SOVIET PHYSICS

JETP

A translation of the Zhurnal Éksperimental'noĭ i Teoreticheskoĭ Fiziki.

Vol. 18, No. 3, pp. 571-881 (Russ. Orig. Vol. 45, No. 4, pp. 833-1282, October 1963) March 1964

STUDY OF PULSED LASER GENERATION IN NEON AND IN MIXTURES OF NEON AND HELIUM

G. G. PETRASH and I. N. KNYAZEV

P. N. Lebedev Physics Institute, Academy of Sciences, U.S.S.R.

Submitted to JETP editor, March 27, 1963

J. Exptl. Theoret. Phys. (U.S.S.R.) 45, 833-839 (October, 1963)

The character of laser generation in Ne, and in mixtures of Ne and He, has been studied under pulsed excitation for a wide range of partial pressures of Ne and He. In pure Ne peak production is observed in three lines at the start of the excitation pulse and continuous generation in two of these lines. Conclusions are drawn concerning the origins of the generation peaks at the start of excitation and after switching it off.

IT is well known [1] that in an He-Ne laser population inversion is attained principally by resonance transfer of energy from metastable atoms of He(2^3S) to atoms of Ne. At the same time significant undesirable population of the lower levels of the working transitions is caused by electronic collisions with metastable atoms of Ne. Studies of the afterglow in this mixture [1,2] have shown that the population of the upper levels of the working transitions is retained after switching off the discharge for a comparatively long time, of order 100 μsec. The population of the lower levels of the working transitions due to collisions with electrons ceases after a time of order 10—20 μsec. Thus, for a certain time after switching off the discharge the difference between the populations of the working levels can be greater than in the steady-state condition. A corresponding increase of amplification after switching off the discharge has been observed experimentally.[1]

From this fact it would be expected that a peak of generation would be observed after switching off the discharge. Such a peak has, in fact, been observed (see [3]). It has also turned out that on increasing the excitation power a second generation peak arises at the start of the pulsed excitation; its origin remains obscure. It is not stated in [3], however, for what transition and under what conditions the generation peaks described were obtained. Yet it is well known that many lines can be generated simultaneously in a He-Ne laser.[1,4] If no spectral resolution was used in [3] or if the resolving power was not sufficiently high, then the observed form of generation could be the result of the total effect of several lines, which greatly hinders the interpretation of the results obtained. In this connection it was desirable to study laser generation under pulsed excitation conditions for various compositions of gaseous mixture and for several lines. Preliminary results of experiments made in this direction are presented in the present paper.

The experiments were made with a laser, the mirrors of which were placed inside the gas chamber. Spherical mirrors with multilayer dielectric coatings were used.[1)] The distance between the mirrors was 105 cm and corresponded almost to

[1)]The authors take the opportunity to express their gratitude to A. Yu. Klement'eva and T. F. Meshcheryakova of the Physics Faculty of the Moscow State University, who fabricated the high-reflection mirrors.

a confocal arrangement. A glass discharge tube with inside diameter 8 mm was used. The discharge was excited in the tube by a specially constructed oscillator at ~23 Mcs. The laser operation was studied both under continuous and under pulsed excitation. In the latter case the master oscillator was unlocked only for a definite time. The rectangular unlocking pulse was provided from a GIS-2 generator through a special circuit. The synchronized oscilloscope sweep was fed from the same generator. The length of the excitation pulses could be varied from several μsec to 1 msec. The repetition frequency of the pulses was varied from tens to hundreds of cycles per second. The rise and decay times of the excitation pulses were approximately 1 μsec. The laser radiation was recorded with a monochromator with a diffraction grating of 300 lines per mm, which was constructed in our laboratory. An FÉU-22 photo-multiplier served as detector. The apparatus allowed us to resolve easily the majority of the Ne lines in the region of the spectrum of interest to us; however, the lines $\lambda = 1.1523\ \mu$ and $\lambda = 1.1525\ \mu$ could not be resolved. The possibility cannot, therefore, be excluded that the results which we ascribed to the $1.1523\ \mu$ line, as being the more intense, correspond to simultaneous generation on these two lines. The spectral region within which we could observe generation was limited on the one hand by the rapid fall-off in the mirror reflection, starting at approximately $1.1\ \mu$, and on the other hand by the sharp fall-off in the photomultiplier sensitivity for $\lambda > 1.2\ \mu$.

GENERATION IN PURE Ne

Previously [5,6] it has been reported[2)] that in pure Ne continuous generation is observed for the $2s_2 - 2p_4$ transition at a wavelength of $\lambda = 1.1523\ \mu$. In addition to this line we discovered generation at two more lines: $\lambda = 1.1143\ \mu$ ($2s_4 - 2p_8$ transition) and $\lambda = 1.1767\ \mu$ ($2s_2 - 2p_2$ transition). For the line $\lambda = 1.1143\ \mu$ both continuous and pulsed generation was observed, and for the line $\lambda = 1.1767\ \mu$ generation was observed only during the peak at the start of pulsed excitation. For the line $\lambda = 1.1523\ \mu$ pulsed generation is observed on decreasing the Ne pressure, starting from a pressure of ~1.0 mm Hg. The generation peak starts approximately 1—2 μsec after the start of the excitation pulse and has a duration of order 2—3 μsec. Our apparatus did not permit more accurate measurements to be made of the form and duration of the first generation peak, since an increase in the temporal resolution greatly decreased the sensitivity. To increase the sensitivity we had to work in many cases with an input-circuit time constant of ~10 μsec. The oscilloscope traces presented here were obtained with such a time constant.

In Fig. 1 is shown the generation peak in pure neon at a pressure of 0.3 mm Hg. Curve 4 characterizes the change of population of the upper level of the working transition. When the pressure of Ne is lowered the generation peak grows, and at a pressure of ~0.1 mm Hg the transition to continuous generation is observed.

For the line $\lambda = 1.1767\ \mu$ the generation peak occurs at approximately the same pressure of Ne, and has practically the same form. At a pressure of ~0.2 mm Hg generation ceases. Continuous generation in this line could not be discovered. For the line $\lambda = 1.1143\ \mu$ both pulsed generation of approximately the same form and continuous generation were observed, but at low Ne pressures.

GENERATION IN Ne-He MIXTURES

To clarify the effect of additions of He on the character of the laser generation, we investigated generation in several lines for various ratios of the partial pressures of Ne and He—the ratio

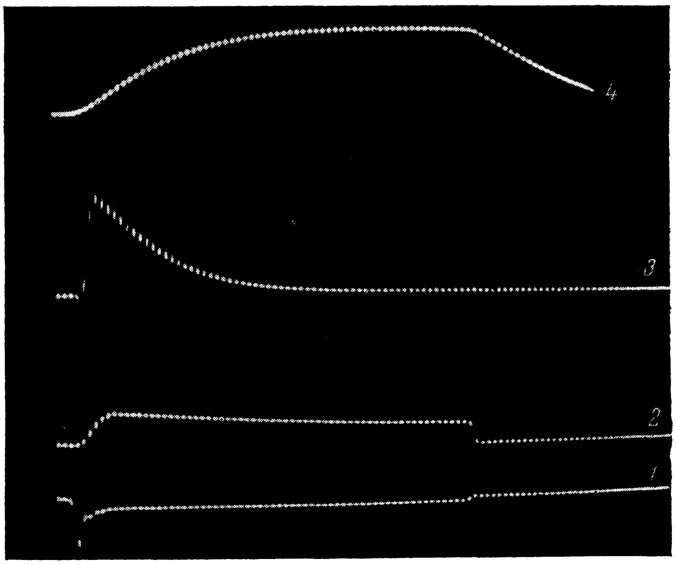

FIG. 1. Generation in pure Ne (p = 0.3 mm Hg). Duration of excitation pulse 63 μsec. Time markers every 1 μsec. Curve 1, – voltage pulse on the discharge tube, 2 – current pulse, 3 – generation pulse for the line $\lambda = 1.1523\ \mu$ ($2s_2 - 2s_4$ transition, 4 – spontaneous emission in the 8865 Å line ($2s_2 - 2p_{10}$ transition).

[2)]For convenient comparison with the papers referred to, we use the Paschen notation for the Ne levels. The corresponding jl-coupling notation is given in the table.

varied from 1 : 0 (pure neon) to ~1 : 80. In particular the following experiment was made. At a pressure of 0.3 mm Hg of pure Ne the generation peak described above was observed at the start of an excitation pulse for the line $\lambda = 1.1523\ \mu$. The length of the excitation pulse in this experiment was ~ 100 μsec. Then, without changing the stable conditions in the discharge tube, we added a small amount of He. After a certain amount of He had been added there appeared, along with the usual preliminary generation peak, a later generation peak, which started approximately 10 μsec after switching off the excitation. The two generation peaks are shown in Fig. 2, as well as the pulse of spontaneous emission in the line $\lambda = 8865$ Å ($2s_2 - 2p_{10}$ transition) which characterizes the growth and decay rates of the population in the upper level of the operative transition. When the pressure of He was further increased the last generation peak increased, and continuous generation could be observed at a certain ratio of He-Ne pressures.

In addition we studied the character of the generation of our laser for several fixed ratios of partial pressures of Ne and He. Altogether we observed under various conditions generation in seven lines, continuous generation, in five under certain conditions, and only pulsed generation in two. Very intense radiation was observed in the line $\lambda = 1.1523\ \mu$. Generation at this wavelength could be observed for all ratios of Ne and He pressures. By choosing the corresponding total pressure of the mixture and the excitation power we always succeeded in obtaining continuous generation in this line.

The form of the pulse of laser generation differed greatly for various lines and various working conditions. We observed continuous generation as well as continuous generation with peaks at the start of excitation and after switching off the excitation, or else generation with only one of the peaks. Under some conditions only pulsed generation was observed. By changing the excitation conditions of the laser we could change the ratio of the peaks to the continuous generation within wide limits. Various forms of generation pulses are shown in Fig. 3. The main characteristics of the laser generation are given in the table. Each column of the table corresponds to the fixed ratio of Ne and He pressures specified at the head of the column and to different total pressures and excitation conditions.

DISCUSSION OF RESULTS

The described character of change in generation with changing ratio of Ne and He pressures shows that the generation peak occurring at the start of the excitation pulse is due to peculiarities in the population of the different levels in the discharge and is not associated with the transfer of energy from the He atoms to the Ne atoms. On the other hand, the generation peak occurring after switching off the discharge is due to the resonance transfer of energy from the long-lived metastable states of He to the Ne atoms. The fact that the last generation peak does not occur in pure Ne, but appears in all lines only when He is added, provides evidence in support of this idea. Apart from this, when the ratio of Ne and He pressures is changed so as to increase the amount of He, a clear tendency is displayed for the latter generation peak to appear more easily and for the number of lines in which generation is observed to increase. This all supports the explanation proposed in [1] for the last generation peak.

As regards the first generation peak, its appearance is apparently associated with the differ-

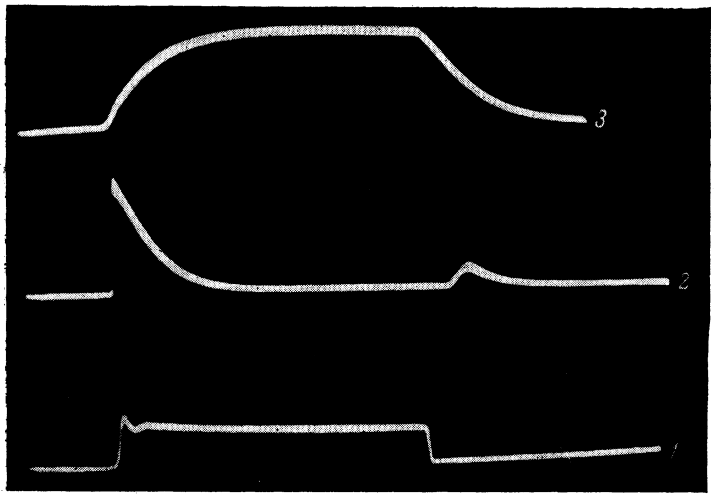

FIG. 2. Effect of additions of He (0.3 mm Hg of Ne + small addition of He). Duration of excitation pulse 100 μsec. Curve 1 – current pulse in discharge, 2 – laser generation in the line $\lambda = 1.1523\ \mu$, 3 – spontaneous emission in the line $\lambda = 8865$ A.

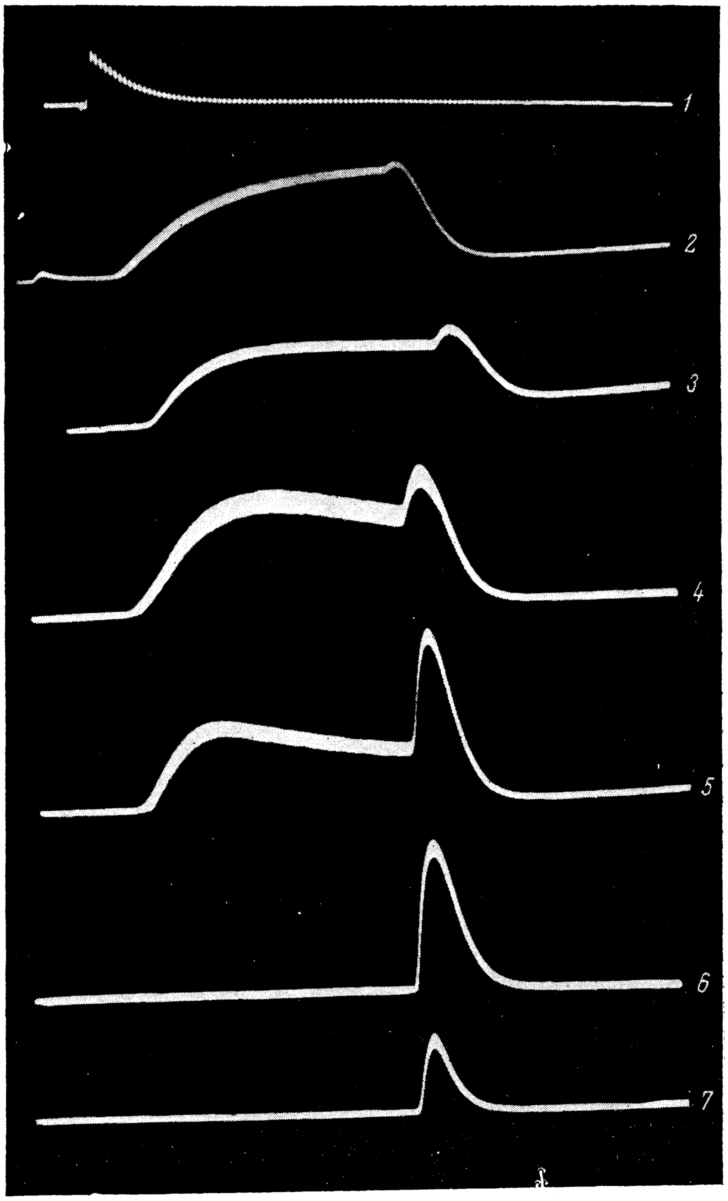

FIG. 3. Examples of laser generation pulses: Curve $1-\lambda = 1.1766\ \mu$ ($2s_2 - 2p_2$ transition) 0.3 mm Hg of Ne. Duration of excitation pulses 60 μsec (markers every 1 μsec); $2-\lambda = 1.1523\mu$; Ne : He = 1 : 10, total pressure 0.3 mm Hg (here and below the duration of the excitation pulse was 200 μsec); $3-\lambda = 1.1523\mu$; Ne : He = = 1 : 34, total pressure 3.4 mm Hg; $4-\lambda = 1.1523\mu$; Ne : He = 1 : 34, total pressure 1 mm Hg; $5-\lambda = 1.1614\mu$ ($2s_3- 2p_5$ transition); Ne : He = 1 : 10, total pressure 1 mm Hg; $6-\lambda = 1.1614\mu$; Ne : He = 1 : 34, total pressure 3.4 mm Hg; $7-\lambda = 1.2066\mu$ ($2s_5 - 2p_6$ transition); Ne : He = 1 : 10, total pressure 0.8 mm Hg.

ent rate of populating the upper and lower levels of the operative transitions when the steady-state condition is being established. Attention is drawn to the fact that all transitions for which generation in the first peak is observed in pure Ne start from the levels $2s_2$ and $2s_4$, which are optically connected with the ground state, while no generation was observed in the front peak in pure Ne for any of the transitions from the $2s_3$ and $2s_5$ levels (dipole transitions into the ground state are forbidden for these levels). Because the probability of excitation by electron collision is usually greater for those transitions which have the greater optical transition probability, it can be thought that in the course of establishing the steady state the rate of populating the levels $2s_2$ and $2s_4$ is greater than for the levels $2s_3$ and $2s_5$. The population of the lower operative levels proceeds principally by electron collisions with atoms in 1s states [2,4,7], i.e. by a cascade process. One can therefore expect that the rate of populating the 2p levels is smaller than that for $2s_2$ and $2s_4$. In this case generation occurs only in the peak at the start of an excitation pulse. In fact, if the upper level is populated more rapidly than the lower, then during establishment of the steady state population inversion can arise for a certain time between these two levels, even if there is no inversion in the steady-state condition. The results of the experiment described fit well into this scheme. It would be desirable, however, to extend the experiments to a greater number of lines, starting from different 2s levels and finishing in various 2p levels, in order to establish more pre-

Transition		λ, μ	Ne : He pressure ratio				
jl	Paschen		1 : 0	1 : 1	1 : 3	1 : 10	1 : 40
$4s\left[\frac{3}{2}\right]_1 - 3p\left[\frac{5}{2}\right]_2$	$2s_4 - 2p_8$	1,1143	cg,fp (0.1)*				sp (4.2)
$4s\left[\frac{3}{2}\right]_2 - 3p\left[\frac{5}{2}\right]_3$	$2s_5 - 2p_9$	1,1177				sp (3.0)	sp (4.2 – 1.4)
$4s'\left[\frac{1}{2}\right]_1 - 3p'\left[\frac{3}{2}\right]_2$	$2s_2 - 2p_4$	1,1523	cg (0.1) fp (1,0—0,05)	cg,fp,sp (0.7—0.07)	cg, fp, sp (0.4)	cg, fp, sp (3,0—0,3)	cg, fp, sp (4.2 – 0.5)
$4s'\left[\frac{1}{2}\right]_0 - 3p'\left[\frac{3}{2}\right]_1$	$2s_3 - 2p_5$	1,1614		sp (0.5)	cg, sp(0.4)	cg, sp (3.0 – 1.0)	cg, sp (4.2 – 1.4)
$4s'\left[\frac{1}{2}\right]_1 - 3p'\left[\frac{1}{2}\right]_1$	$2s_2 - 2p_2$	1,1767	fp (0.7—0,2)	cg, fp (0.25)	cg, fp (0,4)	fp (1.0)	sp (4.2)
$4s'\left[\frac{1}{2}\right]_0 - 3p'\left[\frac{1}{2}\right]_1$	$2s_3 - 2p_2$	1,1985					cg, sp (4.2 – 1.4)
$4s\left[\frac{3}{2}\right]_2 - 3p\left[\frac{3}{2}\right]_2$	$2s_5 - 2p_6$	1,2066					sp (4,2—1,4)

*In the parentheses are given the ranges of total pressures of the mixtures (in mm Hg) over which generation was observed. Abbreviations: cg—continuous generation, fp—first peak, sp—second peak.

cisely the correlation between the occurrence of the first peak and the properties of the upper and lower levels.

The general idea of the possibility of obtaining population inversion when a system is undergoing a transition into thermodynamic equilibrium, i.e., in the process of heating or cooling the system, was put forward by Basov and Oraevskiĭ[8]. In our case we deal, of course, with population inversion in the process of "heating" and "cooling" the electrons when discharge in a gas is started and stopped.

The results of the experiments described permit us to hope that such a way of obtaining population inversion can find wide use for obtaining pulsed generation in gas lasers.

In conclusion the authors express their gratitude to Prof. P. A. Bazhulin for constant interest in the work, and also to V. I. Malyshev, S. G. Rautian and I. I. Sobel'man for valuable discussions of the results.

[1] Javan, Bennett and Herriott, Phys. Rev. Letters **6**, 106 (1961).

[2] A. Javan, Adv. in Quantum Electronics, ed. J. Singer, Columbia Univ. Press, 1961, p. 18.

[3] Brachet, Decomps, Durand, Heriard-Dubreuilh, Lamain, Vasseur, and Vautier, Compt. rend. **255**, 73 (1962).

[4] McFarlane, Patel, Bennett, and Faust, Proc. Inst. Radio Engrs. 50, 2111 (1962).

[5] Patel, Bennett, Faust and McFarlane, Phys. Rev. Letters **9**, 102, (1962).

[6] C. K. N. Patel, J. Appl. Phys. **33**, 3194 (1962).

[7] W. R. Bennett, Adv. in Quantum Electronics, ed. J. Singer, Columbia Univ. Press, 1961, p. 28.

[8] N. G. Basov and A. N. Oraevskiĭ, JETP **44**, 1742 (1963), Soviet Phys. JETP **17**, 1171 (1963).

Translated by K. F. Hulme
145