# POSSIBILITY OF PRODUCING TUNABLE INFRARED GAS LASERS

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1. At the present time, the problem of high-power tunable IR lasers has become particularly vital in connection with work done on stimulation of chemical reactions by laser radiation [1], the possible use of lasers in molecular spectroscopy or molecular biology, etc. However, there are practically no tunable IR lasers having the required characteristics; for example, the tunable pulsed semiconductor lasers operating in this band have a low output power (several dozen watts). IR gas lasers using molecular gases have high efficiency (up to 40%) and power ($\sim 10^3$ W in the continuous regime and $\sim 10^6$ W pulsed), and for this reason are attractive for applications in chemistry, biology, and spectroscopy. We propose here a method of constructing a high-power CO laser that can be tuned smoothly in a wide frequency band (on the order of the generation frequency). The method is based on the possibility of exciting vibrational-rotational transitions of an anharmonic molecule at pressures that are sufficiently high ($\sim 10$ atm) for smooth tuning of the generation frequency between rotational-vibrational molecular bands that overlap as a result of shock broadening. Technical realization of the proposed method became feasible as a result of the development of gas lasers with combined excitation [2], in which the working-gas pressure can amount to several dozen atmospheres.

2. A feature of active laser media with anharmonic molecules is that the molecule energy distribution differs noticeably from a Boltzmann distribution. It turns out that the anharmonicity of the oscillations is a favorable factor for obtaining negative temperatures at the upper vibrational levels [3]: the laser emits in a number of vibrational bands, as many as 15, for example, in a CO laser [4]. Anharmonicity causes the frequencies of the transitions to differ from each other, and the generation spectrum is therefore discrete at low gas pressures. However, when the levels are broadened by the amount of the anharmonicity energy $\Delta E$ of the molecule, the emission spectrum should become continuous. Moreover, it turns out that to obtain a continuous spectrum it suffices to broaden the levels by an amount on the order of the rotational constant of the molecule, which is much smaller than the anharmonicity energy $\Delta E$ of the molecule.

3. The emission or absorption spectrum of an anharmonic oscillator consists of a series of lines separated, for example in the Morse-oscillator model, by a frequency interval [5]

$$\Delta\omega = \omega_{1,0}\frac{\hbar\omega_{1,0}}{2D}, \qquad (1)$$

where $\omega_{1,0}$ is the frequency of the $1 \to 0$ transition and D is the molecule dissociation energy.

At a quantum energy $\hbar\omega_{1,0} = 0.2$ eV and a dissociation energy $D = 10$ eV (a case close to that of the CO molecule) we have $\Delta E = \hbar\Delta\omega = 2 \times 10^{-3}$ eV. Each vibrational energy level is accompanied by a spectrum of rotational levels excited in the frequency interval $\Delta\Omega = kT/\hbar$, where T is the translational temperature of the gas. As $T \simeq 100°K$, the width of the absorption spectrum of the $n + 1 \to n$ transition becomes of the order of $\sqrt{BkT/\hbar} \simeq 4 \times 10^{-3}$ eV. Thus,

the spectra of the neighboring vibrational transitions overlap and in order for the entire radiation spectrum of the anharmonic molecule to become continuous it suffices to broaden the energy levels by an amount on the order of the rotational constant B. For a CO laser, for example, $B \approx 4 \times 10^{-4}$ eV, and consequently a braodening of the CO molecule transitions to a value $10^{11}$ Hz already suffices to produce a continuous frequency emission or absorption line. A typical value of the shock broadening of the transition in the molecular gases amounts to $\sim 10^7$ Hz/Torr. In this case the required gas pressure is $p \approx 10 - 15$ atm. The emission line of a molecule with thus-braodened transitions is inhomogeneous with a width on the order of the frequency $\omega_{1,0}$ of the main transition. A characteristic feature is the high rate of migration of the excitations over the spectrum of the line. Indeed, at $p \approx 10$ atm the time of migration between vibrational levels, due to the vibrational-vibrational relaxation, is of the order of $10^{-8} - 10^{-9}$ sec. An even shorter time ($\sim 10^{-10}$ sec) corresponds to the rotational-relaxation processes (see, e.g., [6]). These are favorable circumstances for the extraction of energy from the entire spectrum of the inhomogeneously-broadened line.

In combined excitation the attained inversion of the working-level populations is exceedingly high for gas lasers. This is the consequence of an increase, proportional to the square of the pressure, of the excitation density of the working levels, whereas the rate of the quenching processes increases with pressure linearly [2]. This makes it possible to obtain generation on much higher vibrational transitions (compared with the ordinary gas-discharge lasers). Indeed, according to [4], the effective vibrational temperature $\Theta_{n+1}$ between the levels $n + 1$ and $n$ (which do not lie close to the dissociation energy of the molecule) is given by

$$k\Theta_{n+1} = -(\hbar\omega_{1,0} - 2n\Delta E) \Big/ \left(\frac{2n\Delta E}{kT} - \frac{\hbar\omega_{1,0}}{k\Theta_1}\right). \qquad (2)$$

The condition $\Theta_{n+1} = \infty$ determines the limiting (lower) inverted level $n_{lim}$; for $n_{lim}$ we get from (2) $n_{lim} = \hbar\omega_{1,0}T/2\Delta E\Theta_1$. With increasing pump, $\Theta_1$ increases and $n_{lim}$ decreases. With increasing $\Theta_1$, in addition, the temperature between the already inverted levels increases in absolute magnitude, which is equivalent to involvement of higher transitions in the generation. Thus, an increase of the excitation power increases the number of transitions participating in the generation, and as a result the range of smooth tuning of gas lasers with combined excitations, using anharmonic molecules, can amount to $\sim 20 - 30\%$ of the central radiation frequency.


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