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Preionization Effects of iso-C_4H_{10} in N_2 TE UV Lasers

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Abstract. In this paper the ionizing role of isobutane (iso-C_4H_{10}) in the operation of a N_2TE UV laser is analyzed. Laser pulse width value modifications, different laser wavelengths generated in the 2^+ system and voltage pulse period modifications are analysed in order to show that isobutane, in very reduced quantities, generates a preionizing effect that can be higher than that produced by a conventional wire preionization system.

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Stimulated emission in gases, under pulsed excitation, has preionization as a fundamental problem. The more efficient the preionization process is, the shorter is the excitation pulse rise-time, giving as a result reduced laser pulse width values. This phenomenon results to be of crucial importance in the case of self-terminating laser systems.

Several methods have already been used to produce ionization in gas laser systems, like pin arrangement [1], dc [2] or pulsed [3] preionization wire devices, corona blade electrodes [4], UV light [5], radioactive sources [6, 7], etc. All of these methods have been carefully analysed and satisfy the need of preionization.

A different way to modify plasma characteristics is to add some other element to the gas to be excited. In the particular case of lasers operating in the UV spectral region, specifically N_2 lasers, additives like He [8, 9], Ar [12], O_2 [13, 15], SF_6 [14–19], NF_3 [1], etc, have already been tested. To summarize, He makes the discharge more uniform by reducing arc formation, Ar is important only in the case of N_2 lasers excited by electron beams and O_2 does not generate significant changes in laser characteristics. The more important effects have been obtained by using SF_6 and NF_3. Both act in the same way, NF_3 having some advantages due to the fact that it does not produce sulphur deposition in the discharge tube.

Nevertheless, it is necessary to mention that, even if SF_6 and NF_3 improve N_2 laser behavior by increasing the peak power output and disminishing laser pulse-width values, their exact role in the laser plasma is still partially unknown.

To conclude, it can be said that the commonest preionizing systems are those specified in [1–4] because, even taken into account their possible complexities from the construction point of view, they are not dangerous to human health, such as radioactive sources [6, 7], they do not contaminate the discharge tube as reported in [14–19], avoid the use of complicated [14–20] or expensive gases [8, 9], etc. It clearly comes up that a simple additive able to replace the electrical preionizing methods, is still not available and would be very useful.

In the present work the addition of isobutane (iso-C_4H_{10}) in a N_2 TE laser discharge tube and the corresponding modifications in the stimulated emission characteristic properties are analysed when the laser operates without any electrical preionizing device. Laser pulse width modifications of vibrational (0–0) band (337.1 nm) transition and the number of detected 2^+ system laser bands are studied together with corresponding voltage pulse period behavior. All parameters have been analysed and compared with those obtained when the laser operates without preionization and only with N_2, and when it operates with N_2 together with a conventional preionization wire setup.

1 Experimental

The laser has a TE configuration, being its corresponding excitation circuit shown in Fig. 1. The charging capacitor (C) has 2.9 nF, the transmission line (C′) was 2.4 nF and the coupling inductance (L) 10 μH. The discharge tube has 60 cm length and an internal diameter of 15 mm. Electrodes were made of Cu, with cylindrical profile of 5 mm diameter. The interelectrode distance d was held constant during all measurements at 5 mm. In Fig. 1 the circuit is shown with a wire preionization device. When iso-C_4H_{10} was added to N_2 in the laser discharge tube, this part of the circuit was disconnected and the laser operated with no electrical preionization.

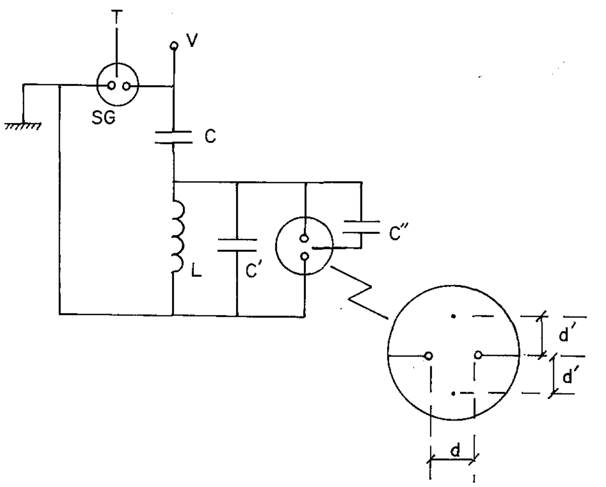

Fig. 1. Excitation circuit: C (charging capacitor) = 2.9 nF; C′ (transmission line) = 2.4 nF; L (inductance) = 10 µH; *d* (interelectrode distance) = 5 mm; *d′* (preionization wire to center of the discharge tube distance) = 6 mm; C″ (preionizing capacitor) = 1.0, 0.5, 0.25, 0.1, or 0.05 nF; V (charging voltage) = 15 kV; SG = spark-gap; T = Trigger pulse

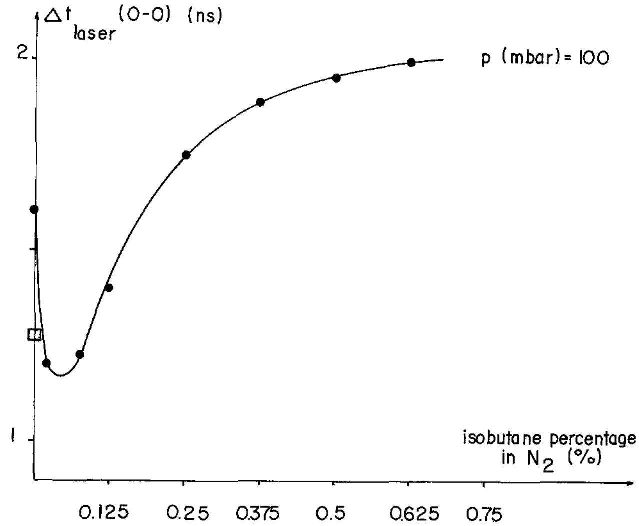

Fig. 2. Laser pulse width behavior of the (0–0) vibrational laser band transition ($\Delta t_{\mathrm{laser}}$ 0–0) at 100 mbar gas pressure condition, as a function of iso-C_4H_{10} percentage in N_2. For comparison purposes, □ corresponds to the case of the laser working in the nitrogen gas flux + wire preionization system case, at the same gas pressure

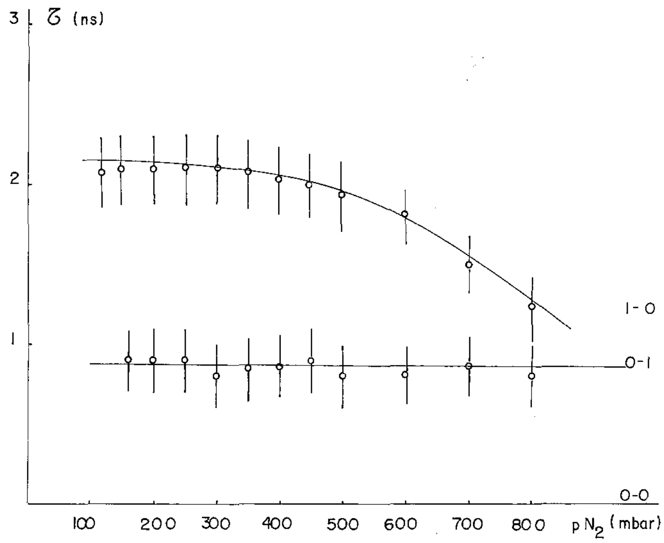

Fig. 3. Temporal interval (τ) between the detection of the (0–0) vibrational laser band at 337.1 nm and other vibrational laser bands belonging to the 2^+ system as a function of the gas pressure. Results were obtained with the help of a wire preionizing system and with only N_2 in the discharge tube

Preionization wires, when used, were located in a plane perpendicular to that determined by discharge electrodes. Wires were made of stainless steel, having 0.3 mm diameter and were located at 6 mm from the center of the discharge tube. As a preionizing capacitor (C″), with 1.0, 0.5, 0.25 and 0.05 nF were tested. The charging voltage (V) was kept constant at 15 kV and the laser operated with commercial grade nitrogen.

An ITL 1850 (100 ps rise-time) vacuum photodiode together with a Tektronix 7104 (350 ps rise-time) oscilloscope were used to analyse laser radiation. Voltage pulses were detected with a Tektronix P6015 voltage probe. When necessary, a Q24 Jenoptik Jena GmbH quartz prism spectrograph was used to analyse laser wavelengths.

2 Results and Discussion

As it has been mentioned before, there is no report of a gas which could replace a preionizing circuit in N_2 lasers. Even if any gas having a ionization potential value lower than 16 eV would be useful, the additional restrictions of avoiding both discharge tube contamination and the absorption in the laser wavelength region, strongly reduce possibilties. A second important quality would be connected with simplicity of operation and low cost.

In the present case iso-C_4H_{10} has been choosen as an additive in N_2 lasers operating in the 2^+ system. This gas has an ionization potential value of 10.57 eV (66% of the N_2 ionization potential), it is reasonably low priced and easily available. All this should be added to the fact that mixing small quantities of iso-C_4H_{10} to N_2 in TE lasers, the laser peak power increases by a factor of 2.5 and no significant changes with respect to laser peak power output and discharge tube are observed after a 120 h operation period.

Pulse width behavior corresponding to the (0–0) vibrational laser band at 337.1 nm was analysed under three different working conditions keeping the total gas pressure constant at 100 mbar. At first, the laser operated without wire preionization system with N_2, secondly, with N_2 and preionization wire and finally with N_2 and iso-C_4H_{10} in different concentrations without preionization wire. Figure 2 presents corresponding results, being necessary to point out two remarkable results. The first one is that the temporal pulse width changes as a function of iso-C_4H_{10} concentration in the gas mixture, and the second is that the minimum of the curve corresponds to a $\Delta t_{\mathrm{laser}}$ of the (0–0) vibrational laser band value which is lower than that obtained in "normal" conditions, i.e., with the laser working with a preionizing wire device and having only N_2 as a gas.

Another important point in connection with the preionization mechanism is the generation of different 2^+ vibrational

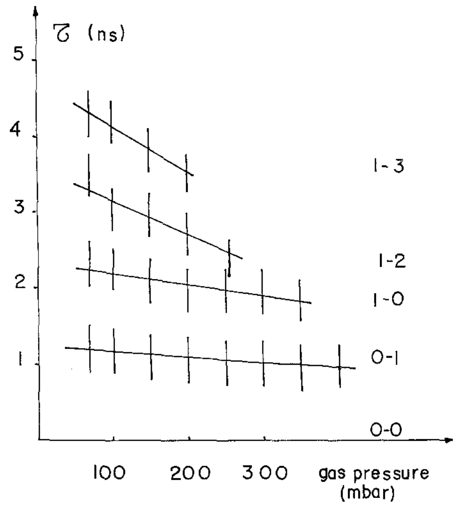

Fig. 4. The same as Fig. 3 for 0.025% of iso-C_4H_{10} in the N_2 gas mixture and without preionization system. The (1–2) vibrational laser band at 353.2 nm and (1–3) vibrational laser band at 375.5 nm are now detected together with the (0–0) at 337.1 nm, (0–1) at 357.7 nm and (1–0) at 315.9 nm laser bands

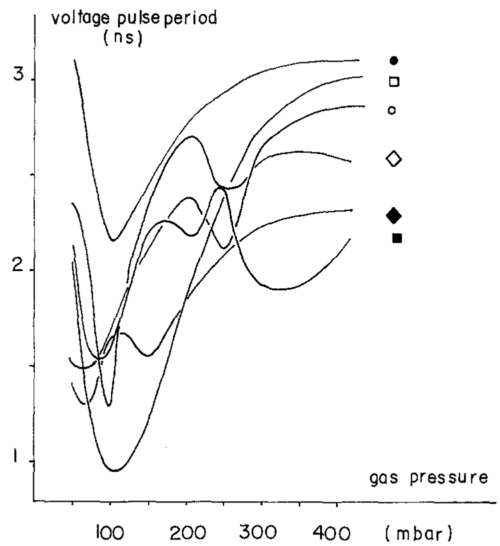

Fig. 5. Excitation voltage pulse period behavior as a function of gas pressure for different iso-C_4H_{10} in N_2 percentages (%). The laser operates without preionization system. • = corresponds to N_2 alone. All others correspond to different iso-C_4H_{10} + N_2 mixtures (□ = 0.025%; ○ = 0.05%; ■ = 0.075%; ♦ = 0.125% and ◇ = 0.375%)

laser bands, that has also been observed. Figures 3, 4 present a summary of the results. The horizontal axis represents the detection of the highest gain vibrational laser band (0–0). The vertical axis (τ) gives the temporal delay between the detection of other vibrational laser bands and the (0–0). The results in Fig. 3 have been reported recently [20], corroborating that the (0–0) at 337.1 nm, the (0–1) at 357.7 nm and the (1–0) at 315.9 nm vibrational laser bands are the most commonly detected ones when exciting the N_2 2^+ system. Results have been obtained with the laser in the N_2 plus preionization wire device operating condition.

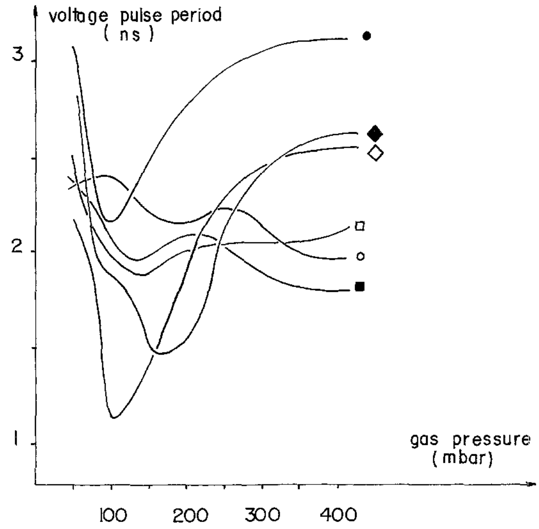

Fig. 6. The same as Fig. 5 for the laser operating with N_2 alone and with a wire preionization system. • ⇒ $C'' = 0$ nF. Other symbols correspond to: ◇ ⇒ $C'' = 0.05$ nF; ♦⇒ $C'' = 0.1$ nF; ■⇒ $C'' = 0.25$ nF; □ ⇒ $C'' = 0.5$ nF; and ○ ⇒ $C'' = 1.0$ nF

Results presented in Fig. 4 were obtained using 0.025% of iso-C_4H_{10} in N_2, which corresponds to the minimum Δt_{laser} detected value.

In other words, the laser operates in optimized conditions. In this case, other laser vibrational laser bands [(1–2) at 353.2 nm and (1–3) at 375.5 nm], are also detected. In the N_2 case particularly, the generation of a high number of vibrational laser bands means a better and a more efficient excitation process generated by a shorter excitation pulse period. This is only possible due to the isobutane presence in the discharge tube.

Both facts we have presented that is, the pulse width reduction of the vibrational (0–0) laser band and the higher number of the 2^+ system vibrational laser bands observed, strongly suggests that a better ionization mechanism has been introduced into the laser emission generation process resulting in shorter excitation pulse period. Then, to analyse excitation conditions, the voltage pulse behavior as a function of gas pressure has been investigated for different iso-C_4H_{10} concentrations in N_2, as shown in Fig. 5.

Again, as in the analysis of the laser pulse width, significant changes can be observed. As an example, it can be pointed out that 0.025% of iso-C_4H_{10} in N_2 gives the minimum voltage pulse period at a 100 mbar gas-mixture pressure. Compared to Fig. 2, this situation corresponds to the minimum observed pulse width of the (0–0) laser band. This coincidence corresponds to the well-known shorter rise-time → lower laser pulse width relation. In the better observed iso-C_4H_{10} plus N_2 relation, the (0–0) vibrational laser band temporal pulse width is reduced by 19%. As an additional comment, it is useful to remember that the way the voltage pulse period behaves in pulsed gas lasers has already been reported [21, 22] and has been attributed to the way C'' modifies plasma capacitance and inductance.

Then, all the modifications in the N_2 laser characteristics iso-C_4H_{10} is generating, clearly demonstrate the existence of an ionization mechanism different from that produced by wire devices.

In order to clarify the statement, it would be very important to obtain the same kind of voltage pulse period behavior presented in Fig. 5 by using only a conventional preionization wire system and without iso-C_4H_{10} in the discharge tube. If that were possible, the ionization capability of iso-C_4H_{10} in N_2 lasers would be strongly reinforced.

To search this, the excitation voltage pulse period has been analysed when the laser operates with a preionization wire setup and with N_2 only. Figure 6 shows the corresponding results. In this case, as explained in [21] and [22], C'' acts as a parameter. Clearly, Figs. 5, 6 show a rather similar functional behavior proving that iso-C_4H_{10} modifies the gas impedance value probably due to its lower ionization potential compared to N_2.

3 Conclusion

The way stimulated emission characteristics in a N_2 TE laser change when isobutane is added to nitrogen is reported. It is shown that the ionizing effects this gas generates is of the same order or higher than that produced by conventional wire preionization system. This result opens up a promising field in pulsed gas lasers in the case where conventional electrical preionizing systems are difficult to operate. The proposed additive is simple, low cost and easily available.

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