of the helium pressure generally grows monotonically. For the xenon pressure 1 Torr this growth is almost linear in the range of helium pressures of from 400–500 Torr to 1200 Torr. The maximum lasing power for the 2 Torr xenon pressure is less than for the 1–Torr pressure. The maximum lasing power for the 3–Torr xenon pressure is still less and increases linearly as the pressure increases up to 900 Torr and then saturation occurs. For the 4–Torr xenon pressure the lasing power decreases again by a factor of 1.5.

The lasing power is an interesting function of the charge voltage (for the 1.73–μm line in a xenon–helium mixture). It has a maximum at the lowest possible charge voltage (as long as the gas discharge gap can be broken down). The lasing power drops dramatically as the voltage increases. When to a mixture of xenon (0.5 Torr) and helium (630 Torr) we add an admixture of neon (15 Torr) the lasing power drops by a factor of 1.5, its decrease with voltage still retains but it becomes much smoother. With an admixture of argon (15 Torr) the lasing power increases by a factor of more than 2.5 and no decay in the voltage dependence of power is observed. When adding krypton (15 Torr) no lasing effect occurs at all. When increasing the argon content in the mixture, the lasing power increases significantly (the capacitance 0.4 μF is used in all these cases).

Thus, the experiments with admixtures show that the mechanism of lasing at the 1.73–μm line of xenon depends on the partial composition of the gaseous mixture both quantitatively and qualitatively, its intensity increases with total pressure and argon content. Decreasing the xenon content to a certain limit also results in an increase in lasing power.

Experiments on studying the infrared lasing lines of neutral argon with active media based on the EOIPD were carried out under small partial pressures of argon (from decimal fractions of Torr to several Torrs). For the 1–Torr argon pressure and in the absence of other gases in noticeable quantities the 1.79–μm line lasing starts already at a voltage of 1 kV higher than the breakdown voltage (device of the fourth type, 0.4 μF) and its intensity only slightly increases with voltage. For the 15–Torr helium pressure there appears lasing at the 2.39–μm wavelength and at the 1.79–μm line the forced emission slightly intensifies. Saturation can be observed at a voltage of 12–15 kV as for the 2.026–μm line of neutral xenon. The maximum lasing power (for the 15 kV voltage) can be observed within the range of pressures about 30 Torr. Then the lasing power begins to decrease; it disappears at the 2.39–μm line for the 60–Torr helium pressure and at the 1.79–μm line for the 75–Torr pressure. The lasing pulse has a simple wave form with a maximum synchronous with the first half–cycle of the discharge current.

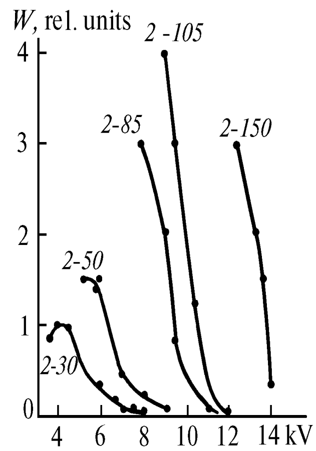

FIG. 3. Dependence of the losing power at the 1.45–μm *neon line on voltage for the third–type device. The first number means the neon pressure and the second (after dash) – the helium pressure, capacitance is* 0.4 μF.

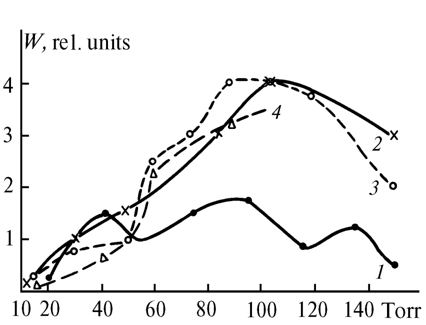

FIG. 4. Dependence of the maximum lasing power at the 1.45–μm *neon line on the helium pressure for the third type device. The neon pressure is* 1 *(1),* 2 *(2),* 4 *(3), and* 8 Torr *(4), and capacitance is* 0.4 μF.

Figure 3 shows the behavior of the lasing signal at the 1.45–μm wavelength in neon[4] (helium–neon mixture) as a function of voltage for different helium pressures (the fourth type of device). Here neon pressure is not varied and is equal to 2 Torr. Note that the decrease in lasing power with increasing voltage (for the helium pressures more than 60 Torr) pronouncedly follows the behavior of the 1.73–μm neutral xenon lines in the xenon–helium mixture. This suggests that the lasing mechanisms for these lines are closely related.

Variation in the maximum lasing power for the 1.45–μm neon line is shown in Fig. 4 as a function of helium pressure for the neon pressures equal to 1, 2, 4, and 8 Torr. Note that with increasing the neon pressure curves become more simple in shape. Addition of noble gases to the helium–neon mixture results in a pronounced decrease in power and in cessation of lasing at the 1.45–μm neon line.

The lasing at the 2.52–μm line in krypton is of less intensity. For the 0.5–Torr pressure neither radiation nor current filament are observed and only a diffusion discharge occurs within the whole chamber volume. But for the 1–Torr pressure the radiation appears and the lasing power increases with voltage reaching saturation at 11–12 kV. When adding helium, the lasing power at the 2.52–μm krypton line decreases.

In the helium–krypton mixture the lasing at the 1.44–μm line in the pure krypton does not occur (the 5–Torr krypton pressure). For the 20–Torr helium pressure lasing was initiated at the 1.44–μm wavelength. When raising the helium pressure up to 210 Torr, the lasing power increases more than fourfold.

Thus, the EOIPD ensures the lasing effect at a number of infrared lines. The elevated pressures of filling gas and technological simplicity of the devices described in this paper make it possible to develop simple, long–lifetime pulsed IR lasers.

REFERENCES

1. A.G. Gridnev, Izv. Vyssh. Uchebn. Zaved., Ser. Fizika, No. 2, 41–46 (1982).

2. A.G. Gridnev and I.I. Murav'ev, *"Photoplasma near a plasma jet: generation and inversion mechanisms,"* VINITI No. 2739–B90, Tomsk, 1990, 13 pp.

3. A.G. Gridnev and I.I. Murav'ev, *"Forced and spontaneous emission by the transitions of noble gases in inhomogeneous media excited by an open discharge,"* VINITI No. 2183–B91, Tomsk, 1991, 18 pp.

4. A.G. Gridnev and I.I. Murav'ev, in: *Abstracts of Reports at the Eleventh AU–Union Conference on Physics of Electronic and Atomic Collisions* (Chuvash University, Cheboksary, 1991), p. 146.