1. Introduction

The thermally excited gas dynamic laser is a device in which the population inversion required for laser action is produced by a rapid, flow-induced change of state of the laser medium. If the upper and lower energy levels of the laser transition relax towards equilibrium at sufficiently different rates, a population inversion can be formed in the nonequilibrium region of the flow, as suggested by Basov and Oraevskii (ref. 1) in 1963. In principle, either a sudden compression through a shock wave or a sudden expansion through a supersonic nozzle can be used to produce the required sudden change of state. The supersonic expansion arrangement (ref. 2) has several advantages, including the production of a low translational and rotational temperature, advantageous in molecular lasers, and also the ability to "freeze" nonequilibrium populations as a result of rapidly falling temperature and density. Shock wave lasers have also been considered (ref. 3). However, the present review will deal only with expansion-type gas dynamic lasers.

The first successful demonstration of high power gas dynamic lasers to be reported was described by Gerry (ref. 4) in 1970. Gerry's lasers were supplied with a mixture of CO_2 and N_2 with a small amount of H_2O, at a high temperature ($\sim 1400^{o}K$) and pressure ($\sim$ 17 atm). The gas mixture, which was provided either by a shock tube or from a combustion chamber, was supplied in thermodynamic equilibrium, and a part of its thermal energy was converted into optical power, so the lasers were thermally excited. When the hot gas was expanded through an array of small supersonic nozzles, the nitrogen vibrational energy froze with the N_2 ($v = 1$)

level overpopulated. The CO_2 (ν_3) mode, coupled closely to this, overpopulated also. On the other hand the CO_2 (ν_1) and CO_2 (ν_2) levels, aided by the H_2O, were able to relax more quickly towards equilibrium, and so their excited levels fell in response to the falling translational temperature. A population inversion was formed before the gas entered the laser cavity. Figure 1 shows typical conditions.

Many other experimental studies of the CO_2-N_2 gas dynamic laser have since been reported (e.g. refs. 5, 6). Other gases have also been studied. For example, population inversions in rapidly expanding CO-A and CO-N_2-A mixtures have been predicted by McKenzie (ref. 7) and others, and Watt (ref. 8) has achieved laser oscillation in a thermally pumped, CO-A gas dynamic laser. Rich et al (ref. 9) have used a combination of gas dynamic expansion and electrical excitation in the plenum chamber ahead of the nozzle to create a population inversion in a CO-H_e mixture. These CO gas dynamic lasers are different from the CO_2-N_2 devices in one important respect, namely, that vibration-to-vibration energy exchange tends to pump vibrational energy to highly excited levels, where molecular anharmonicity effects become important. On the other hand, the performance of the CO_2-N_2 gas dynamic laser may be modelled (ref. 10) in terms of the lowest energy levels which may be regarded as harmonic oscillators.

This brief review of vibrational nonequilibrium effects relevant to gas dynamic laser performance continues (Section 2) with an order of magnitude analysis of maximum possible power output. Section 3 gives the general equations of vibrational energy transfer in a quasi-

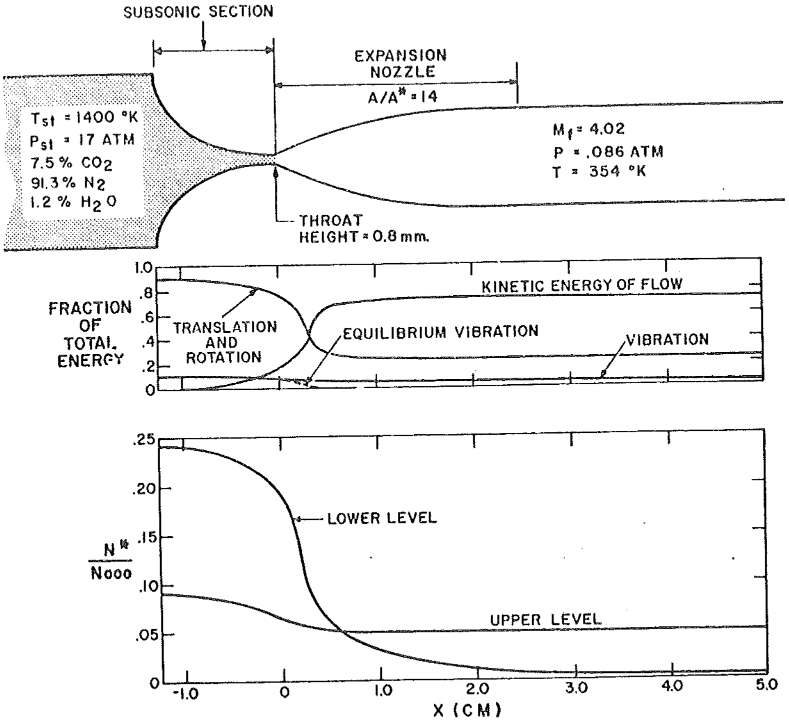

Figure 1 Typical conditions in CO_2-N_2 gas dynamic laser (ref. 4)