

V. ELECTRODYNAMICS OF MEDIA*

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A. TRANSVERSELY EXCITED ATMOSPHERIC (TEA) GAIN STUDIES

1. Introduction

This report presents some preliminary experimental results that have been obtained in gain studies involving the TEA CO₂ laser. Two aspects of the gain of a TEA laser amplifier are being studied: (i) the peak gain and its dependence on the total pressure and the partial pressures of the component gases; and (ii) the temporal behavior of the gain following an excitation current pulse and its dependence on the total pressure and partial pressures of the component gases.

Peak gain measurements have been and are being made by others¹⁻⁵ with very wide ranging results – factors of 5 in population inversion.^{4, 5} The decay of the gain coefficient (which is proportional to the logarithm of the measured gain and to the population inversion) vs time following an excitation pulse should have an exponential behavior. Fluorescence studies⁶⁻⁸ indicate that the time constant of the gain coefficient decay should be linearly proportional to pressure, with the proportionality constant dependent upon the component gas ratios. This is explained by the fact that collisional de-excitation processes that are linearly dependent on pressure dominate over radiative relaxation in the relaxation of the populations.

The equations relevant to this discussion⁹ are

$$\text{Gain} = \exp(aL), \quad (1)$$

where L is the length of the amplifier, and a is the gain coefficient,

$$a = \omega_{12}^2 g_2 (N_2/g_2 - N_1/g_1) T_2 / \epsilon c \hbar. \quad (2)$$

Here, c , \hbar , and ϵ are the speed of light, Planck's constant (divided by 2π), and the dielectric constant; T_2 is the phase interruption time; N_2 and N_1 are the population

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densities of the upper and lower states; g_2 and g_1 are the degeneracies of the upper and lower states (approximately equal in this case); ω_{12} is the frequency corresponding to the energy difference between the upper and lower states; and u is the dipole moment between the upper and lower states. It is expected from consideration of the excitation and de-excitation mechanisms that N_1 reaches an equilibrium value as the gain reaches its peak and that the decay of the gain (and population inversion) is a function of the relaxation rate of the upper laser level.

The experimental arrangement for the gain measurements involves passing the attenuated output of a cw, low-pressure, stable CO_2 probe laser (attenuated to ~ 450 mW) through a 1-m, TEA amplifier containing flowing N_2 , CO_2 , and He. The cathode of the amplifier, 4.45 cm in diameter, is made up of 171 equally spaced, $1 \text{ k}\Omega$ resistors, and the anode is a brass rod. The gap space between the resistor leads of the cathode and the anode is 2.54 cm. A spark-gap trigger circuit with $0.025 \mu\text{F}$ capacitance charged to 17.5 kV is used to excite the amplifier. The attenuator insures that no saturation takes place. The intensity of the output of the amplifier, after it has passed through a filter, is monitored by using a fast rise-time (60 ns with our termination, 1 ns with a 50Ω termination), gold-doped germanium detector. The filter is necessary to block out extraneous radiation which gives misleadingly high peak gain measurements. This radiation is $4.3 \mu\text{m}$ fluorescence given off by the 00^n CO_2 energy level chain. It is detectable because the detector is approximately 200 times more sensitive to $4.3 \mu\text{m}$ than $10.6 \mu\text{m}$ radiation because the excited state of the gas in the discharge decreases radiation trapping, and because of the focusing involved in the detection scheme.

A steady-state DC intensity (within 5-10%) is established first with the amplifier tube empty and then with the amplifier at the desired operating conditions; these intensities differ typically by 5-10% because of absorption. The gain of the amplifier as a function of time following a pulsing of the amplifier is determined from the DC levels and the detector output. The equation for the gain measurement is

$$\text{Gain} = (I'_0 + i(t)) / I_0, \quad (3)$$

where I_0 and I'_0 are the DC detector current outputs with the amplifier empty and full, respectively, and $i(t)$ is the time-variant part of the current that results from the excitation of the amplifier. A labelled sketch of a typical output trace following a pulsing of the amplifier is shown in Fig. V-1. Note that Eq. 3 gives the correct absorption after the steady state is re-established. A pressure gauge (Wallace-Tiernan) and flow tubes (Matheson 602 and 603) are used to determine the total gas pressure and the partial pressures of the nitrogen, carbon dioxide, and helium component gases.

Figure V-2 shows pictures of the time-variant detector output (upper trace) and the TEA excitation current (lower trace) at a pressure of 350 Torr with a ratio of $\text{N}_2:\text{CO}_2:\text{He}$ of 1:2:12. The upper trace has a $20 \mu\text{s}/\text{cm}$ time scale, and the lower trace

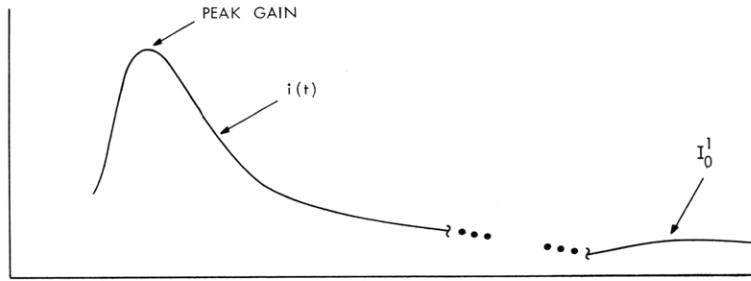


Fig. V-1. Sketch of typical detector output following amplifier excitation.

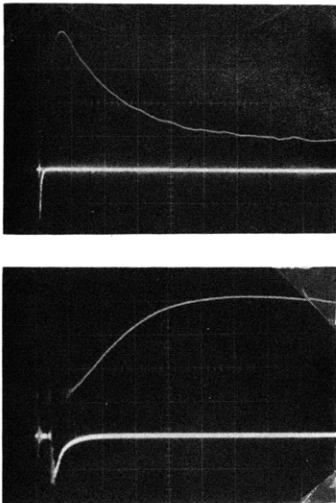


Fig. V-2.

Time-variant detector output (upper trace) and excitation current (lower trace).

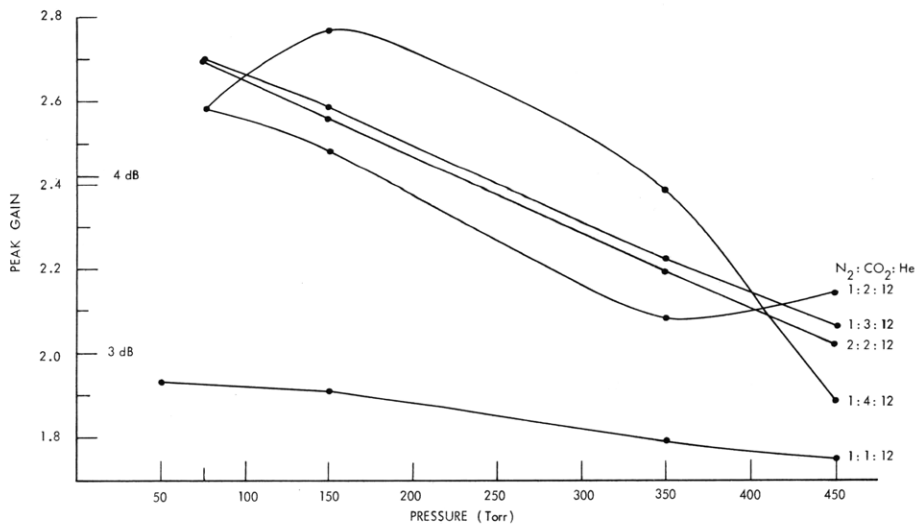


Fig. V-3. Peak gain vs pressure for various component gas partial pressure ratios.

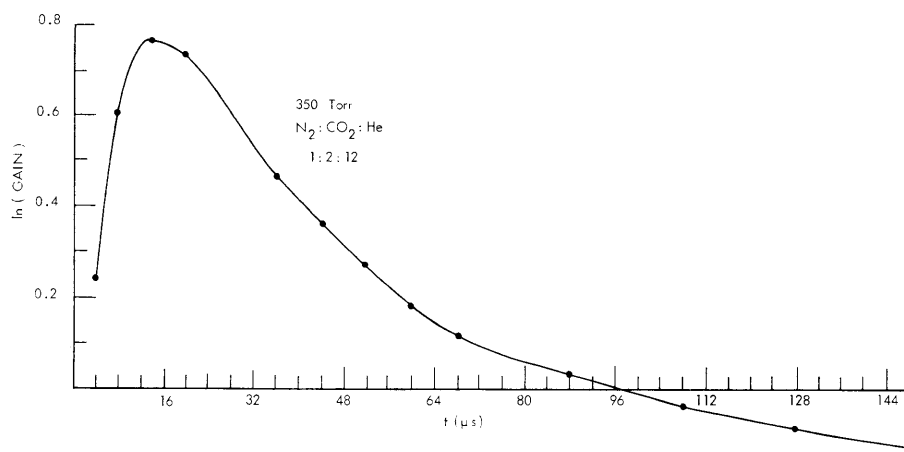


Fig. V-4. Decay of the $\ln(\text{Gain})$, (that is, aL) as a function of time.

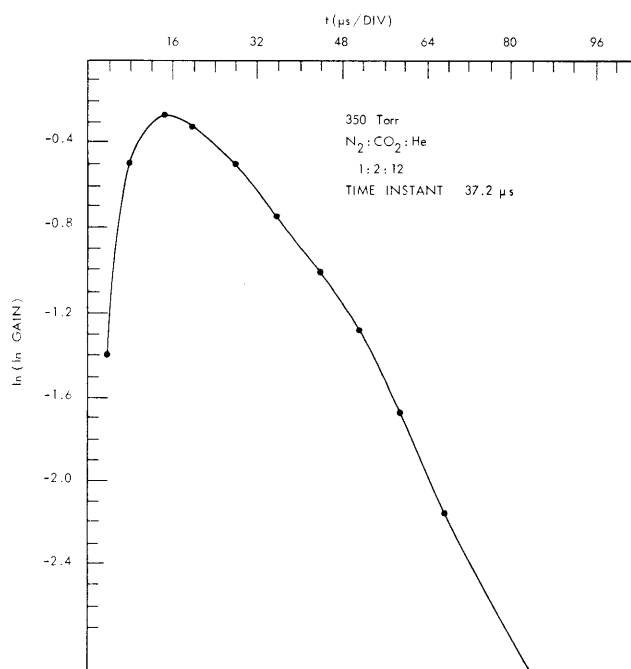


Fig. V-5. Decay of the $\ln(\ln(\text{Gain}))$, (that is, $\ln(aL)$) as a function of time.

a 2 $\mu\text{s}/\text{cm}$ scale. The peak of the discharge current is ~ 600 A (total current).

Figure V-3 is a plot of the peak gain against pressure for various gas ratios. The gas ratios also correspond to flow rates, with a basic unit (the 1 in 1:2:12, etc.) of $300 \text{ cm}^3/\text{min}$ at all pressures except 75 Torr, where the basic unit is $150 \text{ cm}^3/\text{min}$. The points plotted are the averages of the maxima and minima peak gains obtained over 6 pulses at a pulsing rate of 126 times/min. The trend, with some exceptions, is toward increased gain with lower pressures. The variation of the peak gain with pressure indicates that the population inversion is not proportional to pressure; if it were, the peak gain would be independent of pressure (see Eq. 2), as T_2 is inversely proportional to pressure for constant component gas ratios. The discharge is mainly a glow discharge with more arcing coming in with increasing pressure and with an increasing proportion of CO_2 . The excitation current pulse shortens and its peak increases with decreasing pressure.

Figure V-4 is a plot of the natural logarithm of the gain against time at 350 Torr with a 1:2:12 ratio. This curve, from Eq. 2, is proportional to the gain coefficient, α , and hence, to the population inversion. α has an approximately exponential decay as is indicated by the plot of the natural logarithm of αL ($\ln(\ln(\text{Gain}))$) in Fig. V-5. This plot yields a decay time for the upper laser state (following the gain peak) of approximately $37 \mu\text{s}$ – or a rate constant of $77 \text{ sec}^{-1}/\text{Torr}$ for the given gas ratios. This is very different from the $350 \text{ sec}^{-1}/\text{Torr}$ that has been obtained (from fluorescence measurements) by Moore, Wood, and Yardley,⁶ using pure CO_2 up to 250 Torr, but much closer to the $85 \text{ sec}^{-1}/\text{Torr}$ that they obtained using an approximate 1:50 mixture of CO_2 and He up to 470 Torr. We shall make determinations of the decay times at other operating conditions and these should be useful in understanding the roles of the component gases in the relaxation of the population of the upper laser level in the TEA laser.

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