Preionization Effects of iso-C$_4$H$_{10}$ in N$_2$ TE UV Lasers

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Abstract. In this paper the ionizing role of isobutane (iso-C$_4$H$_{10}$) in the operation of a N$_2$TE UV laser is analyzed. Laser pulse width value modifications, different laser wavelengths generated in the 2$^+$ system and voltage pulse period modifications are analyzed 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 analyzed 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 diminishing 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$_4$H$_{10}$) in a N$_2$ TE laser discharge tube and the corresponding modifications in the stimulated emission characteristic properties are analyzed 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 analyzed 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$_4$H$_{10}$ 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.
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 possibilities. A second important quality would be connected with simplicity of operation and low cost.

In the present case iso-C$_4$H$_{10}$ has been chosen 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$_4$H$_{10}$ 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$_4$H$_{10}$ 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$_4$H$_{10}$ concentration in the gas mixture, and the second is that the minimum of the curve corresponds to a $\Delta t_{\text{laser}}$ 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