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The output power of TEM₀₀ He-Ne lasers at 633 mm

This paper follows the previous work about the output power of 633 nm He-Ne lasers, where a method for establishing the optimum geometry for lasers of resonator lengths 135 mm, 450 mm and 1265 mm is described [1, 3], and experimental results are shown [2, 4]. The present work includes resulting graphs for the design of optimum geometry of a TEM_{00} laser with a resonator of 2150 mm and experimental results of lasers with resonator lengths 2150 mm, 1500 mm and 465 mm; their outputs reach the values of about 80 mW, 45 mW and 6.5 mW, respectively.

1. Introduction

The output power of gas lasers is very important when a high radiation density is desired; e.g. in spectroscopy, holography, etc. For most applications the laser must operate in the fundamental TEM_{00} mode, i.e. the radiation must have a uniphase wave front in the whole cross-section of the beam. Hence, a design of optimal parameters of He-Ne lasers which realize the maximum output of the radiation for the TEM_{00} mode is required.

2. Optimal parameters of He-Ne lasers

In principle it can be shown that the maximum output power at the TEM_{00} mode is produced by a laser in which the oscillating mode fills as much as possible the inner space of the discharge tube; in other words, the active medium is fully exploited. (The same result cannot be obtained e.g. by inserting a diaphragm in the cavity). Simple limitation of oscillations to the fundamental TEM_{00} mode is given by diffraction losses directly caused by the inner diameter of the discharge tube. Such a design yields a small cross-section of the capillary tubes; if the tubes are long the discharge path must be divided in two sections in order to decrease the necessary high voltage of the source.

The method for establishing the optimum geometry for a 633 nm He-Ne laser was published elsewhere [1, 2, 3, 4]. This method requires the achievment of the maximum output, i.e. the optimum ratio of Ne and He^3 gases, the optimum total pressure of the mixture, and the optimum transmission of the laser mirrors. It should be noted that oscillations of the competing infrared line 3.39 μ are suppressed by absorption in methane. The gain of that line is decreased by the Zeeman effect caused by permanent magnets used along the discharge tube.

The curves resulting from the optimum geometry design [1, 2, 3, 4], from which the diameter of the capillary tube is determined are shown in figs. 1 and 2. Fig. 1 represents the dependence of the output power on the tube diameter in a resonator of 2150 mm;

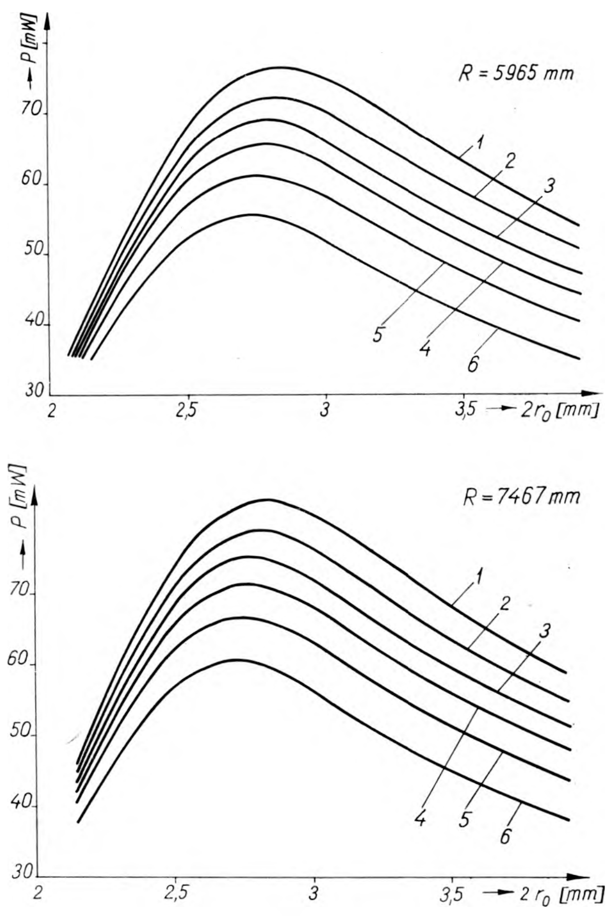

Fig. 1. Output power P vs. the tube diameter $2r_0$ when losses a_z are 0.006–0.02 for the discharge tube 2000 mm and resonator 2150 mm; a) for laser mirrors of radii $R = 5965$ mm, b) for laser mirrors of radii $R = 7467$ mm
$1 - a_z = 0.006$, $2 - a_z = 0.008$, $3 - a_z = 0.010$, $4 - a_z = 0.012$, $5 - a_z = 0.015$, $6 - a_z = 0.02$

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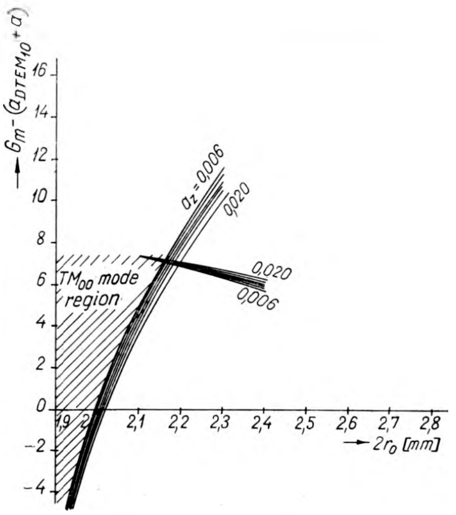

Fig. 2. Graph of the TEM_{00} mode delimitation for a resonator 2150 mm, discharge tube 2000 mm and laser mirrors of radii $R = 5965$ mm when losses a_z are 0.006–0.02. The curves of optimum mirror transmission t_{opt} intersect the curves of $G_m - (a_{DTEM_{10}} + a_z)$ where G_m is the gain, a_z denotes the single pass loss of the cavity including one mirror, and $a_{DTEM_{10}}$ represents diffraction losses for the higher mode TEM_{10}
Resonator — 2150 mm, mirrors — 5965 mm, discharge tube — 2000 mm

a) for laser mirrors $R = 5965$ mm, and
b) for laser mirrors $R = 7467$ mm;
particular curves correspond to different losess in the resonator. The mirror transmission was optimal for the maximum output power and for this type of laser $T_1 = 6.5\%$ when $T_2 = 0.1\%$. At small tube diameters the output is reduced by diffraction losses of the resonator; at larger diameters by unsufficient exploatation of the active medium only, because other factors influencing the output power are included in calculations [1, 2, 3, 4]. The graph in fig. 2 used for the design of the tube diameter delimits the region of TEM_{00} mode oscillations. In the dashed region higher oscillation modes cannot occur due to high diffraction losses. In fact the used diameters of laser capillary tubes are slightly larger, considering the unstraightness of uncalibrated capillaries and the mode competition. The used criterion for the limitation of laser oscillations to the TEM_{00} mode is very severe. In real tubes such a mode structure should be established for which the saturation of the active medium is higher. This allows to choose a little larger tube diameters for the TEM_{00} mode at lasers with higher output power.

Similar calculations and some experimental results for lasers near to those with resonator lengths 1500 mm and 465 mm were published in [1, 2, 3, 4].

3. Experimental results

Some experimental results of the treated lasers are shown in tables. Table 1 refers to the resonator of the longest type (2150 mm). Its output appears in the region of 80 mW as expected from calculations. The values for the resonator of the type 1500 mm are given in table 2. The output can reach 45 mW (all three lasers operated without magnets). As to the type 465 mm the maximum values were 6.5 mW.

Table 1

Specification of experimental lasers with a resonator length 2150 mm and discharge tubes 2000 mm

Discharge tube	Inner diameter $2r_0$	Optimum current $I_{a\,opt}$	Mirror radius		Output power for TEM_{00} mode P
			R_1	R_2	
No.	mm	mA	mm	mm	mW
1	3.1	2×21.5	7467	7467	79
2	3.27	2×20	7467	∞	72.5
3	3.12	2×17	∞	5919	81

Table 2

Specifications of experimental lasers with a resonator length 1500 mm and discharge tubes 1450 mm

Discharge tube	Inner diameter $2r_0$	Optimum current $I_{a\,opt}$	Mirror radius		Output power for TEM_{00} mode P
			R_1	R_2	
No.	mm	mA	mm	mm	mW
1	2.15	2×14	3567	3567	43
2	2.12	2×15	3567	2390	41
3	2.15	2×13	3567	3567	41

To check the mode structure of laser oscillations radio frequency measurements of beat frequencies were made. In the case of oscillation on the fundamental TEM_{00} mode the resulting beat frequency spectrum supplies beat frequency of

$$\Delta f = \frac{c}{2d},$$

where c is the speed of light and d is the resonator length. With higher mode oscillations further frequencies appear.

A laser with the resonator length 1500 mm and mirrors of radii $R_1 = 2390$ mm and $R_2 = 3567$ mm, respectively, may serve as an example of multimode function. The oscillations consist of $TEM_{00} + TEM_{10} + TEM_{01}$ modes combination. The corres-

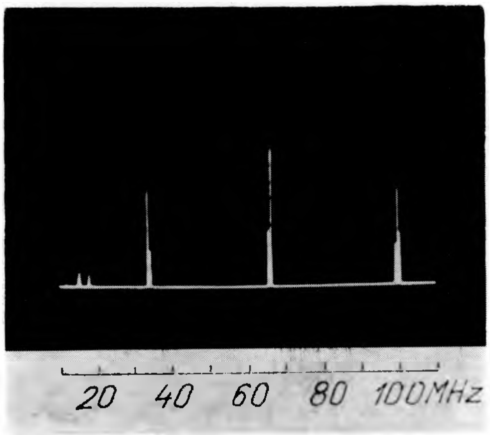

Fig. 3. Beat frequencies of a multimode operation of a 1500 mm laser with $TEM_{00}+TEM_{10}+TEM_{01}$ modes combination; mirror radii: $R_1 = 2390$ mm, $R_2 = 3567$ mm

ponding data recorded by a frequency analyser are shown in fig. 3. The fundamental TEM_{00} mode gives the beat frequency $\Delta f_1 = 100$ MHz. Further beat frequencies between TEM_{00} and TEM_{10} or TEM_{01} modes are $\Delta f_2 = 66.5$ MHz and $\Delta f_3 = 33.5$ MHz, respectively. To achieve the pure TEM_{00} mode it was necessary to use a mirror of radius $R_2 = 5919$ mm instead of $R_2 = 3567$ mm. The whole measuring range 0–100 MHz of the frequency analyser is recorded in fig. 4. One peak alone at any mirror and discharge tube adjustment yields the proof of TEM_{00} mode oscillations only.

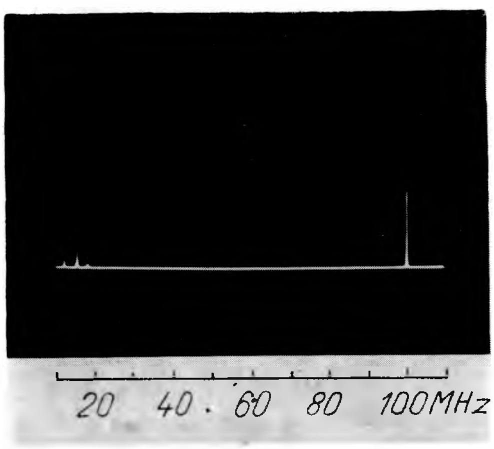

Fig. 4. Beat frequency of a 1500 mm laser with mirror radii: $R_1 = 2390$ mm, $R_2 = 5919$ mm, operating on the fundamental TEM_{00} mode

4. Production of He-Ne lasers

The above mentioned lasers are introduced in production by Metra Blansko Works. Some basic parameters, dimensions included, are listed in table 3.

Table 3

Types of laser heads produced by Metra Blansko Works

Type LA	1001	1002	1003
Transverse mode	TEM_{00}	TEM_{00}	TEM_{0}
Output power (mW)	60	35	5
Beam diameter (mm)	1.6	1.2	0.6
Longitudinal mode spacing (MHz)	70	100	323
Polarization	linear	linear	linear
Extinction ratio	1×10^{-3}	1×10^{-3}	1×10^{-3}
Polarization orientation	vertical	$\pm5^0$	arbitrary
Length (mm)	2400	1600	500
Width (mm)	190	190	cylinder Ø 56
Height (mm)	260	260	—
Weight (kg)	22	15	1,5

The guaranteed values of the output power are lower than those given in table 2. Longitudinal mode spacings for laser of 60 mW, 35 mW and 5 mW amount to 70 MHz, 100 MHz and 323 MHz, respectively. Polarization of all types is linear due to Brewster windows, at both longer types its orientation is vertical, at the smallest type, due to a cylindrical housing, it can be set arbitrarily.

Выходная мощность моды TEM_{00} в гелий-неоновых лазерах для 633 ммкн

Настоящая работа представляет собой продолжение более ранней публикации, касающейся гелий-неоновых лазеров для $\lambda = 633$ ммкн, где был описан метод оптимальной геометрии лазеров длиной резонаторов 135, 450 и 1265 мм [1, 3] и приведены результаты опытов [2, 4]. В настоящей работе приводятся заключительные диаграммы для конструктивного определения оптимальной геометрии для лазера, работающего в моде TEM_{00} с разонатором длиной 2150, 1450 и 450 мм. Их выходная мощность достигала соответственно 80, 45 и 6,5 мвт.

References

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