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Effect of Self-Absorption on the Output Power of CW CO_2 Laser

In this work, the effect of self-absorption by molecules of the active medium on the output laser power of a low-pressure CW CO_2 laser was studied. The effects of discharge current, output coupling and total gas pressure on the output laser power were discussed. It was explained that the self-absorption depends on CO_2 concentration, output coupling and discharge current and there is a threshold value for both output coupling and discharge current at which the absorption is clearly effective.

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1. Introduction

The output power of CO_2 lasers is affected by changes may occur in the optical cavity of laser system such as scattering losses, absorption at mirror edges, diffraction losses as well as absorption by gas molecules those being heated but not excited. The unexcited CO_2 molecules inside CW laser cavity have a sever negative effect on the output power [1]. This effect is attributed to the fluctuations occuring in cavity losses resulted from several reasons, the most important one is the thermal convection originated from the self-absorption of radiation by gas molecules those heated but not electrically excited inside the cavity.

The spectral linewidth relates to the value of population inversion achieved during operation throughout its dependence on gas temperature, which determines this value as follwos [2]:

$$N = N_o \exp(-\frac{\Delta E}{K_B T}) \tag{1}$$

The instability condition in losses occurs at a certain thrshold level of output laser power. This threshold is determined by the initial state of temperature variation resulted from the rapid increase in absorption coefficient of CO_2 molecules with increasing gas temperature. Above this threshold, the output laser power is decreased with increasing losses inside the cavity due to the self-absorption by heated CO_2 molecules.

The gain coefficient (α_0) of active medium at the center of transitions band producing laser as follows [3]:

$$\alpha_o = \frac{\lambda^2}{8\pi\tau_{sp}} g(\nu_o)(N_2 - \frac{g_2}{g_1} N_1) \tag{2}$$

where λ is the wavelength, τ_{sp} is spontaneous emission lifetime, N_1 and N_2 are the population in upper and lower laser levels, respectively, g_1 and g_2 are the degeneracy of each level, respectively, $g(\nu_0)$ is the normalized gain function, which is given by:

$$g(\nu_o) = \frac{1}{8\pi\Delta\nu} \tag{3}$$

where $\Delta\nu$ is the homogenous spectral linewidth (MHz) and is a function of gas pressure (p) inside cavity and gas temperature (T), and given by [4]:

$$\Delta\nu = 7.85p[X(CO_2) + 0.73X(N_2) + 0.6X(He)]\sqrt{\frac{300}{T}} \tag{4}$$

The homogenous spectral linewidth of laser beam related directly to the absorption coefficient of the active medium producing the laser wavelength. The absorption coefficient $\alpha_{\nu 0}(J)$ at the central frequency (ν_0) of the transition *P(20)* is given by [4]:

$$\alpha_{\nu_o}(J) = \frac{\lambda^2}{4\pi^2\Delta\nu\tau_{sp}} X(CO_2)(\frac{2J-1}{2J+1})(F^{(100)} - F^{(001)})N \tag{5}$$

where X is the partial amount of CO_2 in gas mixture, N is the total density of gas molecules, J is the rotational quantum number and $F^{(lmn)}$ is the partial fraction of the vibrational level (lmn) of the rotational quantum number J.

The attenuation resulted from the absorption of the band 10.6μm of CO_2 laser by the gas medium was studied by many published works [5-18]. These works included studying the dependences of the absorption coefficient of pure CO_2 gas as well as CO_2:N_2:He on the total gas pressure [5-6] and its temperature [7-12]. The absorption spectrum of the CO_2 laser gas medium is instrumentated by a homogenous function at total gas pressure of 10torr at the central (ν_0) of the band as given in Eq. (5).

The intracavity attenuation resulted from self-absorption by heated gas moleucles may affect the oscillation line as the absorption coefficient $\alpha_{v0}(J)$ – depending on the rotational quantum number J – is mainly affected by gas temperature. The value of J number, at which the maxiumum value of absorption coefficient $\alpha_{v0}(J)$ is obtained, increases with gas temperature. At temperatures over 400K, the value of $\alpha_{v0}(J)$ is given by an increasing function of rotational quantum number J for J<20. Accordingly, the absorption losses due to the self-absorption is also a function of J-number and increasing within the same range.

In this work, the effect of intracavity attenuation resulted from the self-absorption by active medium molecules on the output power of homemade low-pressure CW CO_2 laser was studied and discussed.

2. Experiment

A homemade axial-flow longiturenal-discharge low-pressure CW CO_2 laser system was used in this work [19-21]. The discharge tube made of pyrex was 60cm in length and 0.8cm in diameter. In order to isolate the ZnSe front mirror from discharge region, a connection tube same as discharge tube was used but with 10cm long. The length of optical resonator was 76cm and 90cm without and with connection tube, respectivvely. The configuration of the resonator was hemispherical with a 5m-curvature gold-coated back mirror. We used four different mirrors with different transmission (40% ZnSe, 60% ZnSe, 40% Ge, 80% Ge) as the output coupler to introduce the effect of transmission on the output power.

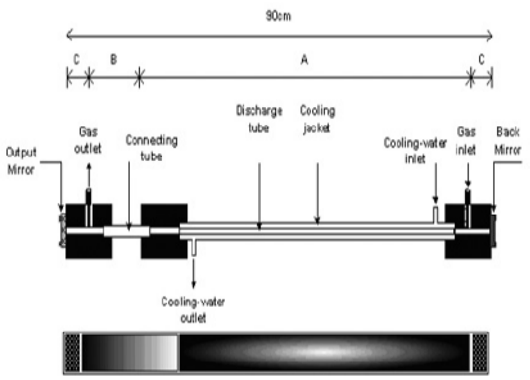

Fig. (1) Schematic diagram of the CW CO_2 laser system and the discharge regions with the intermediate connection tube

3. Results and Discussion

We consider the operation results of CW CO_2 laser system described in previous works [20-21]. They included the dependencies of output laser power on discharge current and total gas pressure inside cavity. In this work, we consider the laser system in presence of the intermediate connection tube, as shown in Fig. (1). In this case, the discharge cavity is divided into three distinct regions.

In the first region (region C), the gas is electrically excited but not cooled at both ends of the cavity. In the second region (region B), the gas is electrically excited and cooled through the gas flow along the cavity. The last one (region A) is the effective region. In region C, the self-absorption of the radiation inside cavity results in gas heating while the losses due to self-absorption in other two regions are neglegible as the gas flow rduces heating effects.

The output laser power was measured as a function of discharge current at different gas pressures inside the cavity, as shown in Fig. (2).

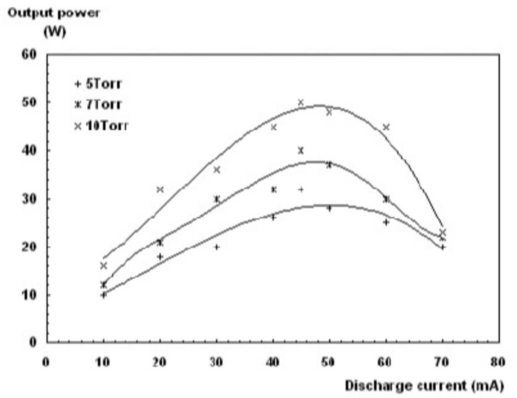

Fig. (2) Variation of output laser power with discharge current at different pressures inside laser cavity

The output power is increasing with discharge current, which represents the electrical power transferred to the gas active medium. This increasing continues to reach the maximum stability at which the maximum output laser power. The output power starts to decrease with increasing pumping power. This decrease may be attributed to the increasing heat generated from the electric discharge as the generated heat power (P_H) relates to the discharge current (I_d) by $P_H=I_d^2.R$, where R is the impedance of the gas medium.

Fig. (3) shows the variation of output laser power with the total gas pressure inside cavity at different values of discharge current. As shown, the output power increases with increasing gas pressure, which means increasing the concentration of active molecules producing laser. Due to the experimental conditions of this work, higher output power requires higher gas pressure taking into account the optimum value of discharge current, as shown in Fig. (2).

The bahavior of output power with discharge current and total gas pressure in presence of connection tube is similar to that obtained without the connection tube [20] with small difference in the optimum value of discharge current.

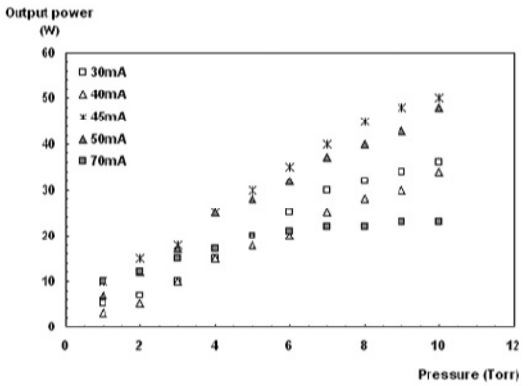

Fig. (3) Variation of output laser power with total gas pressure at different discharge currents

This similarity explains that increasing gas pressure inside cavity (or any of the three gases) leads to increase the laser output power. However, this continuous increasing – at optimum discharge current – will lead definitely to increase the spectral linewidth and hence the value of absorption coefficient (α_v) of the gaseous medium as well as decreasing the gain coefficient (α_0), according to Eq. (2) and (3). As well, reducing gas temperature leads to support the population inversion condition in the laser levels. This leads to increase the spectral linewidth and hence reducing the gain coefficient but – at the same time – reducing the absorption coefficient of the gaseous medium. As shown in Fig. (3), the optimum value of the discharge current is 45mA.

Fig. (4) shows the reasonable variation of output power with discharge current at different amounts of CO_2 in gas mixture.

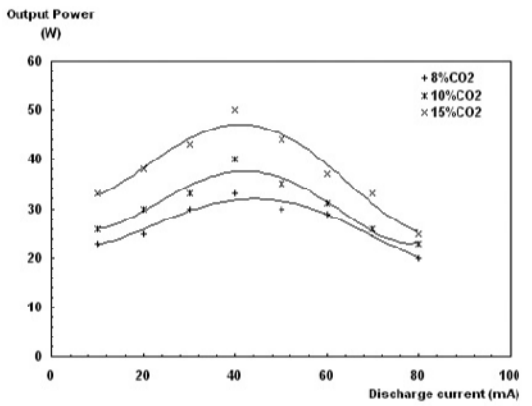

Fig. (4) Variation of output laser power with discharge current for different amounts of CO_2 pressure in the gas mixture

As the absorption coefficient of the gas mixture is proportional to the amount of CO_2, so, it can be said that the threshold condition of absorption losses, resulted from the self-absorption by active medium molecules, may be affected by the partial amount of CO_2 in gas mixture.

The output power was measured with discharge current, as shown in Fig. (5), at different values of output coupler transmission. As the output power is dependent on the transmission, then an optimum value of 60% can be determined, at which the maximum power was obtained.

Fig. (6) shows the variation of output power with total gas pressure inside cavity for two different transmission of the output coupler in two cases; using the intermediate connection tube (presence of region B) and non-using the connection tube (absence of region B).

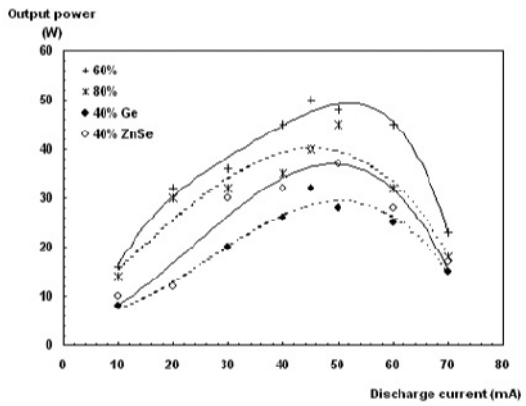

Fig. (5) Variation of output laser power with discharge current for different transmission of the output coupler at total gas pressures of 10torr

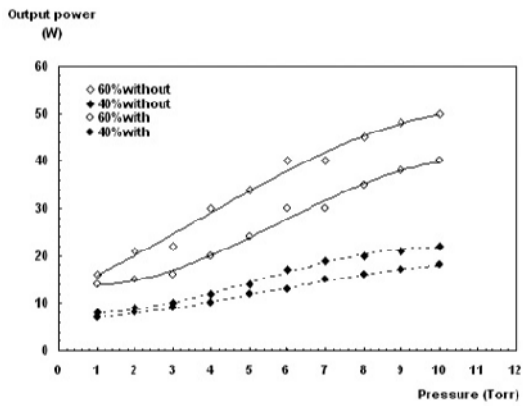

Fig. (6) Variation of output laser power with total gas pressure for two different transmission of the output coupler at the optimum discharge current in case of presence and absence of absorption losses

The presence of connection tube has an effect on output power because it creates a region inside cavity containing of gas molecules those electrically excited but not cooled because it was not surrounded by cooling water and the gas inside did not flow. In such region, the absorption coefficient (α_v) of the gas mixture is increased due to increasing gas temperature, which is originally resulted from the electric discharge. This causes an attenuation for laser radiation produced in the active region of discharge (region A) as it passes region B.

If the intracvity losses are too small, then the laser efficiency at a certain value of discharge current is dependent on gas pressure because both output power and pumping power are proportional to the gas pressure. However, all laser systems, and especially CO_2 lasers, include intracvity attenuation. Supposing intracvity losses due to attenuation resulted from the self-absorption by active medium molecules, the rate of increasing total laser efficiency is lower than the case without such losses, as shown in Fig. (7).

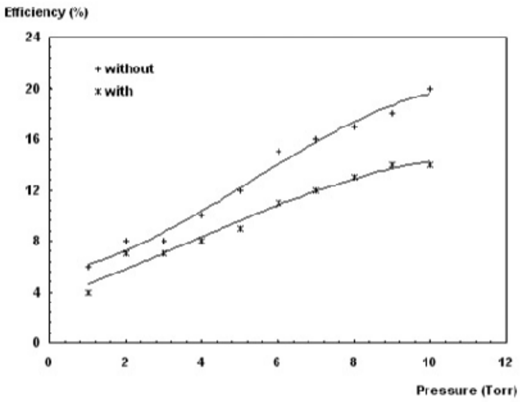

Fig. (7) Variation of total laser efficiency with total gas pressure at the optimum discharge current in case of presence and absence of absorption losses

If the gas mixture is much efficiently cooled in regions B and C throughout increasing gas flow rate or pre-cooling the gases of the mixture before feeding to the cavity, then the absorption losses can be neglected in these regions. This is attributed to the fact that the value of absorption coefficient (α_v) is too small at temperatures lower than 300K and hence the self-absorption loss can be neglected when increasing the cooling rate of gas mixture.

4. Conclusion

According to the conditions and results of this work, when the optical power absorbed by the active medium is high then the characteristics of output power are reasonably affected and the attenuation resulted from the self-absorption by active medium molecules will affect the efficiency of CW laser system. A compensation among several operation parameters, such as total gas pressure, partial amounts of gases, discharge current and output coupler transmission, is necessary to avoid the attenuation due to the self-absorption of laser radiation by the gaseous active medium itself.

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