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CURRENT DEPENDENCE OF THE Ne3s$_2$ LEVEL POPULATION IN A 6328 Å He-Ne LASER

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Abstract: The population of the Ne 3s$_2$ level in the discharge of a He-Ne laser is considered. The current dependence of the output power of the laser beam and the current dependence of the sidelight intensity of the Ne line at 6328 Å are measured. The values for population obtained from measurement are compared with the values calculated using a modified version of Arrathoon's model.

1. *Introduction*

The gain dependence on discharge current in a He-Ne mixture was investigated by Gordon and White$^{1)}$. They have found that the small signal gain dependence on current is related to the influence of laser population.

We tried to find the population of the Ne 3s$_2$ level varies with current under regenerative and nonregenerative conditions. Calculations for the evaluation of the dispersion effect in a He-Ne plasma were performed by Arrathoon$^{2)}$. He proposed a simplified model for the determination of the population of the Ne 3s$_2$ level. Arrathoon's model is based on the assumption that the predominant mechanism for the population of the Ne 3s$_2$ level is the resonant excitation transfer by collisions with He 2^{1}S metastables. A further assumption of his model is that this process is sufficiently effective to neglect direct electron excitation.

In accordance with the model proposed in Ref.[2], the population of the upper laser level in the nonregenerative case can be expressed by

$$N(3s_2)_{NR} = \frac{Z_{1M}}{Z'_{1M} + A_1} \cdot \frac{k_1 i}{1 + k_2 i}. \tag{1}$$

Here Z_{1M} is the rate of excitation transfer to the Ne $3s_2$ state by collision with He 2^1S metastables, Z'_{1M} is the rate of reverse transfer, and A_1 is the Einstein coefficient for spontaneous transitions from $3s_2$ levels. The constants k_1 and k_2 define the variation in generation and destruction of 2^1S metastables with current.

In the regenerative case the rate of Ne $3s_2$ atom depopulation is increased by stimulated transitions. In this case relation (1), in accordance with Ref.[2], becomes

$$N(3s_2)_R = \frac{Z_{1M}}{Z'_{1M} + A_1 + B_1 u(\nu)} \cdot \frac{k_3 i}{1 + k_4 i}. \tag{2}$$

Here B_1 is the Einstein coefficient for $3s_2 - 2p_4$ stimulated transitions and $u(\nu)$ is the energy density inside the laser beam.

2. *Experimental*

In order to verify relations (1) and (2), we used the method of selective perturbation of population of laser levels[3,4]. The laser we used consisted of a tube of 3 mm in diameter, 1 m long, filled with a He-Ne mixture in a ratio of 5 : 1; the $p \cdot d$

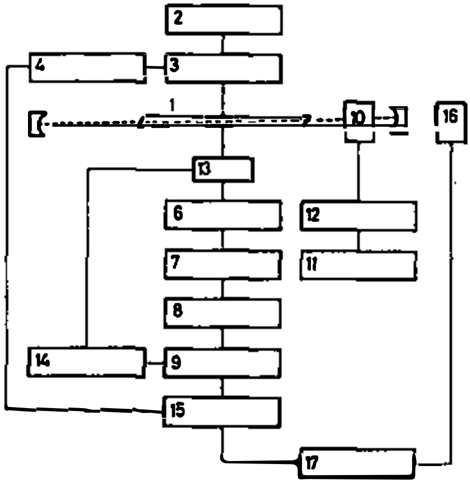

Fig. 1. Schematic diagram of the apparatus.

product was equal to 3. The discharge current in the tube varied continuously between 6 and 20 mA. During these variations the internal laser beam was chopped, while the variation in sidelight intensity was detected at a wavelength of 6328 Å. The dependence of sidelight intensity on discharge current under both regenerative and nonregenerative conditions was recorded with an XY recorder.

A schematic diagram of the apparatus is shown in Fig. 1. The laser tube (1) was fed through a rectifier (3) in conjunction with a programmer (2) to provide high-voltage variations in the rectifier. The discharge current was determined from the voltage drop on the divider (4). The signal from the divider was led to the *x* axis of an XYY· recorder (15). The visible sidelight was detected by a photomultiplier (7) through a monochromator (6) and the signal was fed through a preamplifier (8) and led to a lock-in amplifier (9).

The regenerative and nonregenerative conditions were achieved by interrupting slowly the internal laser beam with a slow chopper (10) fed through a function generator (11) and a power amplifier (12). Sidelight intensities were varied with a fast chopper (13). The reference signal from the chopper was fed to the lock-in amplifier (9) through the oscillator of the chopper. The output signal from the lock-in amplifier was led to the *Y* axis of the recorder. The signal from the photodiode (16) measuring the output power of the laser beam was led to the *y*· axis.

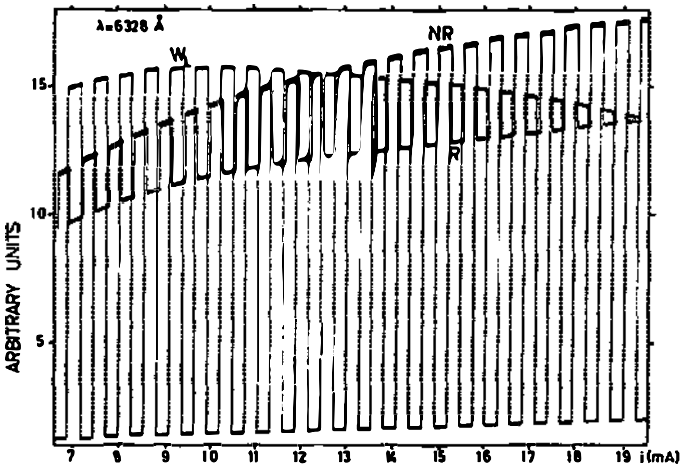

Fig. 2. Measured values of laser power W_L versus discharge current and sidelight at 6328 Å for the regenerative and nonregenerative case.

The rate of interruption of the internal laser beam with the slow chopper (10) was adjusted so as to enable the lock-in amplifier to follow changes in sidelight intensity. An interrupting frequency of 0.5 cps was chosen for the RC constant of the lock-in amplifier. Variations in rate of the discharge current in the laser tube were 1 mA/min.

3. *Results and discussion*

Fig. 2 shows a record taken with the *XYY'* recorder at a wavelength of 6328 Å. Here W_L is the laser power, I_{NR} and I_R are line intensities under nonregenerative and regenerative conditions, respectively.

The difference in population of the Ne $3s_2$ level in the regenerative and nonregenerative case decreased with increasing current, in accordance with the model proposed by Arrathoon²⁾. This behaviour was expected, since the density of laser radiation inside the resonator decreased (Fig. 3) with increasing current (after the maximum). Our measurements, however, show that the difference in sidelight intensity at 6328 Å (and therefore also in populations of the Ne $3s_2$ level) in both the regenerative and nonregenerative case increased with increasing current (Fig. 2), which is in accordance with Ref.¹⁾.

This disagreement with the model arises from the fact that the effect of the direct electron excitation of the $3s_2$ level population was not negligible. At currents higher than the maximum power current the effectiveness of the direct electron excitation of this level increases with increasing electron concentration.

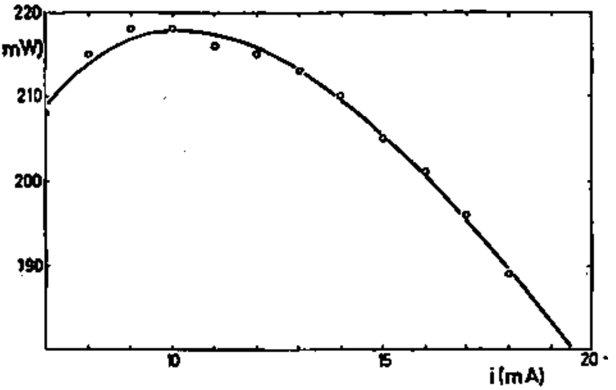

Fig. 3. Dependence of laser power versus discharge current (solid line — calculated values; circled points — measured values).

It is, therefore, necessary to make a modification of Arrathoon's model. We made this by taking into account our experimental results.

Relations (1) and (2) may be written in a more general form

$$N(3s_2)_{NR} = \frac{A_1(i)}{1 + B_1(i)}, \tag{3}$$

$$N(3s_2)_R = \frac{A_2(i)}{1 + B_2(i)}. \tag{4}$$

In the nonregenerative case the population function $A_1(i)$ is simply a linear function of discharge current, and therefore relation (3) can be transformed into the form

$$N(3s_2)_{NR} = \frac{A \cdot i}{1 + B_1 i}. \tag{5}$$

By fitting the experimental results (in Fig. 2), the constants A and B_1 were determined by the least-square method. The values obtained are $A = 3.43$, $B_1 = 0.14$, if the current is measured in mA.

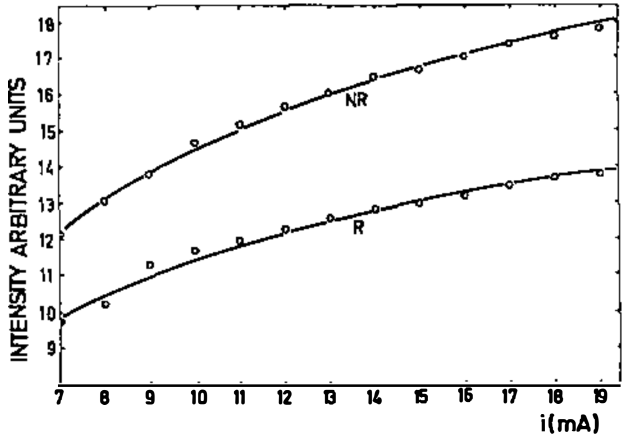

Fig. 4. Comparison of the current dependence of the Ne $3s^2$ level population under regenerative and nonregenerative conditions (solid line — modified version of Arrathoon's model; circled points — measured values).

In the regenerative case the population function $A_2(i)$ can be factorized

$$A_2(i) = \frac{Z_{1M}}{Z'_{1M} + A_1 + B_1 u(\nu, i)} f(i). \tag{6}$$

If we introduce

$$C(i) = \frac{Z_{1M}}{Z'_{1M} + A_1 + B_1 u(\nu, i)}, \tag{7}$$

relation (6) may be written in the form

$$A_2(i) = C(i) f(i). \tag{8}$$

The function $C(i)$ was determined by fitting the data on the dependence of laser radiation power on current (Fig. 3). We assumed the power dependence on discharge current to be of the form

$$P(i)\, d = \frac{K_1 i}{1 + K_2 i} + K_3 i. \tag{9}$$

The constants K_1, K_2 and K_3 were obtained by fitting when the current was measured in mA, and they are $K_1 = 96.66$, $K_2 = 0.15$, and $K_3 = -10.64$.

Measurements indicate that $A_2(i)$ should be a linear function of current, i. e., $A_2(i) = A \cdot i$. Again, by fitting we obtained the values for the constants in relation (4) $A_2 = 2.98$ and $B_2 = 0.16$ (the current was measured in mA) (Fig. 2, regenerative case). In accordance with relation (8), we obtain for $f(i)$

$$f(i) = \frac{A_2 i}{C(i)}. \tag{10}$$

Fig. 4 shows the comparison of the data obtained from measurements with the data calculated using relations (3), (4), (8) and (9) based on the modified version of Arrathoon's model.

References

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STRUJNA OVISNOST NASELJENOSTI $3s_2$ NIVOA NEONA U 6328 Å He-Ne LASERU

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Sadržaj

U radu je razmatrana populacija $3s_2$ nivoa atoma neona u izboju helij-neon lasera. Mjerena je strujna ovisnost izlazne snage lasera i strujna ovisnost intenziteta bočnog svjetla na neonskoj liniji 6328 Å. Mjerene vrijednosti populacije usporedene su s vrijednostima računatim na temelju korigiranog Arrathoonovog populacionog modela.