

THE CORRELATION BETWEEN CO₂-N₂-He DISCHARGE AND CO₂ LASER

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Abstract—A self-made CO₂ laser system is used to investigate the influence of additive gases on a CO₂ laser and the effect of lasing action on a CO₂-N₂-He discharge. The optimum condition for maximum laser power output is found to be a function of gas mixing ratio, gas flow rate, total pressure, and discharge voltage. When the CO₂ laser is lasing, both the discharge current and the electron temperature will decrease due to the fact that the lasing action makes the collisional cross-sections of N₂, CO and CO₂ molecules with electrons increase.

1. INTRODUCTION

This paper presents the results of an experimental investigation of a CO₂ laser discharge. The experiments were performed on the first CO₂ laser system set up in Chiao Tung University. The purpose of the experiments, however, is to investigate the correlation between the plasma properties of gaseous discharge and the CO₂ laser performance, and to examine the effect of additive nitrogen and helium on the CO₂ laser output power.

The experiments were carried out by utilizing a watercooled, gas-flowing laser tube of 1.35 cm in inner diameter and 80 cm in length. As shown in Fig. 1, the cathode and anode of the discharge tube were made of nickel wire, and the tube was sealed with two NaCl windows. The optical resonator was formed by two gold-coated germanium mirrors. A DC power supply with 10 KV maximum voltage and 100 mA maximum current is used as a source of DC excitation. It was connected to the electrodes of the discharge tube in series with a resistor box with resistance up to 80 kilo-ohms. The flowrate of the gases was controlled by needle valve and measured by gas-flow meter. The pressure of the system is in general kept in the range of one to ten torrs. By means of this simple set-up, we can readily obtain the laser output power in the order of a few watts.

In order to diagnose the plasma properties, an electrostatic single probe, made of glass sealed tungsten wire of 0.25 mm in diameter and 0.5 mm in length, was inserted into the discharge column. The probe voltage was supplied by two cascaded power supplies, one was used to apply a bias voltage and the other was connected to "X" of a X-Y recorder. For obtaining the stable probe current, the resistor must be connected to the probe rather to the anode.

In Sec. II, the effect of laser beam on the discharge current will be examined. Sec. III presents the results showing the effect of added helium and nitrogen on the

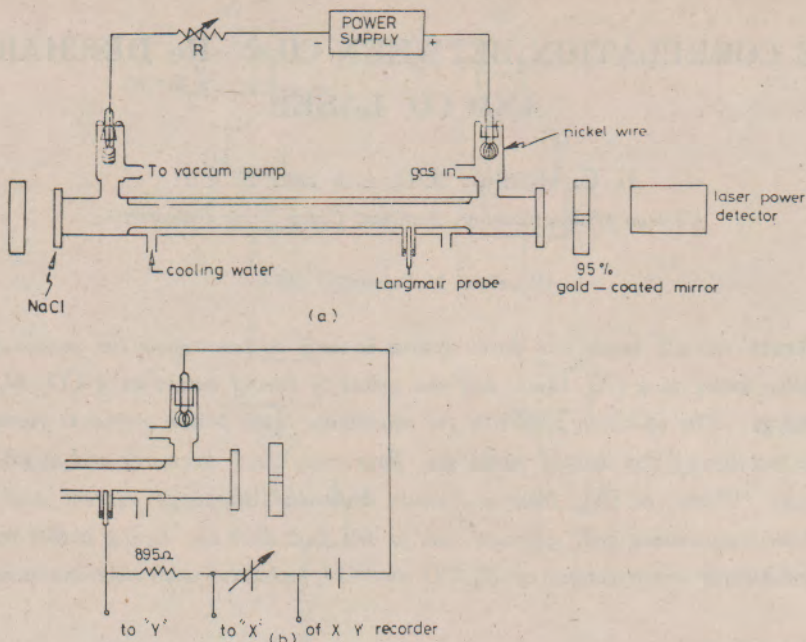


Fig. 1. (a) The arrangement of a CO₂ laser system.
 (b) The arrangement of probe circuit An electrostatic Langmuir Probe

laser power while in Sec. IV, the effect of laser action on the electron temperature will be discussed. The conclusion will be made in the last section.

2. THE EFFECT OF LASER BEAM ON THE DISCHARGE CURRENT

By close inspection, we found that the discharge column at non-lasing condition is brighter than that at lasing condition. The V-I characteristic curves plotted in Fig. 2 indicate that when CO₂ laser discharge is switched from lasing (such as point "a" in the curve) to non-lasing (as the corresponding point "a" the discharge current is increasing while the discharge voltage is decreasing. The variation becomes more evident when laser has a significant output power.

We know that the 00°1 upper laser level of a CO₂ molecule is a metastable state with lifetime up to milliseconds. In the gaseous discharge, the 00°1 level population can be efficiently pumped by direct impact of electrons or can be excited by collisions with excited N₂ or CO molecules. Thus, when the system is under the condition of non-lasing, the 00°1 state has high probability of being occupied because of its long lifetime. The population of the upper CO₂ laser state tends to be saturated if there is no laser beam passing through. The saturation of population then slows down the rate of energy transfer between the 00°1 state of the CO₂ molecules and the first vibrational states of N₂ and CO molecules. Conversely, if the system is lasing, the population of this upper state can be reduced significantly by stimulated emission of laser light. In this case, the further pumping of this level will continue directly or indirectly by electron impact. In other words, the collisional cross-section of the

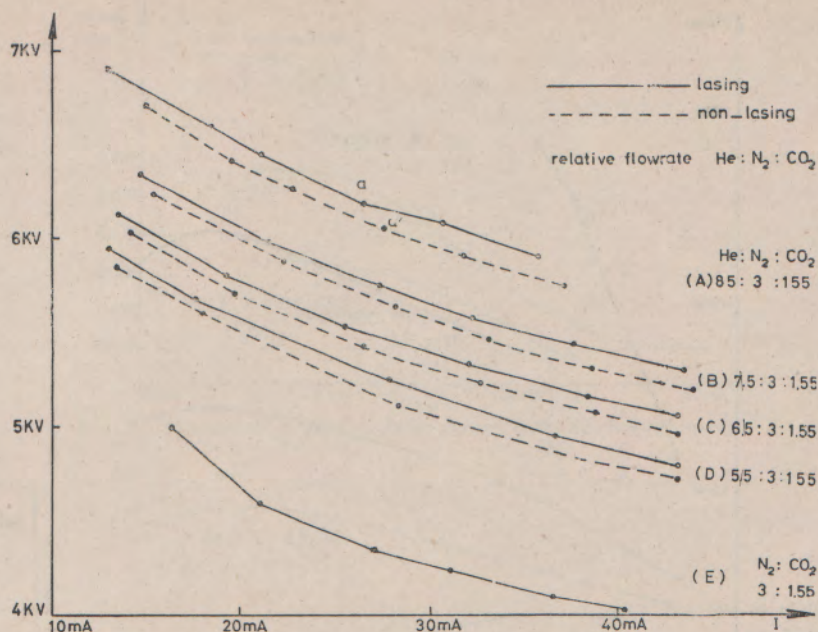
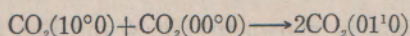
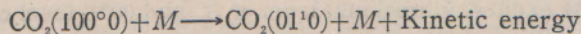


Fig. 2. The V-I characteristics of the CO₂ laser discharge when CO₂ laser is lasing and non-lasing

electron will effectively increase. It turns out that the electrons suffer more collisions and thus reduce their drift velocities along the discharge tube. The decreasing in the drift velocity can be account for the decreasing of the discharge current. The increasing of the voltage is due to the constant applied voltage of the power supply.

3. THE EFFECT OF THE ADDED HELIUM AND NITROGEN ON THE LASER POWER

When a 00⁰1 upper state CO₂ molecule is stimulated by a photon, it will jump down to the 10⁰ lower state. In order to maintain the population inversion, the 10⁰ state CO₂ molecules must also decay immediately. In a CO₂-N₂-He gas mixture, the deactivation of the lower laser state is accomplished by vibration-translational relaxation when the CO₂ molecule collides with molecules in the gas-mixture (such as He, N₂ and CO₂ molecules). The following processes are quite important in our discharge:



where *M* stands for CO₂, N₂ or He molecule.

Since the rate of relaxation is dependent on the reduced mass of the colliding pair, the CO₂-He collision is more efficient in the relaxation processes. It was reported¹ that CO₂-He collision is about twenty two times more efficient than CO₂-CO₂

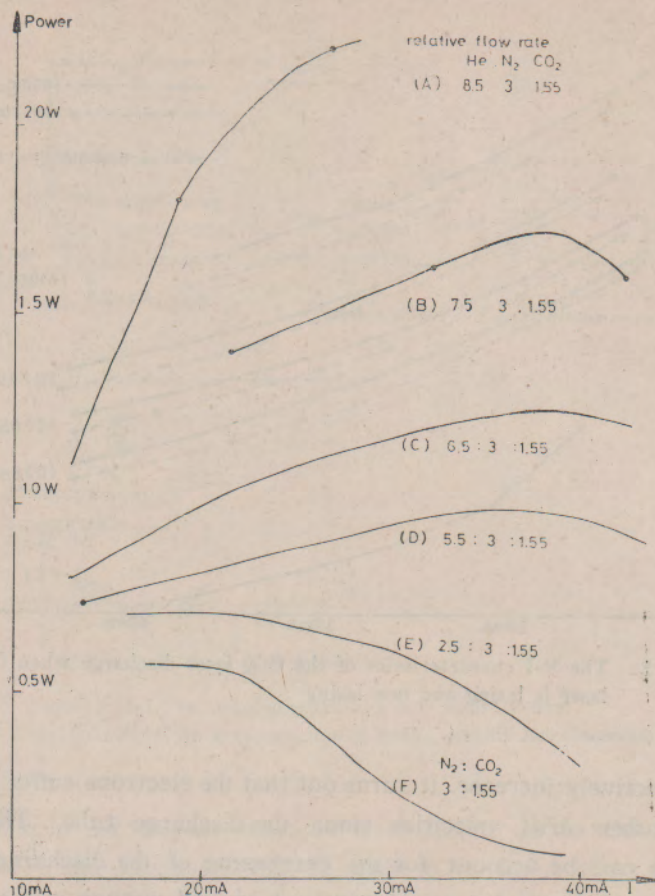


Fig. 3. Variation of laser power with discharge current and flowrate of helium

collision for relaxation of the 10^0 lower state. As a result, the addition of helium increases the laser power by a significant amount, as shown in Fig. 3. In the figure, we also find in a N_2 - CO_2 laser that the output power decreases when the discharge current exceeds 20 mA . The decreasing of the power can be attributed to the overheating of gas mixture caused by the discharge current. With the helium added, both the power and current limit will increase. As shown in the figure, it can be seen that, for relative flowrate of the gases being $6.5:3.1:1.55$, the maximum power is 1.25 watts and the current limit will increase to 38 mA .

The near resonance of the first excited vibrational level of N_2 and 00^01 level of CO_2 can be used to selectively excite the upper laser level by energy transfer from the vibrationally excited N_2 molecule. The output power of a CO_2 laser will be increased with addition of nitrogen gas. This phenomenon is shown in Fig. 4 and Fig. 5. In Fig. 4 we found in N_2 - CO_2 laser that the power increases with more addition of nitrogen gas. The drastically decreasing of the output power at high discharge current is due to the high population of 10^0 lower state in the absence of helium. In Fig. 5, the comparison of the laser power is made between He- N_2 - CO_2 laser and

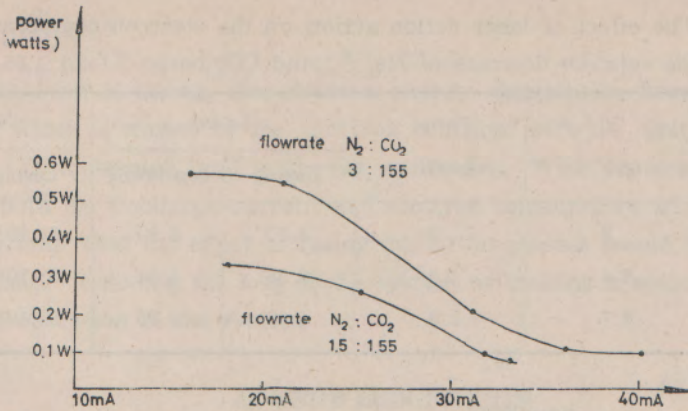


Fig. 4. Variation of N₂-CO₂ laser power with discharge current

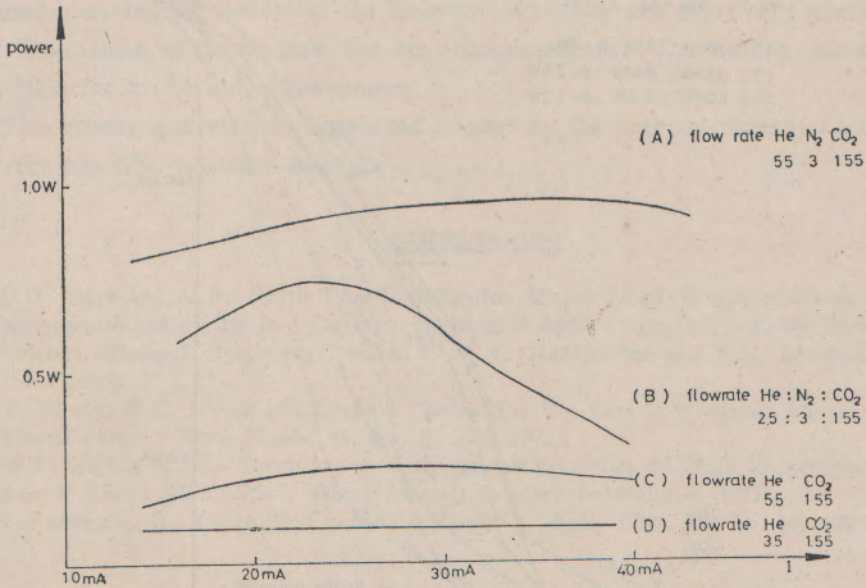


Fig. 5. Comparison of laser power of He-N₂-CO₂ laser and He-CO₂ laser

He-CO₂ laser. The effect of nitrogen is evident in this figure. By further increase of nitrogen gas, the laser power will be limited by CO₂ gas.

4. THE EFFECT OF LASER ACTION ON THE ELECTRON TEMPERATURE

The local plasma density and electron temperature are measured by Langmuir probe. A family of Langmuir probe curves was obtained at different discharge conditions with fixed relative gas flowrate. These curves have been analyzed according to the theory described in Ref. 2. and 3. and the results were tabulated in Table 1.

As discussed in Sec. II, the electrons collide more frequently with N₂, CO or CO₂ molecules when the laser action takes place. The increasing of collisional frequency will cause the decreasing of the electron temperature, since the electrons will lose part of energy during the collision. The decreasing of electron temperature is

Table 1. The effect of laser action on the electron temperature, with the relative flowrate of He, N₂ and CO₂ being 7.1:3.1:1.55

I (mA)	V (KV)	Power (watt)	Te(ev)		Ne(#/cm ⁴)	
			Lasing	non-lasing	Lasing	non-lasing
20	8	2	4.70	6.10	6×10 ¹⁰	5×10 ¹⁰
32	8.4	2.8	2.58	5.54	8×10 ¹⁰	6×10 ¹⁰
40	8.7	2.3	3.02	5.85	9×10 ¹⁰	6.6×10 ¹⁰

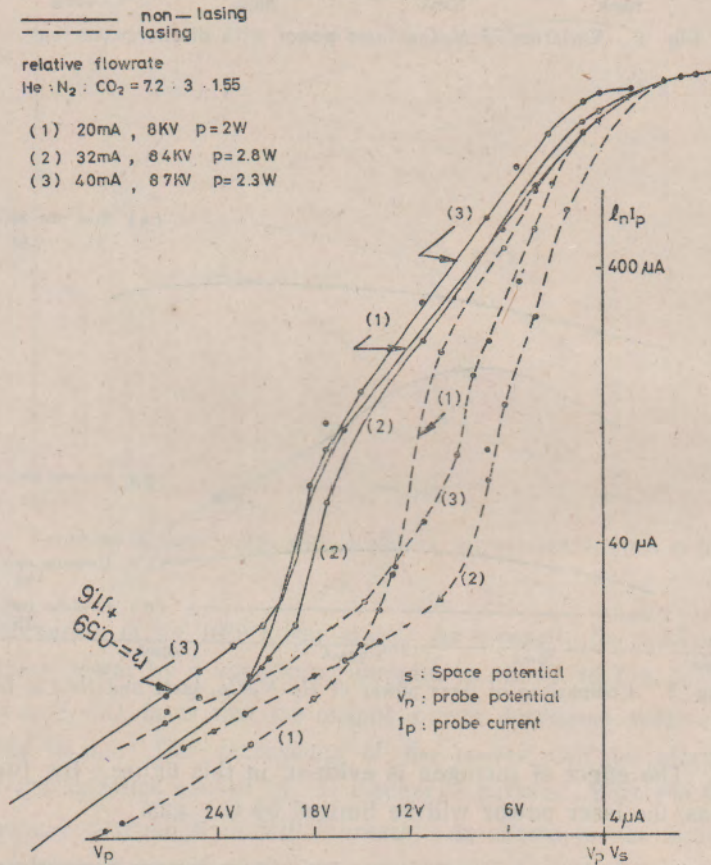


Fig 6. Semilog plot of probe current showing electron "burning" when laser is lasing

accompanied by the decreasing of discharge current. In Fig. 6 we plotted the $\ln I_e$ vs. V curves with I_e indicating the random electron current collected by the probe and V indicating the bias potential of the probe. It demonstrates the influence of laser action on the electron energy distribution in the form of a pronounced depletion of electrons. The burning of these electrons indicates that the cross section for collision of vibrationally excited nitrogen molecules with electrons is appreciable at this burning energy. The more detailed theoretical analysis in this respect is referred to Ref. [4].

5. CONCLUSION

As a CO_2 laser is lasing, the electron energy distribution becomes non-thermal equilibrium which is caused by the electron collision with the first vibrational state of N_2 and CO molecules, and with CO_2 molecules. With increasing of collisional frequency, both the discharge current and electron temperature will decrease.

It is obvious⁵ that the effect of lasing action on plasma would be reduced as the losses increase. Reducing the loss of the system or making a sealed-off laser would improve the operation of the system.

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