Analysis of the influence of helium additions on the laser output and stability of a TEA nitrogen laser

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Recibido el 12 de agosto de 1997; aceptado el 6 de enero de 1998

An experimental method to study the laser output and stability of a small TEA nitrogen laser is presented. The method is based on the amplitude analysis of the fluorescence produced by the interaction of the laser ultraviolet radiation with a yellow filter. Using this method, the influence of helium additions on the laser output energy and stability is analyzed. The experimental data shows that in our conditions, the higher laser output energy and stability are reached when the He represents the 45% of the gas mixture coinciding with the helium concentration for which a spark-free laser discharge is produced.

Keywords: Gas lasers, nitrogen, stability

En el presente trabajo se describe un método experimental para el estudio de la estabilidad de un láser TEA de nitrógeno mediante el análisis de la amplitud de la fluorescencia producida por la radiación láser en un filtro óptico, empleando para esto un sistema espectrométrico nuclear. Con este método es estudiada la influencia de la adición de helio al nitrógeno sobre la energía de emisión y estabilidad del láser. De esta manera fue determinado que en nuestras condiciones específicas los mejores resultados se alcanzan cuando el He representa el 45% de la mezcla gaseosa, coincidiendo con la concentración de helio para la cual los arcos en el canal láser desaparecen.

Descriptores: Lasers de gas, nitrógeno, estabilidad

PACS: 42.55

1. Introduction

Laser energy output stability of pulsed lasers is an important parameter in many applications and it is a sign of a correct design and an efficient operation. The stability of commercially available compact TEA nitrogen lasers with an output energy up to 100 μJ is in the range $\pm$ (3–5)%, relatively more stable than other non-laser pulsed ultraviolet sources as xenon lamps, whose instabilities can reach up to 50% and require complex stabilizing systems when they are employed for analytical purposes [1].

The sources of output energy instabilities are various. For a compact TEA nitrogen laser with an open-air discharge, there can be pressure variations at the laser channel or variations of the photoionization intensity. Variations of the resistance and inductance of the connecting plasma at the switching element generate deviations of the laser output energy. The quadratic dependence of the stored energy of the charging voltage is mentioned as a possible source of laser output fluctuations when the high voltage power supply is not stabilized. Finally, the laser plasma instabilities, which favor the transition from the glow discharge to a breakdown type discharge, are an important source of laser output variations.

The analysis of output energy variations requires the detection and record of a number of laser pulses, which makes their posterior statistical analysis possible. For a nitrogen laser, the radiation detector has to be sensible to the ultraviolet radiation and be able to work at repetition rates of 20 to 50 Hz, which is the common range for these lasers. On the other hand, the associated-to-detector electronics has to be fast enough to resolve pulses with a few nanoseconds of duration. Since the last requirement is not satisfied by conventional electronics, the analysis of instability of nitrogen lasers by the pulse amplitude is not simple to perform. In this case a kind of integration has to be performed, for example using a pyroelectric ceramic as detector. However, the pyroelectric ceramics available to us are not able to work at repetition frequencies exceeding 10 Hz, which limits any analysis for higher frequencies and enlarges the measurement time.

In the present work, an experimental method to study the laser output energy and stability of a compact TEA nitrogen laser is described. The method is based on the analysis of the fluorescence produced in a yellow filter, when it is irradiated with pulsed ultraviolet laser radiation. The fluorescence is detected by a silicon photodiode and registered by a nuclear spectrometric system with a multichannel analyzer as the main element. In this scheme the integrating element is the optical filter, whose fluorescence is proportional to the laser energy. The filter fluorescence lifetime is several times longer than the laser pulse duration and can be registered by a common spectrometric track. For such a system, the maximal allowed repetition frequency outnumbers in several orders the laser repetition frequency.

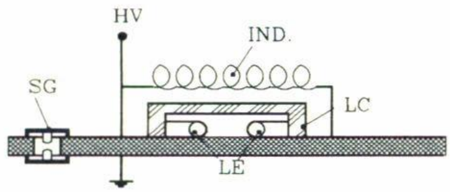

FIGURE 1. Experimental arrangement of the N_2 laser. SG is the spark gap, IND is the uncoupling inductance, LC is the laser camera, LE are the laser electrodes and HV is the high voltage.

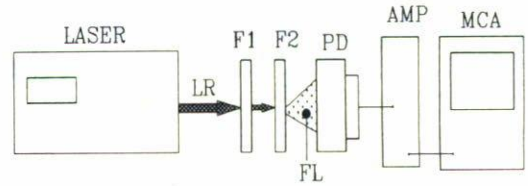

FIGURE 2. Experimental set-up schematic diagram. LR is the laser radiation, F1 and F2 are the ultraviolet and fluorescing filters, FL is the fluorescence, PD is the photodiode, AMP is the amplifier and MCA is the multichannel analyzer.

Using this experimental setup, the dependence of a TEA nitrogen laser output and stability of the percentage of helium added to the nitrogen is investigated. The results show that in our experimental conditions, both the laser output and the laser stability reach the maximum when the helium represents the 45% of the gas mixture, and under these conditions a spark-free laser discharge is produced. For higher or lower helium concentrations, the laser energy and its stability decrease and the number of observed sparks in the laser channel increases as the concentration goes far away from the optimal value.

2. Nitrogen laser

The TEA nitrogen laser is based on a Blumlien generator with an open-air discharge (Fig. 1). The high voltage capacitors are made of 1.5-mm epoxy based double side circuit board, with a total capacitance of 1 nF and were charged up to 12 kV. The laser channel is defined by two tungsten 140-mm long cylindrical electrodes mounted on two brass holders. A triggered spark gap was employed as switching element and allowed the control of the repetition frequency that was kept constant and equal to 15 Hz. The laser construction allowed the direct observation of the laser discharge channel. For this laser the presence of sparks between laser electrodes was characteristic, especially for a pure nitrogen flux. The flux of the N_2 : He gas mixture and of each component in separately were controlled. For a pure nitrogen atmosphere this laser yielded a maximal output energy of 12 μJ with a pulse duration no longer than 1 ns.

3. Experimental setup

The experimental setup is represented in Fig. 2. The laser radiation is sent to a dark camera, at the entry of which an ultraviolet filter with a 90% transmittance for 337.1 nm and a high absorbance coefficient in the visible zone is placed. After this filter another one is placed to attenuate the laser radiation up to levels for which the yellow filter fluorescence does not saturate the photodiode. The photodiode signal is amplified by a timing-filter amplifier *Camberra 2110* and registered by a multichannel analyzer AMC-03, 1024 channels *Instrumentacion nuclear*.

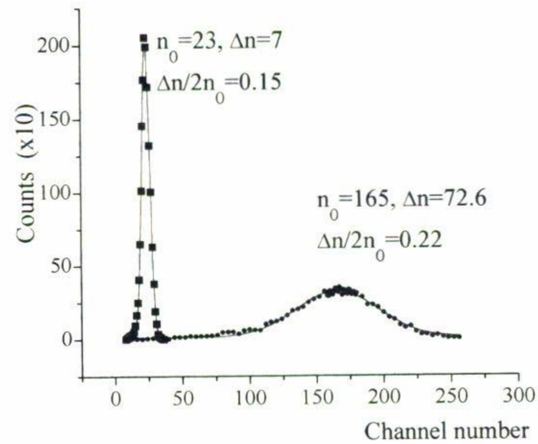

FIGURE 3. Example of two different experimental distributions of laser pulse energy with the parameters of the fitted Gaussian.

$$G(n) = \frac{A}{\Delta n \cdot \sqrt{\pi/2}} \exp\left[\frac{-2(n-n_o)^2}{(\Delta n)^2}\right] \quad (1)$$

The data was collected during 10 minutes with 256-channel resolution, and then transmitted to a PC, where it was fitted to a Gaussian distribution [Eq. (1)], from which the central channel (n_0) and width of the distribution (Δn) were determined (Fig. 3). Here A is the total count and n the channel number.

The ratio between the half of the distribution width ($\Delta n/2$) and the corresponding most probable energy channel (n_0) was taken as the criterion to analyze the laser output stability. According to this criterion, the increment of the ratio $\Delta n/2n_0$ means the increment of the laser output fluctuations. The stability analyzed through this criterion does not depend on the laser energy, amplification coefficient, or multichannel analyzer resolution, however the last statement is only valid when there is a lineal relationship between the laser output energy and the fluorescence signal.

To verify the system linearity, the laser radiation was attenuated with filters of known transmittance for the 337.1 nm and for each filter the experimental distribution was measured and from it, the parameter n_0 was determined. Figure 4 shows the good correlation between the filter transmittance and the channel number corresponding to the most probable laser energy.

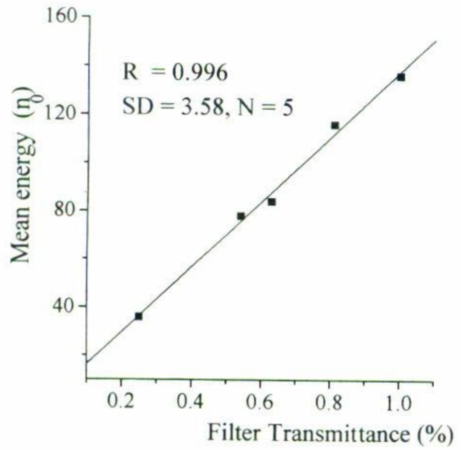

FIGURE 4. Central channel position (n_0) *vs.* attenuation of the laser radiation.

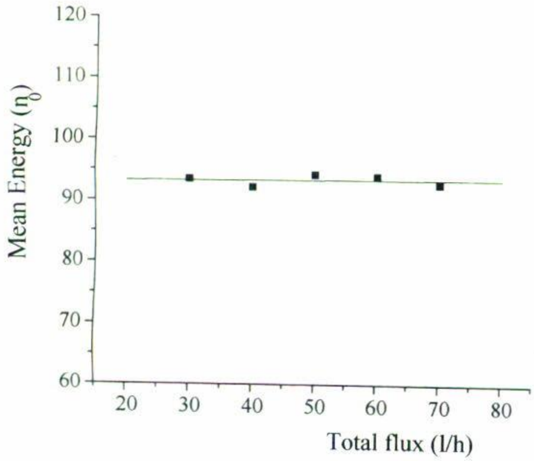

FIGURE 5. Central channel position (n_0) *vs.* 1:1 gas mixture flux.

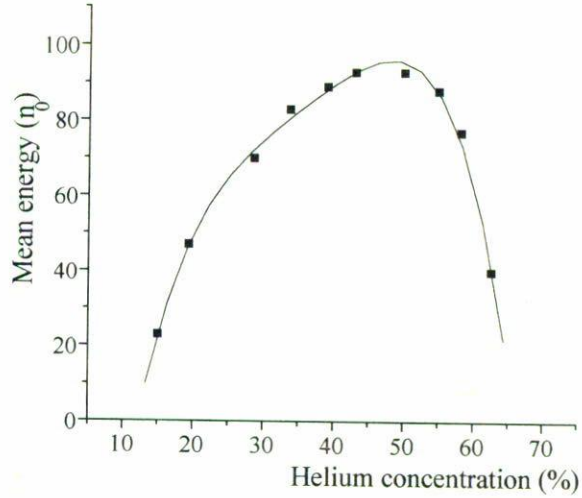

FIGURE 6. Central channel position (n_0) *vs.* percentage of He in the gas mixture.

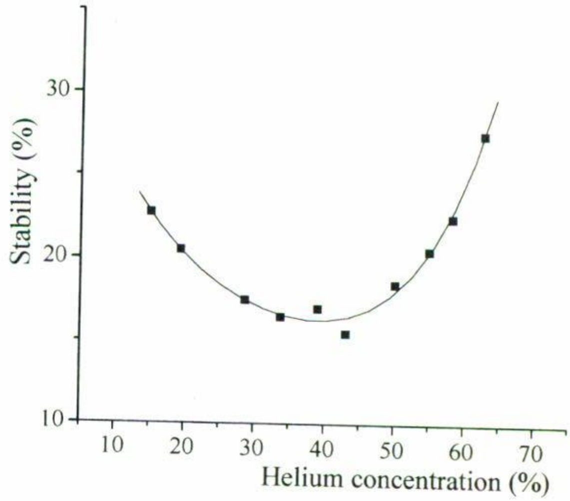

FIGURE 7. Laser output stability ($\Delta n/2n_0$) *vs.* percentage of He in the gas mixture.

4. Influence of helium addition to the nitrogen

Employing the method described above, the influence of helium addition to the laser output energy and stability was investigated. Figure 5 shows the dependence of the central channel (mean energy) for different values of the total flux through the laser channel, when the ratio between nitrogen and helium concentrations was 1:1. As it is shown, the laser energy remains constant for the studied interval of fluxes, indicating that small variations of the flux value are not responsible for the output energy variations.

The dependence of the laser output energy for different proportions of He and N_2 was investigated, keeping the total flux constant and equal to 60 l/h (Fig. 6). Starting from the lowest He concentration, the laser output increased as the percentage of helium was increased, reaching the maximum when the He was the 45% of the gas mixture. The following increment of the helium concentration produced a rapid reduction of the laser energy and above the 65% the laser stops generating.

A similar behavior was obtained for the laser stability (Fig. 7). After the initial increment of the He concentration, an improvement of the laser stability was observed, reaching the maximal value for the same concentration where the laser energy reached its maximum. However, when the helium prevails over nitrogen (above 55%) the stability rapidly fell down.

The influence of He additions on the laser plasma homogeneity was evaluated by the number of observed sparks. The result of such evaluation can be resumed as follows: As the helium concentration begins to be increased, the number of observed sparks in the laser channel decreases, disappearing completely in the range of He concentrations where the laser energy and stability reach the maximum. When the helium came to 55% of the gas mixture the sparks newly appeared and their number grew up when the He concentration was increment.

5. Discussion

The increment of the laser output for a lower concentration of N_2 in the gas mixture is a sign of laser efficiency improvement. One of the reasons explaining this behavior is the reduction or suppression of sparks at the laser discharge. The absence of sparks favors the efficient input of energy to the laser plasma and the efficient extraction of the laser radiation [2]. A similar result was reported by Kurnit *et al.* [3] where the He was employed as a discharge stabilizer with the difference that the maximal output was obtained for lower nitrogen partial pressures.

The helium stabilizing effect on nitrogen discharge may be explained through several mechanisms. One of those mechanisms is the deactivation of metastable electronic levels in the N_2 molecule, reducing that way the probability of the two-step ionization, which is considered an important source of plasma instabilities in nitrogen discharge [4]. In the two-step ionization the molecule is excited to metastable state by a first electron collision, and from this state, the molecule is ionized by a second electron collision. The relatively long life of the metastable rises the probability of occurrence of the two-step ionization. Another mechanism is related with the improvement of preionizing conditions through the increment of the initial free charges [2,5,6]. Since the helium emission spectrum is rich in ultraviolet and vacuum ultraviolet lines, it is expected that the presence of helium will increment the electron emission from the cathode due to photoeffect. Besides, the nitrogen molecule can be photoionized in presence of He, because of the higher ionization potential of the last one. Both mechanisms increment the number of initial free charges in the laser inter-electrode zone.

The helium moderation of fast electrons, responsible for the development of the streamer type discharge, could be an important mechanism of arc suppression. The high thermal conductivity of He is considered another stabilizing mechanism through the effective cooling of the laser electrodes, specially in zones where the local heating could produce an anomalous electronic emission.

Although the specific contribution of each mechanism is beyond the scope of the present work, it can be concluded that all these mechanisms stabilize the laser discharge, preventing the transit to the streamer-type discharge. Since the moment and place of spark development have a random nature, the increment of sparks at the laser channel rises the variability of the conditions in which the laser radiation is produced.

Above was mentioned that the sparks in the laser discharge hinder the efficient input of energy into the laser plasma and the extraction of the laser radiation. For such a reason the increment of sparks in the laser channel also reduces the laser pulse energy. Although laser output stability depends not only on the number of sparks in the laser channel, our results show the importance of avoiding spark formation in order to achieve an efficient laser operation.

6. Conclusions

The presented method is simple and allows the evaluation of the laser output energy and stability of a TEA nitrogen laser. Using this method the influence on the laser output energy and stability of the helium addition to the nitrogen was investigated. It was shown that in our specific conditions, both the laser energy and stability reach a maximum when the He represents the 45% of the mixture. For lower (below 20%) and higher (above 55%) helium concentrations the laser energy and stability fall down, which is correlated with the observed increment of the number of sparks distributed along the laser channel. Although this method was developed for the study of a small TEA nitrogen laser, it is also perfectly applicable to the stability study of other pulsed ultraviolet lasers such as the excimer ones.

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