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Runaway self-absorption in multikilowatt CO_2 lasers

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Runaway self-absorption within a CO_2 laser cavity, recently reported at high pressure, has also been observed in a low pressure (50 mbar), multikilowatt cw CO_2 laser. A numerical model of the laser discharge is used to simulate the runaway absorption and gives results consistent with experiment. Runaway absorption is readily suppressed by eliminating regions of stagnant gas within the cavity.

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In a recent paper, Hishii *et al.*[1] have described the effects of runaway self-absorption in the unexcited gas within the optical cavity of their high pressure CO_2 lasers. We initially observed similar phenomena on the prototype of our 5-kW transverse flow laser operating at a much lower pressure of 50 mbar. With increasing laser power the efficiency was observed to fall discontinuously by typically 10%. Associated with this loss in efficiency was the appearance of a faint green glow in the unexcited gas in front of the cavity mirrors and measurement of very high gas temperatures in this region ($\sim$700 °C). Reducing the laser power only recovered the original efficiency at much lower powers, indicating the presence of a latching mechanism such that once the gas was hot, abnormally high absorption was maintained at much lower intensity.

Experimentally, it was found that the threshold intensity for runaway self-absorption was reduced at higher total pressure, at higher CO_2 partial pressure, and at higher temperature, and was also strongly influenced by impurities in the laser. The problem was most severe in front of the 45° rooftop reflectors in the folded cavity, where the intensity is locally doubled. The problem was overcome by the same method used by Hishii *et al.*, that is, by avoiding regions of stagnant gas within the cavity. In our original (1976) design, the optics had been well isolated from the main gas flow. Adding baffles to increase the circulation of gas near the mirrors was sufficient to avoid this problem altogether. Subsequently, a similar design has been used on a 10-kW laser using two of the 5-kW modules and operating at substantially higher cavity intensity. No thermal runaway has been observed on this laser.

The physical processes involved in the absorption are very similar to those in the discharge region of the laser. A numerical model of the discharge based on a four-temperature model (Armandillo and Kaye[2]) has been readily adapted to simulate runaway absorption by imposing a uniform finite

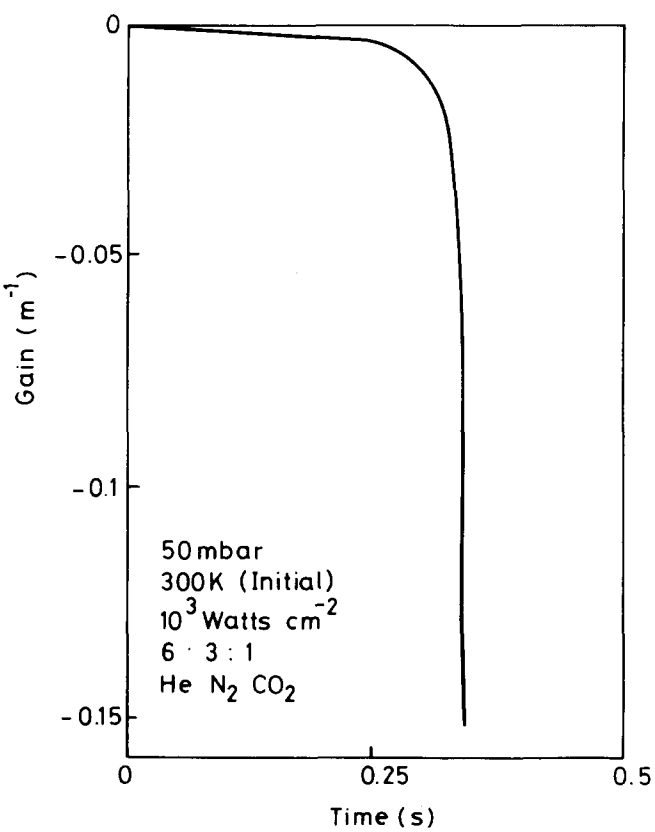

FIG. 1. Typical computed increase in absorption with time of a static CO_2 laser gas exposed to 10.6-μ radiation.

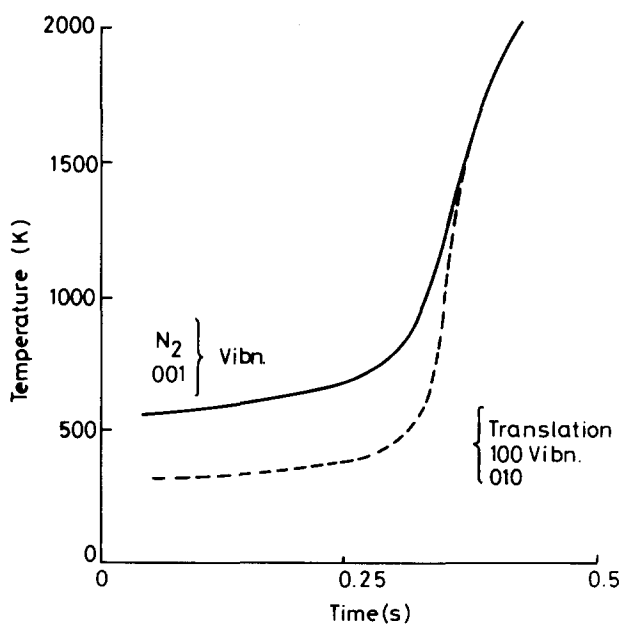

FIG. 2. Computed translational and vibrational temperatures corresponding to Fig. 1.

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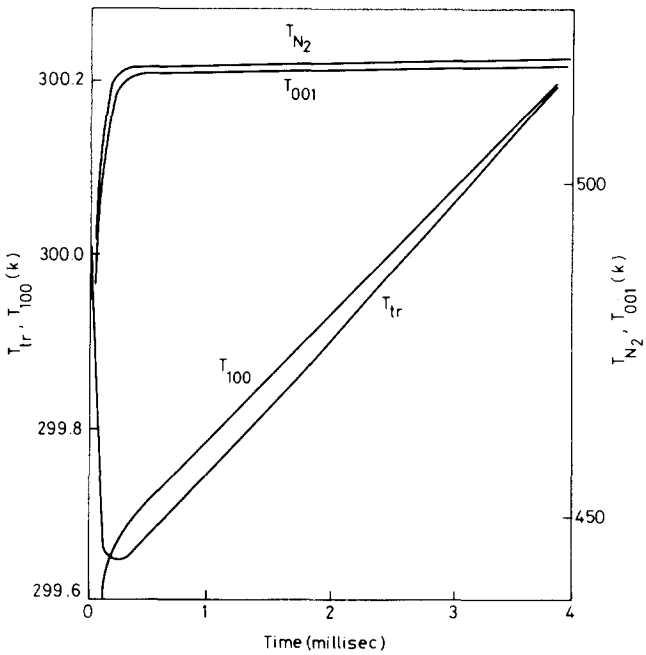

FIG. 3. Initial change in translational and vibrational temperatures corresponding to Fig. 1.

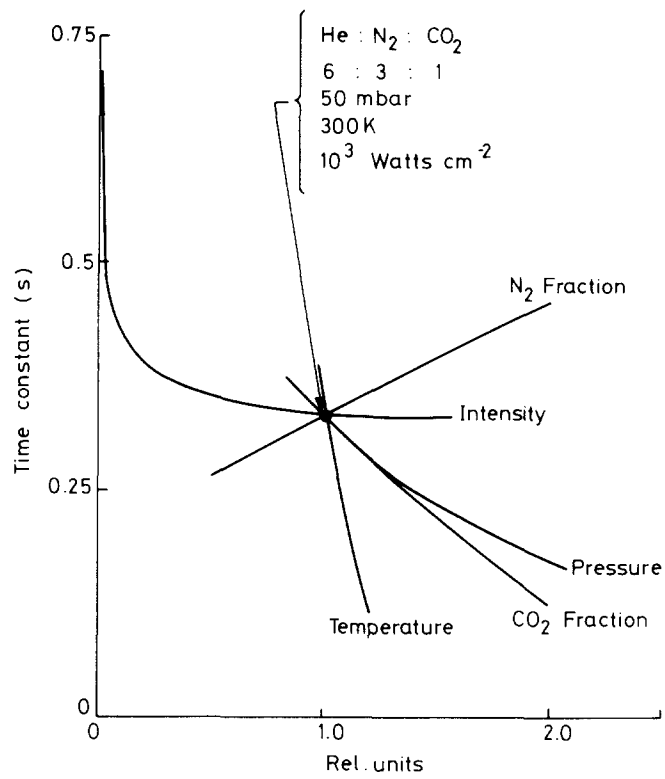

FIG. 4. Effect of changes in pressure, gas mix, temperature, and intensity on the time constant for runaway absorption under typical laser conditions.

radiation intensity whilst setting the discharge current to zero. The model thus simulates a gas flowing transversely to a uniform beam in a constant area duct. Evolution with time of a sample of gas suddenly exposed to a uniform beam is approximated by dividing distance of flow by the flow velocity; this ignores loss mechanisms such as natural convection, and also assumes a one-dimensional rather than two-dimensional expansion of the gas. A typical result is shown in Fig. 1. The gain is observed to be negative as expected and to remain small for typically a few hundred milliseconds, before decreasing sharply to values less than $-0.1\ m^{-1}$. The corresponding translational and vibrational temperatures are shown in Fig. 2, where a similar sharp increase in temperature is observed. The model will not accurately simulate conditions at longer times as new processes become important at the very high temperatures produced.

The change in temperature at the start of the absorption is shown in Fig. 3. It is seen that the upper vibrational level heats very rapidly ($\sim 100\,\mu s$), whilst the lower level is cooled over this time scale. The translational temperature is in turn slightly reduced for a few hundred microseconds. This phenomenon of kinetic cooling has been recognized previously (Smith[3]) and is of importance in thermal blooming of pulsed laser beams.

The scaling of the time constant for thermal runaway (taken as the time to reach $0.1\ m^{-1}$ absorption) obtained from this model is shown in Fig. 4 for modest changes in operating conditions about the normal running conditions. It is clear that increasing the gas temperature reduces the time constant particularly strongly as expected. Increasing the CO_2 partial presure and the total pressure is also deleterious. On the other hand, it is clear that the absorption is effectively saturated above about 500 W cm^{-2}, which is typical of the laser cavity. Absorbing impurities will reduce the time constant through the consequent increase in gas temperature. Impurities may also increase the absorption saturation intensity with deleterious effects at high cavity intensities.

The time constant for the onset of thermal runaway under conditions typical of our laser is 0.3 s. A flow velocity of typically $1\ ms^{-1}$ across the 50-mm-diam beam is therefore sufficient to suppress this phenomenon. This is very small compared to the flow velocity in the main discharge.

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[2]E. Armandillo and A. S. Kaye. J. Phys. D **13**, 321 (1980).
[3]D. C. Smith. Proc. IEEE **65**, 1679 (1977).