



Study of Geometrical-Dependence of Glow Discharge on Gain Coefficient in a TE-N₂ Laser

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Abstract: Based on a set of experiments, using a transversely excited (TE) oscillator-amplifier N₂-laser system (OSC-AMP) with the AMP effective length of 31cm, measurements have been carried out for small signal gain, g_0 , and saturation energy density, E_s , for different AMP gap separations. It was found that the gain-value depends on the AMP electrode gap separation, d_{AMP} and thereby the corresponding gain coefficient dependency on the E/p , T_e , and pd values are introduced. This experiment shows that in addition to laser excitation length dependency of the gain coefficient, the electrode gap-separation is also an important factor for determining the gain-value, where in the present system it is maximized for $pd_{AMP} \sim 55$ Torr.cm. In addition, it was found that, regardless of the type of lasers, and their geometrical configurations, the measured E_s -parameter is linearly related to the output energy density, E_0 .

Keywords: N₂-Lasers, Gain and Saturation Energy Measurements

1-Introduction

The N₂-laser is an efficient UV light source which produces short pulse and high peak power in the $C^3\Pi_u \rightarrow B^3\Pi_g$ transition at 337.1 nm. This laser has been introduced in longitudinally excited (LE) and transversely excited (TE) schemes. So far, many attempts have been made to improve the operational performances of the laser in both modes of operation by applying varieties of laser designs and configurations, and also by introducing various types of preionizers [1-10]. On the other hand, the laser parameters (small signal gain, g_0 , and saturation energy density, E_s) of the active medium have been considered to be the main parameters characterizing the operational performances of the laser. The g_0 -parameter for a number of laser designs and configurations have been measured by different researchers, either by the use of a single oscillator or by applying a laser system consists of an oscillator and an amplifier (OSC-AMP), where in the latter case the laser beam from the oscillator (probe beam) is injected into the amplifier after an optical path of suitable length to achieve the optimum amplification. The results of some g_0 -measurements for both TE and LE laser types have been tabulated in our previous publication with no further considerations [11]. Based on our previous measurements for TE amplifiers of 31-[12, 13]

and 94 cm [14] in length, along with other reported g_0 -values, obtained from different laser designs, deduced from table 1 of reference [11], we realized that g_0 -values in TE lasers for active lengths of ~30 to 94cm are following a characteristic curve showing that length of laser channel is a dominant parameter in governing the g_0 -parameter, and consequently a strong dependence of the output power on the length of laser channel was realized [12, 13]. So far no further information has been reported for excitation lengths of <30cm. In the present work, it is shown that for an AMP with a fixed excitation length of 31 cm, the gain parameter depends also on the AMP gap separation, and consequently the laser gain dependency on the corresponding E/p -value, or the electron temperature, T_e , has been determined.

Furthermore, based on our present measurements with a TE N₂-laser, and our previously reported E_s -value for the LE laser, along with other published data appeared in the literature, we found that the E_s -parameter in both TE and LE lasers are linearly related to the output energy density, and the corresponding E_s -values which lie in the lower output energy density portion of the proposed function belong to the E_s -values of the longitudinally excited N₂-lasers, and that proves the reason for the lower output energy that is expected to be obtained in LE-N₂ lasers.

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In this paper the main concept has been oriented to introduce the fact that g_0 -parameter in TE N₂-lasers not only depends on the length of laser channel, but also depends on the electrode gap separation, d_{AMP} , where the electrodes separation is also playing an important role on the E/p-value, or the laser operational electron temperature, provided that the laser is operated in an optimized condition of the N₂ gas-pressure. This observation is clearly indicating that regardless of the input voltage, the geometrical configuration of a N₂-laser device, including the length of laser channel, and the electrode gap separation, determine the gain value, and consequently the operational electron temperature.

2-Experimental arrangement

The schematic diagram of the OSC-AMP Blumlein excitation circuit, used for the gain measurements is given in references [12, 13]. Briefly, the 93×44cm² commercial printed circuit board is a double-sided copper with a thickness of 1.5mm fiberglass insulation. The board has been cut to produce two excitation circuits of 34×24cm² for the OSC, and 50×44cm² for the AMP sections. Copper strips of 24 and 85mm are removed from the sides and the front section of the printed board to prevent arcing. Also, 23-and 30-mm strips of copper are removed from central parts of the OSC, and AMP sections to serve as corona sources, and to produce three capacitors of 3.45, 2.75 and 0.63 nF each. These areas serve as corona sources. The AMP in the TE-TE configuration has an effective length of 31cm, and the electrode spacing can be varied up to 11mm. The AMP is operating with the surface-corona discharge as a preionizer with the main electrodes clamped at a height of 35mm above the surface discharge. The excitation length of the OSC is 19cm and the electrode gap separation has been fixed at 5mm.

Throughout the experiment with this system the pulse repetition rate was kept constant at 10Hz. The input voltage was kept at 14kV. A fast detection system consisting of a vacuum photodiode (ITL, Model TF 1850) with an oscilloscope (Model 7904 Tektronix, with 7A19 plug in unit) was used for the pulse detection. Also, for the power measurement a disk calorimeter (Scientech, Model 360001) and a calibrated photodiode were used. Several

calibrated neutral density filters were applied for varying the power of the probe beam entering into the AMP.

3- Experimental results

The results of the output-input energy densities (E_0 and E_i) measurements for two different AMPs with the length of 31cm in the present work, and 94cm, reproduced from our previously published paper [14], for two different AMP gap separations of 7 mm, and 15mm, respectively, are shown in fig.1(a). The length of laser channels and the operational conditions in each experiment are indicated in this figure. These two experimental results, which correspond to two different AMP excitation lengths and electrode gap separations, are clearly showing that the output energy density changes by the change of the electrode gap separation and also by the change of the AMP excitation length. The solid lines in this figure correspond to the theoretical simplified model introduced by Frantz and Nodvik [15], where the model has been applied to gas lasers when the pulse duration of the incident beam is shorter than the upper state life time of the molecule. Each point in the figure is determined by averaging over at least 20 laser shots, and the g_0 and E_s -values were determined by the method of least-squares fit of the experimental points to the proposed function [11], using a 4.15 MB nonlinear fitting program (Origin, Version 5). Fig.1(b) shows the measured gain value, G , expressed in dB, i.e., $10\log(E_0/E_i)$, versus the logarithm of the input energy density E_i for the same data points presented in Fig.1(a). A clear distinction between the corresponding gain profiles deduced from two different laser configurations is evident from this figure. By varying the AMP electrode gap separation, it was found that the measured gain-value is also dependent on the separation between the AMP electrodes; and it was found that by increasing the gap separation, the gain coefficient drops to lower values. The results of our measurement for a TE laser with the length of 31cm, along with two other previously published works, corresponding to the AMPs of 31 and 94cm in length, and the gap separations of 0.7 and 1.5cm, respectively [13,14], as well as the published results of Serafetinides et al [16] are given in Fig.2 As it is indicated in this figure

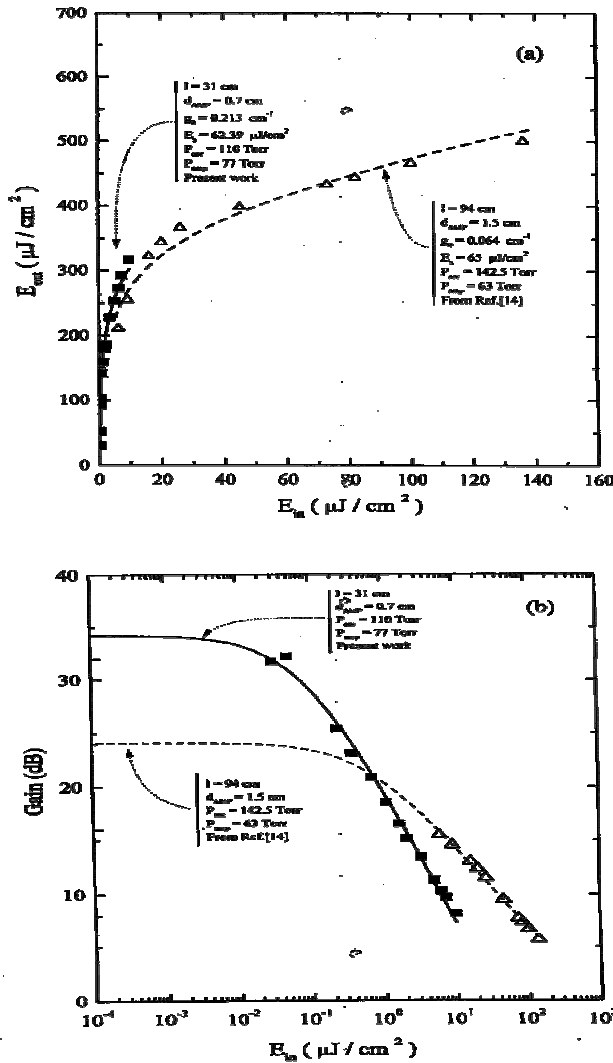


Fig.1(a) Plots of the output-input energy density in TE amplifiers with the excitation lengths of 31cm for the present work (■), and 94cm obtained from our previous report [14] (Δ). (b) Gain in dB (i.e. $10 \log E_o/E_i$) vs log of the input energy density. Data points are the same as in Fig.1(a). Input voltage in both systems is 14kV.

the gain coefficient drops linearly as the AMP gap separation increases. It is interesting to observe that although the experimental data correspond to different laser configurations (d_{AMP} , l) as well as, different operational N_2 gas pressure (p), a linear relation exists between g_0 and the corresponding gap separation, d_{AMP} . The geometrical laser designs, including d_{AMP} , and the length of laser electrodes, l , along with the operational gas pressures for each experiment are indicated in the parentheses.

Figs. 3 and 4 show, respectively, the profiles of the g_0 -parameter, with respect to the E/p_{AMP} -value (where E is the electric discharge field, and p_{AMP} is the AMP gas pressure) and the

corresponding electron gas temperature, where they are related by the following equation [17],

$$kT_e(\text{eV}) = 0.11(E/p_{AMP})^{0.8}. \quad (1)$$

$E = V_0/d_{AMP}$, is the static discharge electric field, and V_0 is the input voltage. In Fig. 5. a plot of g_0 versus the pd_{AMP} -value is introduced. Again, in this figure the data corresponding to our previous work [13, 14], along with the work of Godard [18] are introduced. $l_m = 15$ cm in the Godard's work is referring to the length of laser channel where the gain measurement was carried out, while l is referring to the laser

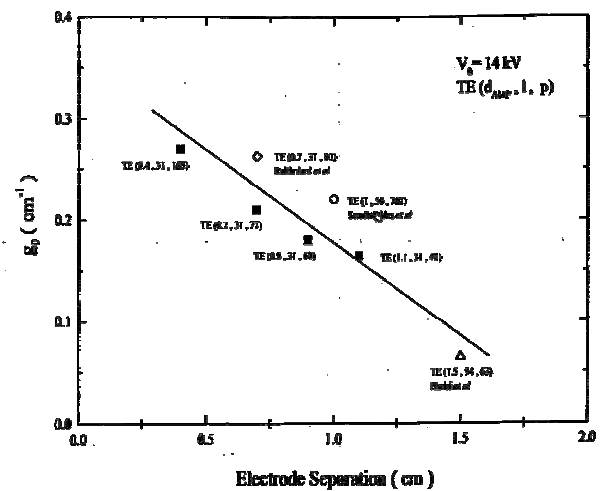


Fig 2. Measured values of g_0 -parameter versus the electrode gap separation, d_{AMP} . The gain measurements correspond to Hariri et al [14] (Δ), Rahminian et al [13] (◇); Serafetinides et al [16] (○), and the present work (■).

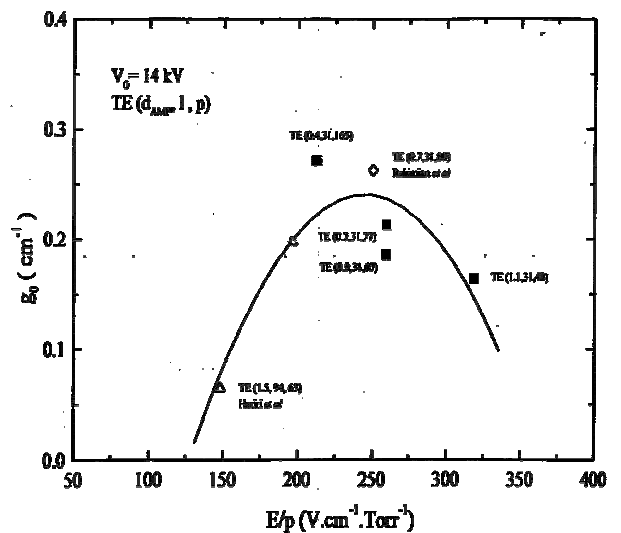


Fig 3. The measured g_0 -value vs E/p . The measurements correspond to Hariri et al [14] (Δ), Rahminian et al [13] (◇), and the present work (■).

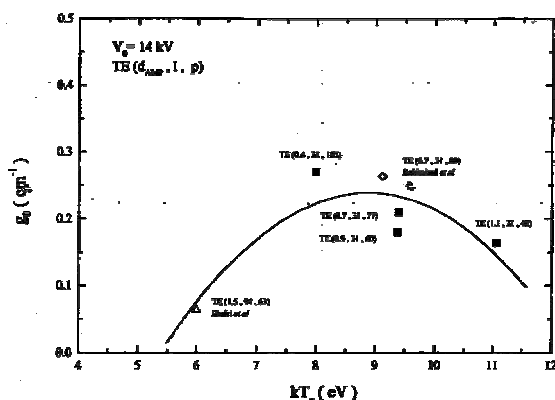


Fig 4- The measured g_0 -value vs electron temperature, T_e . The data points are the same as in Fig 3.

channel length. The profile which is introduced in Fig.5. seems to be applicable for intermediate gas pressures and the maximum gain value occurs at the pd_{AMP} -value of ~ 55 Torr.cm. Finally, the plot of E_s -value with respect to the output energy density, E_0 is shown in Fig.6. In this figure, we have also introduced our measured E_s -values for LE- N_2 -laser [11]. The numbers on each experimental point are referring to the AMP gap separation (or tube diameters for the LE type of N_2 -laser), the AMP excitation length, l , and the laser optimized gas pressure, p . This figure shows clearly that regardless of the type of N_2 -laser, E_s and E_0 are linearly correlated, and the E_s values corresponding to LE N_2 -lasers lie in the lower part of (E_s , E_0) profile. This observation proves the reason for the lower output energy that can be extracted from longitudinally excited self-termination N_2 lasers.

4-Conclusion

In this work, we have show that in a laser system consists of an oscillator (OSC) and amplifier (AMP), where the light beam from the OSC is used as a probe beam; the gain coefficient, g_0 , gets lower values when the AMP gap separation increases. The profiles corresponding to the g_0 -behaviour have been introduced, and consequently the g_0 - E/p , g_0 - T_e or g_0 - pd curves have been determined. This observation is indicating that the geometrical configuration of the glow discharge, including the length of laser channel (l), as introduced in our previous work, as well as the space between two electrodes (d_{AMP}) are playing important roles on operational performances of

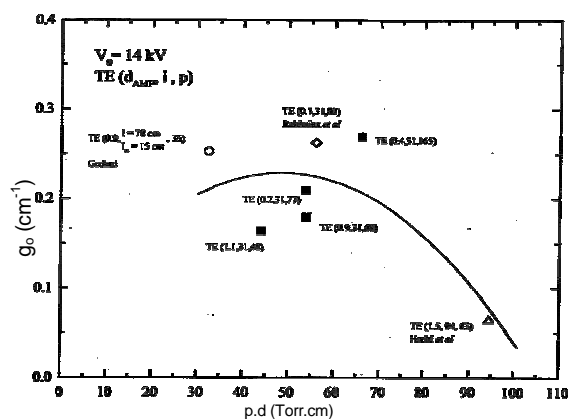


Fig 5- The measured g_0 -value vs pd_{AMP} . The data points correspond to Hariri *et al* [14] (Δ), Rahimian *et al* [13] (\diamond), Godard [18] (\circ), and the present work (\blacksquare). In the Godard's work the length of laser channel for the gain measurement was $l_m=15$ cm. The maximum value of g_0 occurs at ~ 55 Torr.cm.

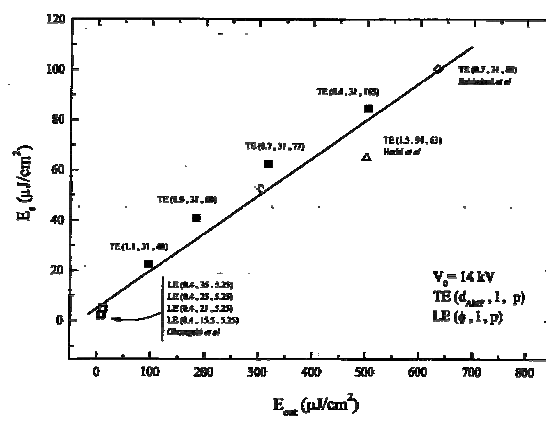


Fig 6- The measured E_s -value with respect to the output energy density: The measurements correspond to Hariri *et al* [14] (Δ), Rahimian *et al* [13] (\diamond), Ghoreyshi *et al* [11] (\square), and the present work (\blacksquare).

TE N_2 -lasers. Also, it was realized that in some intermediate gas pressure, the gain-coefficient reaches its maximum value at $pd_{AMP} \sim 55$ Torr.cm. In addition, it was found that regardless of the type of N_2 -laser and its geometrical dimensions, the saturation energy density is linearly related to the output energy density. A fact that has not been introduced so far in gas lasers.



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