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 ± 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