EFFECTS OF IGNITION ON GAIN IN AN INVERTED N₂O FLOW

Yu. I. Grin', Yu. B. Konev,
S. I. Kryuchkov, N. N. Kudryavtsev,
I. N. Oraevskii, V. G. Testov,
and A. N. Khmelevskii

Studies on N₂O GDL with thermal pumping have shown that the same population inversion can be realized at temperatures lower than those for CO₂ mixtures [1, 2]; however, raising the temperature, which increases the vibrational energy, is restricted by reactions that tend to reduce the concentration of the working species, which occurs at temperatures lower than those for CO₂ GDL. Therefore, improving the characteristics of an N₂O laser requires research on the reaction kinetics in relation to the composition and temperature.

The species used as vibrational-energy reservoir (N₂ or CO) determines what substantially different paths the reactions of N₂O may take, as do uncontrolled impurities (H₂ and H₂O). The initiation temperatures also differ considerably. We have examined the effects of composition changes in N₂O + N₂ + He, N₂O + CO + He mixtures on the gain, as well as the cross effects of N₂O and CO₂ on the population inversions. We used the compositions given in Table 1.

The following elementary stages were considered to determine the composition changes in N₂O + N₂ + He mixtures:

1. \[ \text{N}_2\text{O} + \text{M} \rightleftharpoons \text{N}_2 + \text{O} + \text{M}, \]
2. \[ \text{N}_2\text{O} + \text{O} \rightleftharpoons \text{N}_2 + \text{O}_2, \]
3. \[ \text{N}_2\text{O} + \text{O} \rightleftharpoons 2\text{NO}, \]
4. \[ \text{M} + \text{O} + \text{NO} \rightleftharpoons \text{NO}_2 + \text{M}, \]
5. \[ \text{O} + \text{NO}_2 \rightleftharpoons \text{NO} + \text{O}_2. \]

Composition and temperature calculations showed that there is virtually no decomposition of N₂O for \( T_0 = 1300^\circ \text{K} \), but when \( T_0 \) is increased to 1400°K, N₂O begins to dissociate within \( 2\times10^{-3} \) sec, and within \( 3\times10^{-3} \) sec, the N₂O concentration has decreased by an order of magnitude. At \( T_0 = 1600^\circ \text{K} \), the same occurs in \( 3.75\times10^{-6} \) sec (Fig. 1).

The temperature rises when reactions occur, and three characteristic stages can be distinguished (Fig. 1):

TABLE 1

<table>
<thead>
<tr>
<th>Mixture</th>
<th>N₂O</th>
<th>N₂</th>
<th>CO₂</th>
<th>CO</th>
<th>He</th>
<th>H₂</th>
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<tr>
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<td>—</td>
<td>0.7</td>
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<td>0.048</td>
<td>0.667</td>
</tr>
<tr>
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<td>0.095</td>
<td>0.19</td>
<td>—</td>
<td>—</td>
<td>0.048</td>
<td>0.667</td>
</tr>
<tr>
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<td>—</td>
<td>0.2</td>
<td>0.2</td>
<td>—</td>
<td>0.7</td>
</tr>
<tr>
<td>4</td>
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<td>0.1</td>
<td>—</td>
<td>—</td>
<td>0.1</td>
<td>0.7</td>
</tr>
<tr>
<td>5</td>
<td>0.15</td>
<td>0.15</td>
<td>—</td>
<td>—</td>
<td>0.075</td>
<td>—</td>
</tr>
<tr>
<td>6</td>
<td>0.075</td>
<td>0.15</td>
<td>—</td>
<td>—</td>
<td>0.075</td>
<td>—</td>
</tr>
<tr>
<td>7</td>
<td>0.1</td>
<td>0.2</td>
<td>—</td>
<td>0.7</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>8</td>
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</tr>
</tbody>
</table>

1) times $0-t_1$, the ignition delay, where the temperature rise is $\Delta T = 2RT^2/E_a$ (activation energy $E_a = 58$ kcal/mole);

2) stage $t_1-t_2$ characterizes the time when the mixture ignites; and

3) combustion occurs at $t > t_2$.

The ignition stage has the maximum rate of temperature rise; Fig. 2 shows calculations on the ignition delay $\tau_1$ (curve 1 in Fig. 2) and the dissociation delay $\tau_d$ (curve 2).

Calculations on jet flows with allowance for chemical kinetics show that the vibrational temperatures $T_3$ and $T_4$ increase, while the gain passes through a maximum. For example, with the stagnation parameters $T_0 = 1400^\circ$K and $p_0 = 0.81$ MPa, the fall in the gain sets in after $2 \times 10^{-3}$ sec, but when that temperature is raised to $1500^\circ$K ($p_0 = 0.91$ MPa), the fall sets in much earlier ($5 \times 10^{-4}$ sec), although $T_3$ and $T_4$ continue to increase in the region of falling gain.

The ignition and dissociation were examined from measurements ahead of the nozzle and after the end of it (Fig. 3).

Before the critical section, at $1.0 \times 10^{-2}$ m from the end of the shock tube, we measured the absorption for a probe N₂O laser beam, the pressure, and the spontaneous emission at 4.5 μm (00°-1-00° transition in the N₂O molecule) with a filter transmission band of 0.26 μm. We also recorded the pressure change at the end. Beyond the end of the nozzle, the N₂O concentration was monitored from the change in gain for the probe laser.

Parts b-d of Fig. 4 illustrate the changes in absorption and spontaneous emission (Fig. 4e and f) in relation to the SW intensity. The pressure recordings (Fig. 4a, e, and f) showed that there is a characteristic step H in the pressure, which increases with the SW intensity, in the interval between the arrival of the reflected SW front O and of the compression wave C arising by interaction of the reflected wave with the contact surface. A similar pressure reduction has been found in air [3, 4]. The pressure change is not reflected in the absorption (Fig. 4b, where the reference signal from the probe laser is given). As the stagnation parameters increase, the duration of the absorption signal decreases (Fig. 4c and d). With $u_1 = 1.6 \times 10^3$ m/sec ($T_0 = 1580^\circ$K), there is a range where the absorption is