On Saturation Mechanisms in PC He–Cd+ Lasers

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Abstract—The results of experimental studies on the saturation mechanisms in He–Cd laser discharge are presented. It is concluded that the saturation effects may be explained in terms of the influence of the discharge parameters on the helium triplet metastable density.

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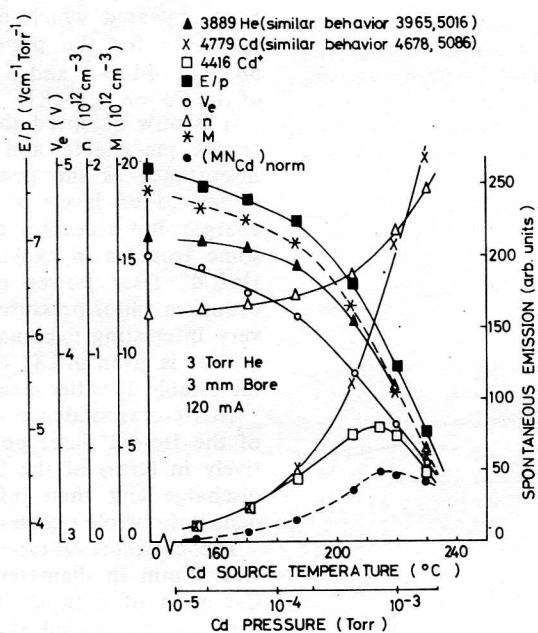
Since the proposal of the He–Cd+ laser [1] many papers have appeared which discuss the excitation mechanisms responsible for the population inversion on the $5s^2 \, ^2D_{5/2}$ – $5p \, ^2P_{3/2}$ 4416-Å and $5s^2 \, ^2D_{3/2}$ – $5p \, ^2P_{1/2}$ 3250-Å transitions of the Cd ion [2]–[8].

It is now accepted that Penning collisions between helium triplet metastable and cadmium ground-state atoms have importance as the process of population of the preceding upper Cd-ion levels in the positive column He–Cd laser discharge. But according to this excitation mechanism there are some troubles in explaining the effects of saturation of the He–Cd+ laser power output, especially when at constant cadmium vapor pressure the discharge current is increased. A very interesting explanation of the behavior of He–Cd+ laser output is given in [8] on the basis of the behavior of the He metastable densities measured in the He–Cd discharge.

This correspondence shows that the saturation mechanisms of the He–Cd+ laser power output can be explained qualitatively in terms of the behavior of plasma parameters of the discharge and their influence on the He triplet metastable density in whole region of interest.

The cataphoresis-type discharge tube used in these studies was 3 mm in diameter and about 40 cm in active length. Cadmium of natural isotopic abundance was supplied from the side arm placed at $\frac{2}{3}$ of the active length, closer to the anode. The side-arm temperature was stabilized to better than $\pm\frac{1}{2}°C$. All parts of the tube except the small region of cadmium condensation were put in the oven at a temperature of $350 \pm 7.5°C$. The experiments were made over the following range of parameters: the discharge current, 15–155 mA; helium pressure, 1.5–6 torr; cadmium vapor pressure, 10^{-5}– $2 \cdot 10^{-3}$ torr. The cadmium pressure in the discharge was estimated from the temperature of the side arm. The plasma parameters: electric field, electron temperature, and density were obtained using the double-probe technique modified [9] to avoid the difficulty in getting the electron density in the He–Cd discharge from the conventional double-probe method [10].

Because of using the probes in the active region of the tube the behavior of the 4416-Å spontaneous-emission sidelight was observed instead of the laser power output. But fortunately, it is known from our experiments and those of the others [8], [11] that the spontaneous-emission sidelight at 4416 Å follows the same behavior as the laser output. It seems that the He–Cd+ laser output depends on the pumping of the upper laser level rather than on the excitation and trapping effects of the lower laser level. This allows an explanation of the behavior of the He–Cd+ laser power output at 4416 Å in terms of the spontaneous-emission sidelight following the power.

Typical results of the experiments are presented in Figs. 1 and 2. Fig. 1 shows the influence of increasing cadmium vapor density on the intensities of the spontaneous-emission sidelight of the Cd+ at 4416 Å, Cd at 4799 Å, and He at 3889 Å and on the reduced electric field E/p, electron temperature V_e, and density n. These results were obtained for the fixed He pressure and discharge current optimal in the sense of the maximum of intensity of the 4416-Å laser line. The broken lines in Figs. 1 and 2 illustrate the variations of the He triplet metastable density M and normalized product of MN_{Cd}, where N_{Cd} is the density of the neutral cadmium atoms in the discharge. The plots of M and MN_{Cd} were obtained from the calculations based on the data of these experiments and on the rate equation for the He triplet metastable population in pure He discharge [8], modified by taking into account the destruction of the triplet metastables by Penning process in the He–Cd laser discharge. The final shape of the equation describing the He triplet metastable density in the He–Cd

Fig. 1. Spontaneous emission of 3889-Å He, 4799-Å Cd, and 4416-Å Cd⁺ lines, reduced electric field (E/p), electron temperature (V_e), and density (n), helium triplet metastable density (M), and normalized product MN_{Cd} (N_{Cd}-cadmium density) as functions of cadmium pressure in He–Cd laser discharge for fixed He pressure and discharge current. The broken lines show the results calculated.
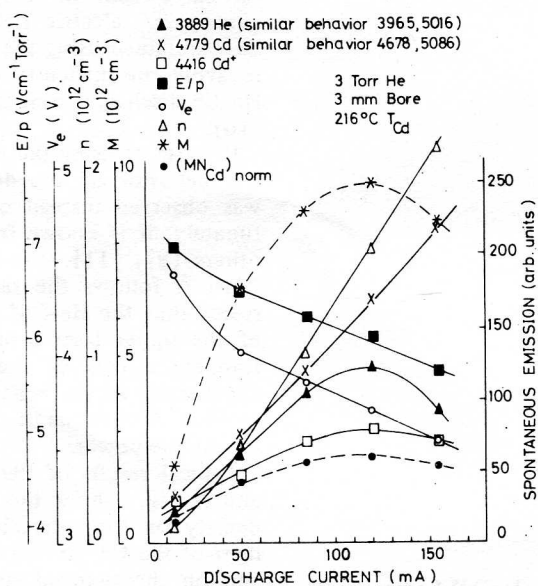

Fig. 2. Spontaneous emission of 3889-Å He, 4799-Å Cd, and 4416-Å Cd⁺ lines, reduced electric field (E/p), electron temperature (V_e), and density (n), helium triplet metastable density (M), and normalized product MN_{Cd} (N_{Cd}-cadmium density) as functions of discharge current in He–Cd laser discharge for fixed He and Cd pressures. The broken lines show the results calculated.

discharge is as follows [12]

$$M = \frac{540n}{70n + N_{Cd} + 47}(E/p - 4) \qquad (1)$$

where M and n are expressed in 10^{12} cm⁻³ and E/p in Vcm⁻¹ torr⁻¹

It is seen from Fig. 1 that the electron temperature and reduced electric field decrease with increasing cadmium density, contrary to the electron density. These are due to the inelastic collisions between electrons and neutral cadmium atoms. Also the metastable density decreases as cadmium density increases. It can be easily shown from (1) that the

decreasing of the metastable density is essentially determined by decreasing the reduced electric field rather than through the destruction of Penning process and electronic-collision effects in the region of interest. It is interesting to notice that the spontaneous emission of the 3889-Å line terminating on the triplet metastable level follows the metastable density plot. Spontaneous emission of the 4799-Å Cd indicates the increasing density of neutral cadmium atoms in the discharge.

According to the assumption that Penning collisions are the dominant source of the excitation of the upper level state the intensity of the 4416-Å emission sidelight would be proportional to the product of MN_{Cd} [2]. This was confirmed by these experiments. As is seen from Fig. 1 the normalized plot of MN_{Cd} follows the same behavior as the experimental values of sidelight intensity for the 4416-Å transition of Cd$^+$. Both these quantities saturate for the same value of cadmium vapor pressure of about $0.9 \cdot 10^{-3}$ torr. This means that the dependance of the spontaneous-emission sidelight at 4416 Å (and laser power output) on cadmium pressure can be understood in terms of the importance of Penning ionization in pumping processes of PC He–Cd$^+$ lasers.

Fig. 2 shows the behavior of the preceding quantities as the functions of discharge current for fixed He and Cd vapor pressures optimal in the sense of the maximum of the 4416-Å emission sidelight. According to (1), despite rapidly increasing electron density the He triplet metastable density saturates for the current of about 120 mA because of the decreasing reduced electric field when the discharge current increases. It means that the reducing of the mean electron energy and the E/p or V_e corresponding to it, due to the inelastic collisions of electrons in the He–Cd discharge, is important in the saturation mechanisms of the He triplet metastable density. As may be seen from Fig. 2 the 4416-Å emission sidelight follows the behavior of the metastable density and the plot of the product MN_{Cd}, and this is consistent with the generally accepted assumption that Penning ionization is important in the excitation mechanisms in the PC He–Cd$^+$ lasers.

It is worthwhile to notice that the plots of the triplet metastable density calculated herein is in a good agreement with those of measured values presented in [8].

It can be concluded that the saturation mechanisms in the PC He–Cd$^+$ lasers may be explained qualitatively by the behavior of the He triplet metastable density saturated due to the influence of the plasma parameters of the He–Cd discharge, the reduced electric field mainly.

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