Improved Operation of N₂O TE Lasers

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Abstract—The operation of a transversely excited N₂O laser is improved by the addition of H₂ or CO to the discharge. The improvement is due to the effective nullification of the dissociative electron attachment reaction with N₂O.

The flowing-gas CW CO₂ laser can be easily converted to operation on N₂O wavelengths [1] by the simple replacement of CO₂ by N₂O in the gas flow. Since the CW discharge is controlled by diffusion losses to the walls in the low-pressure gas mixture, the increased attachment rate due to N₂O is not a serious problem for discharge stability. For optimum CW N₂O laser operation, the output coupling should be decreased and the flow rate increased in order to compensate for the lower gain and higher dissociation rate of N₂O [2]. Reference [2] also notes that the output power can be nearly doubled by the addition of CO to an optimized mixture of N₂O, N₂, and He. Low-pressure (~5 Torr) pulsed longitudinal discharge N₂O lasers have also been demonstrated [3, 4].

High-pressure (~300 Torr) transverse excitation of an N₂O laser was demonstrated by Wood et al. [5] and by Gilbert et al. [6] using resistively ballasted pin discharges. The output power in Wood’s device was only one sixteenth that obtained with CO₂ at 760 Torr. An electron-beam-sustained discharge has been used [7] to obtain N₂O lasing at 5 atm total pressure. In this case, N₂ was replaced with CO in order to obtain greater energy input (higher discharge current), while the efficiency remained unchanged.

Although operation of a transversely excited CO₂ laser using two solid electrodes was first reported in 1971 [8], the first report of operation of such a device with N₂O did not appear until 1979 [9]. In this work, a capacitor was used in parallel across the discharge electrodes, which had the effect of decreasing the current pulse duration from 150 to 25 ns. With this arrangement, an output energy of 65 mJ (1.66 J/l. atm) was obtained from a N₂O:He:N₂:3:20:10 mixture at 250 Torr with an efficiency of ~0.31 percent. Comparable results in the same device without the parallel capacitor with a CO₂:He:N₂:1:8:1 mixture at 1 atm were an output energy of 3 J (25.2 J/l. atm) with an efficiency of ~13 percent. The only other reference found in a literature search for the use of N₂O in a TE laser was a report by Smith et al. [10] that addition of N₂O to a TEA CO₂ laser encouraged the transition to arcing because of higher electron attachment rates.

The TE laser used in our experiments consisted of a pair of solid copper electrodes with approximate Rogowski profile and a discharge volume of ~2 x 2 x 100 cm³. The energy storage capacitor of 100 nF was connected to the electrodes through a triggered spark gap by ten pairs of insulated wires with a total circuit inductance of ~125 nH. The UV preionization was provided by a sliding-spark board on one side of the electrodes, which could be fired 0–20 µs before the main discharge. Typically, the delay used was 1–2 µs. The stored energy for the flash board was ~1 J. With a CO₂:He:N₂ mixture of 0.14:0.50:0.36 mole fraction at 160 Torr, this device has produced ~5 J/l. atm with an energy input of ~275
J/l · atm for an efficiency of ~1.8 percent. Discharge arcing was not a problem over a wide range of mixtures, pressures, energy loadings, and time delays between preionization and main discharge. The ~10 μs FWHM laser pulse started ~5 μs after the ~0.3 μs FWHM discharge current pulse. The discharge repetition frequency was ~1 Hz, and the gas flow rate was ~15 std l/min corresponding to ~3 changes/min.

When the N₂O mixture used in [9] was tried in this device, discharge arcing became a persistent problem and no lasing was observed. Upon varying the gas mixture, pressure, and charge voltage, only weak lasing (~2 mJ) was obtained under a limited range of conditions near 150 torr and with very low N₂O concentration, although discharge arcing persisted. Discharge arcs were observed visually and by means of oscillatory behavior of the discharge current. The presence of N₂O caused the discharge to change from being recombination controlled and stable to an unstable attachment-dominated condition because the dissociative attachment cross sections for N₂O are 1–2 orders of magnitude larger than for CO₂ for the range of electron energies expected in the discharge [11].

Warman et al. [12] reported in their study of electron attachment to nitrous oxide that the dissociative electron attachment reaction

\[ e^- + N_2O \rightarrow N_2 + O^+ \]

can be nullified by the addition of H₂ or CO by means of the reactions

\[ O^- + H_2 \rightarrow H_2O + e^- \]

or

\[ 0^+ + CO \rightarrow CO_2 + e^- \]

They also noted that “If a sufficient amount of either of these gases is added to the system the O⁻ ions will be rapidly converted into electrons. That part of the total attachment rate constant which corresponds to the formation of O⁻ ions will then be effectively reduced to zero.”

Indeed, when H₂ was added to the N₂O laser mixture, discharge arcs dramatically disappeared, and a laser output energy of 50 mJ was readily obtained. Under these same conditions, the Nz was replaced with CO and the laser energy decreased to 35 mJ, indicating that CO is less effective than N₂ in pumping the N₂O upper laser level. However, when the H₂ was removed from the flow, stable glow discharges were obtained using CO and the laser energy increased to 40 mJ. Thus, either H₂ or CO can be used to stabilize the N₂O TE laser discharge. These results are consistent with those of Deutsch [13], who found that the addition of H₂ to a CO₂ TEA laser suppressed the formation of bright arcs.

In optimizing the N₂O/He/N₂/H₂ gas laser mixture, we found that the laser output energy increased as the H₂ concentration was decreased to a point at which discharge arcs appeared, and the laser output was greatly reduced. Replacement of H₂ by CO required a much greater concentration of CO to eliminate arcing, and the laser energy was reduced.

Since the N₂O laser operated better with less H₂ to the limit of arcing, we added a capacitor in parallel with the discharge electrodes in the manner of Rothen and Rosenwaks [9]. A parallel capacitor effectively eliminates the inductance of the switch, storage capacitor, and connecting wires, so that the glow discharge can take place in a shorter time, and thus allow less time for an arc to develop. The parallel capacitor consisted of 16 ceramic capacitors (total capacity 15 nF) connected with copper sheet along the length of the electrodes in a low-inductance configuration. Unfortunately, we did not have provision to measure the resulting discharge current pulse shape. The effect of the parallel capacitor was that the H₂ concentration could be reduced to ~one half its previous value without arcing, and the laser energy was increased by ~10 percent.

After optimizing the gas mixture, pressure, and output coupling, the highest laser energy obtained was 0.42 J at 260 torr (4.8 J/l · atm) at an energy loading of 266 J/l · atm for an efficiency of ~1.8 percent [14]. At a lower energy loading of 166 J/l · atm, the output energy was 0.3 J (3.9 J/l · atm) for an efficiency of ~2.4 percent. The laser pulse started ~2 μs after the discharge current initiation, and after an initial ~0.4 μs spike, lasted for ~10 μs FWHM. The optimum gas mixture was N₂O:He:N₂:CO₂:0.03:0.69:0.27:0.01 mole fraction, and the optimum output mirror transmission was ~20 percent. Higher output energy could be obtained from this device by more efficient use of the available discharge aperture and by increasing the energy input at some sacrifice of efficiency.

We have shown that N₂O TE laser operation is made possible and improved by the addition of H₂ or CO. The improvement is due to the effective nullification of the electron attachment reaction with N₂O, and the resulting stabilization of the glow discharge.

References

Abstract—Perturbation theory is used in order to calculate the effective-index distribution in dielectric waveguides that exhibit slow lateral variations. As an example, the method is employed to find the optical modes in diode lasers with lateral spatial variations in thickness. Very good agreement with experiment is obtained for the case of GaAlAs double heterostructure lasers with a crescent-shaped waveguide.

The analysis of dielectric waveguides, in which the guided modes are confined in both transverse and lateral directions (perpendicular to the direction of propagation), is important for the design of diode lasers as well as for integrated optics applications. In many diode laser structures, which exhibit such two-dimensional waveguiding, the waveguide parameters vary continuously and slowly in the lateral direction, parallel to the p-n junction plane. Examples of such structures are gain-guided lasers [1] and diode lasers with lateral variations in layer thicknesses [2]. One technique that is desirable, however, to have an explicit relation between the effective-index distribution and the variations in the waveguide parameters. Such a relation was found for the case of double heterostructure (DH) diode lasers in which the refractive indexes vary laterally, but the thickness of the active region remains uniform [7]. In the present work, we use perturbation theory in order to obtain a general (approximate) expression for the effective index distribution in a dielectric waveguide with slowly varying parameters. This expression is then employed in the analysis of waveguiding in DH diode lasers with lateral thickness variations.

Consider the two-dimensional dielectric waveguide described in Fig. 1. The boundaries of the different dielectric regions that are indicated by the solid lines in this figure vary slowly with y. For definiteness, we refer here to the case of the region waveguide, although the method described below can be readily extended to include any desired number of layers. The waveguide in Fig. 1 is characterized by its refractive-index distribution \( n(x,y) \). It is also assumed that the lateral y-direction variation of \( n(x,y) \) is small compared to its variation in the transverse x-direction. In the following we will assume TE modes only.

The electric field \( E_y \) approximately satisfies the wave equation

\[
\nabla^2 E_y(x,y,z) + \frac{k_0^2 n^2(x,y)}{\epsilon} E_y(x,y,z) = 0
\]

where \( k_0 = 2\pi/\lambda_0 \) is the free space wavenumber. The slow variation in y enables us to solve for the two-dimensional optical modes by using the effective index method [3], [7]. The electric field is written in the form

\[
E_y(x,y,z) = F(x,y) \exp(i\beta z)
\]

where \( F(x,y) \) is assumed to be slowly varying in y and \( \beta \) is the modal propagation constant. According to the effective index method, the first step is to solve for a given value of y

\[
\frac{\partial^2 F}{\partial x^2} + \left[k_0^2 n^2(x,y) - \beta^2 \right] F = 0
\]

and then to use \( \beta(x,y) = k_0 n_{\text{eff}}(y) \) to obtain \( G(y) \) and \( \beta \) from

\[
\frac{d^2 G}{dy^2} + \left[k_0^2 n_{\text{eff}}^2(y) - \beta^2 \right] G = 0.
\]

Obviously, the function \( n_{\text{eff}}(y) \) can be obtained by solving (3) repeatedly for each value of y [4]–[6]. However, taking advantage of the slow variation of \( n(x,y) \) with y, it is possible to relate \( n_{\text{eff}}(y) \) to \( n_{\text{eff}}(y) \) by using perturbation theory. The resulting function \( n_{\text{eff}}(y) \) closely approximates the actual effective index distribution within a wide lateral range, due to the above-mentioned slow variations. In order to obtain the