PROSPECTS FOR THE DEVELOPMENT OF SMALL-SIZED N_2 LASERS

A.I. Fedorov

Institute of Atmospheric Optics,
Siberian Branch of the Russian Academy of Sciences, Tomsk
Received October 9, 1997

Results of experimental investigations into the development of small-sized and miniature transverse- and longitudinal-excitation N_2 *lasers with various UV preionization types are presented. An analysis of basic research works on* N_2 *lasers has opened up fresh opportunities for the increase of their lasing efficiency.*

Nitrogen lasers have been attracting attention of many researchers for more than 20 years because they can operate at room temperature, use inexpensive easily available gas, can be easy fabricated, and are promising for obtaining high specific parameters of UV radiation and high lasing efficiency η.

Results of experimental investigations into the development of small-sized and miniature longitudinal- and transverse-excitation (TE) low, atmospheric (TEA), and high (TEAH) pressure N_2 lasers with UV corona, spark, or plasma preionization or without it are generalized in the present paper. In addition, an analysis is made of basic research works on N_2 lasers summarized in Tables I–IV. It should be noted that only the works in which new elements of laser systems were used or at least one maximum output lasing parameter was achieved were considered.

TABLE I. Basic research works and maximum output parameters of the nitrogen TE lasers.

Serial number	Pumping generator	P, Torr	L, cm	V, l	U_0, kV	W, MW	W_{sp}, $\frac{MW}{(l \cdot atm)}$	Q, mJ	Q_{sp}, $\frac{J}{(l \cdot atm)}$	$\tau_{h/2}$, ns	η, %	Year	Reference
1	$C_{sl} - C_{cab}$	20	200	–	25	0.2	–	–	–	–	–	1965	9
2	$C_{sl} - C_{cab}$	20	200	–	25	0.3	–	–	–	–	–	1965	11
3	Bl	30	183	–	75	2.5	–	10	–	4	–	1967	16
4	$C_{sl} - C_{sl}$	35	100	–	30	2	–	20	–	10	–	1968	10
5	$C_{sl} - C^{**}_{peak}$	30	80	0.1	20	0.3	60	3	0.6	10	–	1972	12
							P_{av} = 1.5 W		f = 1200 Hz				
6	$C - C_{cab}$	55	100	–	30	1.1	–	13	–	12	–	1973	17
7	Bl (C)	30	100	0.07	20	1.4	400	10	2.8	7	0.1	1973	1*
8	2 Bl (C)	30	104	0.07	15	2.1	600	11	3.2	5	0.1	1974	2*
9	Bl	70	70	0.006	6 11	3 9	$48 \cdot 10^2$ $14 \cdot 10^3$	– –	– –	4	1	1974	13
10	C–Bl	50	50	0.015	12	0.17	100	1	1.4	6	–	1976	18
11	Bl	30	60	0.045	25	1	400	7	3.2	7	0.1	1978	19
12	$C_{sl} - C^{**}_{co}$	110	30	0.001	10	0.2 0.2	$13 \cdot 10^2$ $16 \cdot 10^3$	2.2 2.6	15 19	11 1.2	3 0.5	1986	15

*My works.
**The works in which peaking capacitors were used to produce a space in an active medium.

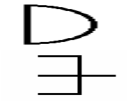
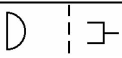
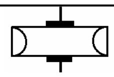
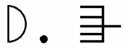
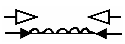
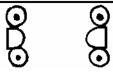
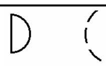
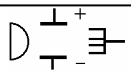
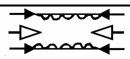
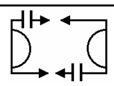
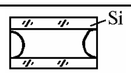
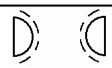
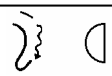
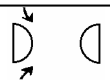
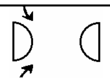
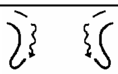
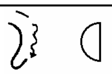
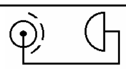
Table I tabulates the basic research works and the maximum output lasing parameters of the first low-pressure lasers without UV preionization. It should be noted that dual capacitive exciting circuits (C–C) were used in Refs. 9–12. Capacitors represented strip lines (C_{sl}), cable segments (C_{cab}), or coaxial cylinders (C_{co}) used to decrease the inductance of the discharging circuit.

More recently investigators used primarily the Blumlein strip-line generators that produce short exciting pulses. Thus, Godard[13] obtained a peak power of 9 MW at η = 1%.

We pioneered the use of the Blumlein generators on ceramic capacitors[1,2] [Bl(C)] and the dual Blumlein [2Bl(C)]. These methods of producing space charges were subsequently used in excimer lasers.

0235-6880/98/02-03 120-05 $02.00

TABLE II. Main works and the maximum lasing parameters of the nitrogen lasers with various UV-preionization sources.

Serial number	Pumping generator	UV preionization type	$P(N_2)$, Torr	V, l	Q, mJ	Q_{sp}, $\frac{J}{(l\cdot atm)}$	$\tau_{h/2}$, ns	η, %	Year	Reference
1	2 Bl		30 He	0.03	3	2	2.5	–	1972	25
2	Bl		100 He	–	–	–	4	–	1974	26
3	Bl		100	0.05	14	2.4	7	0.1	1974	27
4	2 Bl		180 SF_6	0.04	18 20	2 2.5	8.5 6	– –	1974	28
5	Bl		380 760	–	0.9 0.7	– –	1.4 0.9	0.03 0.02	1975	29
6	–"–	–"–	1140	0.004	1	0.16	1	–	1976	30
7	2 Bl (C)		320 He	0.003	0.13 0.15	1.25 0.2	5 2	– –	1976	3*
8**	$C_{st}-C_{peak}-C_{UV}$		150 He He:NF_3	0.12 $D \times H =$ 1.7×2	1.2 4.5 10	0.05 0.04 0.09	9	0.01 0.02 0.05	1979	20
9	2 $C_{st}-C_{sl\ peak}$		30 SF_6	–	18 30	– –	14 19	– –	1980	21
10**	$C_{st} - C_{peak}$		60 He:NF_3	0.5 2.5×3.5	20 25	0.04 0.05	4 10	– –	1982	22
11	$C_{st} - C_{peak}$		60	0.03	1	0.3	7	–	1984	31
12	2 $C_{st}-C_{sl\ peak}$		760 He	–	0.04	–	–	0.07	1985	32
13	$C_{st} - C_{peak}$		150 He:SF_6	0.1	6.1 7.7	0.3 0.08	5 4.7	– 0.04	1986	33
14	$C_{st} - C_{peak}$		110 He	0.006	2	0.25	9	0.07	1986	34
15	–"–		55	0.025	2.3	0.9	7	0.07	1987	23
16**	–"–		100 CO_2	0.46 2.5×2.6	0.3 600	0.004 8.6	5 12 μs	– –	1988	35
17	–"–		114	0.18	10	0.4	5	0.04	1989	4*
18	2 Bl (C)		70	0.08	10	1.25	6	–	1990	36
19**	$C_{st} - C_{peak}$		100	0.008 0.6×0.7	0.5	0.4	5	0.01	1990	5*
20	–"–		150	0.009	0.3	0.15	5	0.06	1991	6*
21**	–"–		120	0.006 0.4×0.7	0.13	0.13	5	0.03	1995	7*

*My works.
**The works in which the radiation aperture satisfied the condition $H \geq D$.

We also proposed a new quasistationary regime of excitation for the dual exciting circuit in which the peaking capacitor played a leading part in the formation of preliminary space discharge in the active medium.[14] Targ[12] succeeded in exciting an active volume of 0.1 l and obtaining an average output power of 1.5 W at f = 1.2 kHz. Oliveira Dos Santos[15] obtained η = 3% with the use of dual exciting circuit in which coaxial peaking capacitor served as a laser chamber (for minimum parasitic loss of stored energy), which allowed the working pressure to be increased up to 110 Torr without preionization. By this way a reserve of the N_2-laser capabilities was found.

The use of additional UV preionization sources extended the range of working pressures of N_2 lasers and led to the increase of the output lasing parameters. It turned out that the lasing efficiency depended strongly on the preionization source type and gaseous additions of He or He:$NF_6(SF_6)$, which affected the parameters of space discharge in the active medium. In this case the notion of the TEA lasers, in analogy with the CO_2 lasers, turns out to be ambiguous. For example, if the optimal pressure N_2 = 150 Torr and that of the buffer gas He = 600 Torr, the laser can be classified as the TEA laser. If N_2 = 760 Torr and He = 2000 Torr, it is the high-pressure laser called the TEAH laser. We pioneered the use of automatic corona preionization of both electrodes for the TEAH laser as well as plasma electrodes[5] and corona preionization stabilized with a grid electrode[7] for the TEA lasers. The further increase of the output parameters was achieved through the regime of energy pumping in the discharge[7,14] (dual exciting circuits with UV-preionization source) and the choice of electrode type.

Table II summarizes the first and the main works devoted to the nitrogen lasers with various UV-preionization sources and additions of He or He:$NF_3(SF_6)$ that have the maximum output parameters. Thus, Rothem and Rosenwaks[20] achieved the radiating aperture $D \times H$ = 1.7×2 cm^2 for the dual exciting circuit with corona preionization. This was achieved by virtue of a highly stable discharge obtained when the ratio of the storage capacitance to the peaking one was $C_{st}/C_{peak} \geq 3$. Additions of He:NF_6 led to the increase of the output energy by an order of magnitude in comparison with pure N_2. In Refs. 21–23 we investigated the effect of the quality of electrode surfaces on the output lasing parameters.

Rebhan et al.[21] obtained a maximum energy of 30 mJ and a pulse duration at half maximum of 19 ns in a system with corona preionization of the anode and finely textured cathode surface with additions of He:SF_6. They confirm the model of explosive electron emission proposed by Mesyats[24] as a source of primary electrons in the gas discharge gap. Armandillo[22] obtained Q = 25 mJ in the mixtures He:NF_6 with the radiating aperture $D \times H$ = 2.5×3.5 cm^2 at atmospheric pressure. The grid cathode served as a preionization source, that is, grid inhomogeneities stabilized the discharge. This type of discharge stabilization was observed only in dual circuits with quasistationary regime of pumping.[4,7] We obtained analogous results with plasma[5] and corona[7] preionization.

Based on experimental investigations, we developed small-sized TE and TEA lasers with variable radiating apertures and automatic spark,[4] plasma,[5,6] or corona preionization in dual pumping circuits through the grid cathode. It should be noted that the stability of space discharge in N_2 depended on 1) regime of energy pumping in the gas, 2) working surfaces of the electrodes, 3) type and intensity of the UV-preionization source.

Table III gives the maximum lasing parameters of the TE, TEA, and TEAH lasers obtained by various authors. The highest lasing parameters are tabulated irrespective of the working pressures. The average charging voltage $U_{0,av}$ is also given to compare the efficiency of excitation. The maximum lasing parameters were mainly recorded for the TE lasers at optimal working pressures 0.05–0.15 atm. Thus, for ideal matching of the pumping system with the active volume (for minimum losses of the stored energy on elements of the circuit) η = 1% for the Blumlein generator and η = 3% for the dual pumping circuit. In addition, the longest generation pulses with $\tau_{h/2}$ = 19 ns were obtained for the N_2 laser. However, a maximum lasing energy of 30 mJ was obtained for the TEA laser with addings of He:SF_6. The main advantages of the TEAH lasers were their superminiature size and the shortest lasing pulses with $\tau_{h/2}$ = 0.5 ns.

TABLE III. Main works and maximum lasing parameters of the nitrogen TE, TEA, and TEAH lasers.

Regime	Excitation type	P_{opt}, atm	$U_{0,av}$, kV	W, MW	Q, mJ	Q_{sp}, $\frac{J}{(l \cdot atm)}$	$\tau_{h/2}$, ns	η, %
I	Te	0.05–0.15	6–10	9 Ref. 13	20 Ref. 10	19 Ref. 15	1.2–19 Refs. 17 and 21	1–3 Refs. 13 and 15
II	Te A	0.05–0.2 He:$NF_3(SF_6)$	15	5 Ref. 21	30 Ref. 21	0.16 Ref. 30	2–10 Refs. 3* and 21	0.07 Ref. 34
III	Te Am	1–2.5	12	0.6 Ref. 29	0.6 Ref. 29	1 Ref. 37	0.5–2 Refs. 38 and 39	0.18 Ref. 40

*My works.

A comparison between the specific lasing parameters of the transverse- and longitudinal-excitation N_2 lasers is very important from practical and scientific viewpoints.

Furuhashi and Goto[45] obtained highly uniform laser radiation at relatively low charging voltages of ~ 20 kV with the use of longitudinal sectional discharge with UV preionization. It should be mentioned for comparison that Tarasenko and Kurbatov[41] used a working voltage of 100 kV at a pressure of N_2 of 10 Torr for pumping to provide an active length of longitudinal discharge of 22 cm without preionization source. We developed a series of miniature longitudinal-excitation lasers[8,48] with spark preionization at charging voltages of 6–12 kV. The output lasing parameters were investigated as functions of energy pumping in the gas and elements of the pumping circuit.

Table IV summarizes the main works devoted to the miniature N_2 lasers with the maximum specific lasing parameters and transverse or longitudinal excitation. The works are also given for comparison that did not use preionization source. In that case the average charging voltage was 50 kV, that is, more than 4 times higher than for lasers with UV preionization.

TABLE IV. Main works and maximum lasing parameters of miniature nitrogen lasers with longitudinal and transverse excitation types

Regime	Excitation type	P_{opt}, Torr	$U_{0,av}$, kV	W, MW	W_{sp}, $\frac{MW}{(l \cdot atm)}$	Q, mJ	Q_{sp}, $\frac{J}{(l \cdot atm)}$	$\tau_{h/2}$, ns	η, %
I	Longitudinal	10	50	0.02 Ref. 41	0.18 Ref. 43	0.1 Ref. 44	10 Ref. 44	5 Ref. 41	–
	Longitudinal with UV preionization	30–60	12	0.16 Ref. 42	0.02 Ref. 45	1.3 Ref. 42	2 Ref. 42	2.5–8 Refs. 8* and 42	0.01 Refs. 8* and 45
II	Te A	30–110	12	0.33 Ref. 23	0.08 Ref. 3*	2.3 Ref. 23	15 Ref. 3*	2.5–10 Ref. 34 and 43	0.1 Ref. 3*
	Te Am	760	12	0.1 Ref. 46	2.5 Ref. 46	0.2 Ref. 37	1.25 Ref. 46	0.5–2 Refs. 47 and 3*	0.18 Ref. 40

Instantaneous lasing powers for systems with UV preionization are practically the same. The maximum specific lasing power for the TEAH lasers reached 2.5 $MW \cdot l^{-1} \cdot atm^{-1}$. It should be noted that for longitudinal and transverse discharges the maximum energy was at a level of several millijoles, that is, their efficiency values were comparable. However, at present η of TEA and TEAH lasers are higher than of longitudinal-excitation lasers. This is indicative of higher potentialities of the longitudinal-excitation N_2 lasers.

In the course of investigations of the longitudinal- and transverse-excitation N_2 lasers with various UV-preionization sources at pressures from 10 Torr to several atmospheres we obtained the following results:

1. For the first time we have demonstrated the high efficiency of the use of the Blumlein generators based on ceramic capacitors in the TE, TEA, and TEAH lasers.

2. Automatic corona preionization with electrodes was first used in the TEA and TEAH lasers at pressures up to 20 atm with He as a buffer gas as well as the corona preionization in combination with the grid electrode and dual pumping circuit to obtain the radiating aperture $H > D$ for the TEA laser.

3. We pioneered in obtaining the generation in nitrogen with the use of plasma electrodes for the two pumping regimes. At pressures ≤0.4 atm pumping was traditional and the radiating aperture $H \geq D$. At pressures >0.4 atm, the electrodes in the form of two parallel strips were used for pumping by two sliding surface discharges.

4. It has been demonstrated that the maximum specific lasing parameters are functions of the regime of energy pumping in the discharge, preionization source, and working surface of electrodes.

5. The optimum and most reliable pumping circuit of the N_2 laser is the dual pumping circuit with automatic stabilized corona preionization.

6. It has been demonstrated that the miniature longitudinal-excitation N_2 lasers are competitive with the TEA lasers.

REFERENCES

1. V.F. Tarasenko, Yu.I. Bychkov, V.F. Losev, and A.I. Fedorov, Kvant. Elektron., No. 3 (15), 103–105 (1973).

2. V.F. Tarasenko, A.I. Fedorov, and Yu.I. Bychkov, Kvant. Elektron. **1**, No. 5, 1226–1227 (1974).

3. V.F. Losev, V.F. Tarasenko, and A.I. Fedorov, Prib. Tekh. Eksp., No. 5, 213–214 (1976).

4. A.I. Fedorov, S.I. Tikhomirov, and B.A. Zhunusov, Atm. Opt. **2**, No. 9, 849–851 (1989).

5. B.O.Zikrin, G.P.Kuz'min, S.I.Tikhomirov, and A.I.Fedorov, in: *Abstract of Reports at the Sixth All-Union Conference on Laser Optics*, Tomsk (1990), p. 414.
6. A.I. Fedorov, in: *Abstracts of Reports at the Ninth All-Union Seminar on Metal Vapor Lasers and their Application*, Rostov-on-Don (1991), p. 6.
7. A.I. Fedorov, Atmos. Oceanic Opt. **8**, No. 11, 918–920 (1995).
8. A.I. Fedorov, Atmos. Oceanic Opt. **9**, No. 2, 100–101 (1996).
9. D.A. Leonard, Appl. Phys. Lett. **7**, 4–6 (1965).
10. M. Geller, D.E. Altman, and T.A. Detemple, Appl. Opt. **7**, No. 11, 2232–2237 (1968).
11. E.T. Gerry, Appl. Phys. Lett. **7**, 6–8 (1965).
12. R. Targ, IEEE J. Quant. Electron. **QE–8**, 726–728 (1972).
13. B. Godard, IEEE J. Quant. Electron. **QE–10**, No. 2, 147–153 (1974).
14. Yu.I. Bychkov, S.V. Mel'chenko, G.A. Mesyats, et al., Kvant. Elektron. **9**, No. 12, 2423–2431 (1982).
15. B. Oliveira Dos Santos, C.E. Fellows, J.B. De Oliveira, et al., Appl. Phys. **B41**, 241–244 (1986).
16. J.D. Shipman, Appl. Phys. Lett. **10**, 3–4 (1967).
17. B.W. Woodward and V.J. Enlers, Ref. Sci. Instrum. **44**, No. 7, 882–887 (1973).
18. C.P.Wang, Ref. Sci. Instrum. **47**, No. 1, 92–95 (1976).
19. Yu.L. Sidorov and A.N. Sukhanov, Kvant. Elektron. **5**, No. 3, 580–589 (1978).
20. A. Rothem and S. Rosenwaks, Opt. Commun. **30**, No. 2, 227–230 (1979).
21. U. Rebhan, J. Hildebrandt, and G. Skopp, Appl. Phys. Lett. **23**, 341–344 (1980).
22. E. Armandillo, Appl. Phys. Lett. **41**, No. 7, 611–613 (1982).
23. K.A. Stankov, S.Z. Kurtev, and I.Y. Mibev, Opt. Commun. **62**, No. 1, 32–34 (1987).
24. Yu.D. Korolev and G.A. Mesyats, *Autoemission and Explosive Processes in a Gas Discharge* (Nauka, Novosibirsk, 1982), 253 pp.
25. D. Basting, P.F. Schafer, and B. Steyer, Opto-Electronics **4**, 43–49 (1972).
26. V. Hasson, D. Preussler, J. Klimek, et al., Appl. Phys. Lett. **25**, No. 11, 654–656 (1974).
27. V.N. Ishchenko, V.N. Lisitsin, and V.N. Starinskii, Opt. Mekh. Promst., No. 3, 32–34 (1974).
28. J.I. Levatter and Lin Shao-Chi, Appl. Phys. Lett. **25**, No. 12, 703–705 (1974).
29. H.M. Von Bergmann, V. Hasson, and D. Preussler, Appl. Phys. Lett. **27**, 553 (1975).
30. V. Hasson, H.M. Von Bergmann, and D. Preussler, Appl. Phys. Lett. **28**, No. 1, 17–18 (1976).
31. A. Bojara, W. Gawlik, R. Grabski, et al., Rev. Sci. Instrum. **55**, No. 2, 166–168 (1984).
32. K. Stankov and S. Kurtev, Opt. Commun. **56**, No. 1, 36–38 (1985).
33. T. Efthimiopoulos and Ch. Bacharides, Opt. Eng. **25**, No. 9, 1055–1057 (1986).
34. K.R. Rickwood, A.A. Serafetinides, A.D. Papadopouls et al., in: *Proceedings of Reports at the UK Conference on Electro-Optics and Lasers*, Brighton (1986).
35. P.P. Brynzalov, B.O. Zikrin, N.V. Karlov, and G.P. Kuz'min, Pis'ma Zh. Tekhn. Fiz. **14**, No. 22, 2033–2036 (1988).
36. V. Serbezov and P.A. Atanasov, Meas. Sci. Technol. **1**, 601–604 (1990).
37. H.M. Bergmann and A.J. Penderis, J. Phys. **E10**, 602–604 (1977).
38. I.M. Knyazev, V.S. Letakhov, and V.G. Movsev, Opt. Commun. **6**, 250–252 (1972).
39. H. Houtman and J. Meyer, Rev. Sci. Instrum. **54**, No. 12, 1629–1630 (1983).
40. C. Iwasaki and T. Jitsung, IEEE J. Quant. Electron. **QE–18**, 423–427 (1982).
41. V.F. Tarasenko and Yu.A. Kurbatov, Prib. Tekh. Eksp., No. 1, 182–183 (1973).
42. H. Furuhashi, M. Shimizu, and T. Goto, Meas. Sci. Technol. **1**, 401–405 (1990).
43. C.H. Brito Crus, V. Loureiro, A.D. Tavares, et al., Appl. Phys. **B35**, 131–133 (1984).
44. A.I. Gorlov, V.V. Kyun, V.S. Skoz, et al., Kvant. Elektron. **16**, No.9, 1781–1784 (1989).
45. H. Furuhashi and T. Goto, Rev. Sci. Instrum. **59**, No. 12, 2552–2556 (1988).
46. V. Hasson and H.M. Von Bergmann, Rev. Sci. Instrum. **50**, No. 1, 59–63 (1979).
47. H.M. Von Bergmann, J. Phys. **E10**, 1210–1212 (1977).
48. A.I. Fedorov, Atmos. Oceanic. Opt. **7**, No. 1, 53–56 (1994).