An efficient and simple spark-gap design for gas lasers

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Abstract. — This work presents a spark-gap with a new design, using properties of electric discharges on insulating surface materials. It generates pulses with high frequency components of larger amplitudes, when compared with conventional spark-gap designs. Testing this spark-gap design in an N₂ TE UV laser, laser emission shows an increase of 60% in peak power output and a temporal width value reduction of 40%. This new design is very simple and strongly modifies laser output characteristics.

Introduction.

Pulsed gas lasers generate stimulated emission having characteristics that are strongly dependent on excitation pulses. This fact becomes critical when the laser belongs to the so-called self-terminated systems.

A thyratron or a spark-gap usually make the control of the excitation pulse. Spark-gaps generate high-frequency, high voltage pulses in a simple way, but it is not easy to obtain a high repetition rate — high pulse to pulse stability regime. The use of thytrons allows high repetition rate and good pulse to pulse stability, with the disadvantage of higher costs, when compared with spark-gaps.

The basic of spark-gap principle is very well-known and we will not devote time to it. Typical examples of conventional spark-gaps are available in [2, 3]. The discharge begins with a « trigger » command and develops having gas in the discharge chamber as the only support.

The present work uses a different principle as a basis for the functioning of the spark-gap, taking the walls of the discharge chamber (isolating material made) as a preferential way for the electric discharge. Several works have used this principle in H₂ laser discharge tubes [see 4-6, for example] and, very recently, in N₂ lasers also [7]. When applied to the spark-gap design, the electric pulse has shown — as expected — a low frequency component and,

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superimposed to it, a high frequency one. Making a comparison with a conventional spark-gap operating at the same conditions, the high frequency component/low frequency component amplitude's ratio shows a significant increase.

Applying this spark-gap design to the operation of an N₂ laser (337.1 nm wavelength), the corresponding stimulated emission characteristics present a 40 % reduction in temporal pulse width values (FWHM) and a 60 % increase in peak power, if compared with results of the laser operating at the same conditions but with a «conventional» spark-gap design.

Experimental set-up.

The laser used has a capacitive charge transfer circuit. Reference [8] describes it in detail and figure 1 shows the corresponding excitation circuit. The charge capacitor \( C \) is 4.32 nF, the transmission line \( C' \) 3.63 nF and the coupling inductance \( L \) 7.2 \( \mu \)H. The discharge tube has 70 cm length and the main electrodes are copper made. They have cylindrical profile and 5 mm diameter value, being the inter electronic distance value \( d \) equal to 7mm. In a plane perpendicular to that determined by the electrodes, two stainless steel wires are located at a 5 mm distance \( d' \) up and down from the discharge tube center. They have 0.3 mm diameter value and behave as a pre ionizing wire set-up. The pre ionizing capacitance \( C'' \) is 1.0 nF.

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\begin{align*}
\text{Fig. 1. — Laser excitation circuit. } & \text{ } C \text{ (nF)} = 4.32 ; C' \text{ (nF)} = 3.63 ; L \text{ (} \mu \text{H)} = 7.2 ; \text{discharge tube length (mm)} = 700 ; d \text{ (mm)} = 7 ; d' \text{ (mm)} = 5 ; C'' \text{ (nF)} = 1.0.
\end{align*}
\]

The radiation detection system consist of a 1850 ITL vacuum photo diode (0.1 ns rise-time), and a 7104 Tektronix oscilloscope with a 7A29 Tektronix vertical unit (0.3 ns rise-time).

Capacitive voltage dividers and/or a P6015 Tektronix voltage probe perform the experimental system for excitation pulse measurements.

The laser operates with commercial grade nitrogen.

Results and discussions.

In the operation of H₂ VUV lasers, the usual requirement is high current density values, obtained by the reduction of the laser discharge channel dimensions [4-6].
Recently, Castro et al. [7] analysed this requirement and applied it to the functioning of an $\text{N}_2\text{TE UV}$ laser (337.1 nm wavelength) [7]. Results show that electric discharge takes the insulating wall surfaces of the laser discharge tube as a preferential way to develop. Because of that, excitation pulses have both higher frequencies and amplitudes, compared with excitation pulse characteristics measured in more conventional configurations.

In the present work, results of [7] are applied to the development of a spark-gap. The way this kind of design modifies laser emission properties is also studied.

A spark-gap having a «conventional» design can be observed in figure 2. The more important point is that discharge, between A and B electrodes, has in principle almost no contact with the lateral sides of the discharge chamber, insulating material made, being surrounded by the gas inside the discharge chamber.

![Figure 2](image)

Fig. 2. — Conventional spark-gap design. A, B = main electrodes; T = trigger electrode; C = insulating material. In this design, electric discharge has almost no contact with the walls of the discharge chamber.

Figure 3a shows the new spark-gap design. Its principle is the same than that of the laser discharge tube reported in [7] (see Fig. 3b). Electrodes, A, B and C, are brass made while teflon is used for the insulating pieces, D and E. A detail to point out is that both A and B electrodes help electric discharge to choose the side of the spark-gap chamber as a preferential way, because of the geometry. To give an idea of the dimensions, the inter electric distance ($d$) is 10 mm while distance between $B$ and the «trigger» electrode ($d'$) is 3 mm.

Figure 4 presents the electrical circuit used for the analysis of excitation pulses generated by the conventional and modified spark-gap designs. From now on, and for simplicity purposes, CSG is the label for the conventional spark-gap while NSG is the corresponding one for the new design.

Figure 5a presents a typical excitation pulse obtained with CSG while figure 5b shows the corresponding result obtained with NSG. In both cases, charging voltage is 6 kV, $C = 10 \text{nF}$ and $L = 3.2 \text{ \mu H}.$

Figure 5 presents typical RLC discharge pulses, with a low frequency component (LFC) having a period around 80 ns and, superimposed to it, a high frequency component (HFC) with a corresponding 30 ns value. With both CSG and NSG, period values are the same, taking into account the experimental uncertainty of our measurements. On the other side, and looking at the peak to peak amplitude of the high frequency components (HFCA) and that of the low frequency components (LFCA), it can be observed that the percentual ratio between maximum
Fig. 3. — a) Modified spark-gap design. Main electrodes, A and B, are plane, having sharp edges that are located almost in contact with the side of the insulating body D, thus making easier for the electric discharge to develop mainly on lateral sides of the discharge chamber. A, B and C are brass made; D and E are made of teflon; $d$ (mm) = 10; $d'$ (mm) = 3. b) Laser circuit used in [7], showing discharge tube section in detail. It has been observed that electric discharge takes both sides of the discharge chamber in a preferential way, thus making the insulating material its guide and support.

Fig. 4. — Electric circuit used for excitation pulse measurements. $SG =$ spark-gap; $T =$ trigger; $C$ (nF) = 10; $L$ ($\mu$H) = 0.8, 3.2 or 10.1.
Fig. 5. — Typical discharge pulses obtained with figure 4 set up. a) Result obtained with a conventional spark-gap (CSG). b) Result obtained with the modified spark-gap design (NSG). Making a comparison between a) and b) it clearly comes up that high frequency component amplitudes have a significant increase when NSG is used. Other experimental parameters are \( C \) (nF) = 10, \( L \) (\( \mu \)H) = 3.2, \( V \) (kV) = 6.

amplitude for high frequency components against low frequency components, \([\text{HFCA} \cdot 100/\text{LFCA}]\), is 40% when CSG is used and 79% when replacing by NSG. This proves that NSG generates pulses having a higher statistical weight of high frequency components. When using 0.8 and 10.1 \( \mu \)H \( L \) values instead of the 3.1 \( \mu \)H value, the functional behaviour remains the same, that is, the \([\text{HFCA} \cdot 100/\text{LFCA}]\) ratio is always higher when NSG is used instead of CSG. This results should be important for pulsed gas lasers, particularly in the case of the self-terminated systems.
The next step is the analysis of an N\textsubscript{2} TE UV laser behaviour when using different spark-gap designs in the electric circuit. This is done with the laser at constant 120 mbar N\textsubscript{2} pressure, \( L = 7.2 \) \( \mu \)H and 9 kV charging voltage value condition.

We now observe a 60\% peak power output (1.45 MW) increase — 40\% \( \Delta t_{\text{laser}} \) (FWHM) value (0.6 ns) reduction when using NSG instead of CSG. As the time resolution limit of our detection system is around 0.35 ns, and changes in \( \Delta t_{\text{laser}} \) (FWHM) are almost of the same order, we modify the laser circuit to generate excitation pulses with higher rise time values, by using an \( L = 10.4 \) \( \mu \)H inductance. The purpose is to observe \( \Delta t_{\text{laser}} \) behaviour with more precision.

As expected, peak power output values diminish in a significant way, comparing with the case of the laser with \( L = 7.2 \) \( \mu \)H value. Nevertheless, we measured a peak power output 60\% higher (0.21 MW) with a \( \Delta t_{\text{laser}} \) (FWHM) value 40\% lower (1.65 ns), when replacing CSG by NSG.

To have an idea of the confidence of obtained data, pulse energy measurements are compared in both cases, that is, with CSG and NSG. With \( L = 7.2 \) \( \mu \)H, a comparison between laser pulse energies \( (E = P \cdot \Delta t_{\text{laser}} \) (FWHM)) obtained with the two spark-gap designs (CSG and NSG) gives 0.84 \( \mu \)J against 0.81 \( \mu \)J. For the \( L = 10.4 \) \( \mu \)H situation we obtain 0.33 \( \mu \)J and

![Fig. 6. — Laser power output (MW) as a function of N\textsubscript{2} pressure (mbar). 1: Laser operating with NSG and \( L (\mu \)H) = 7.2; 2: Laser with CSG and \( L (\mu \)H) = 7.2; 3: Laser with NSG and \( L (\mu \)H) = 10.4; 4: Laser with CSG and \( L (\mu \)H) = 10.4. In all cases, and around 120 mbar N\textsubscript{2} pressure situation, laser peak power increases by around 60\% when CSG is replaced by NSG. Other experimental parameters are \( C \) (nF) = 4.32; \( V \) (kV) = 9.](image-url)
0.34 μJ. Results are different by 3.7% and 3%, respectively, thus giving a good «Higher power output-lower Δt_{laser} (FWHM) relation» at a constant input energy condition.

To conclude, figure 6 shows the behaviour of peak power output (MW) against N₂ pressure (mbar), with L being 7.2 and 10.4 μH, while figure 7 shows the corresponding results for the Δt_{laser} (FWHM) characteristics.

As a final remark, some comments are necessary concerning lifetime and time stability of this switch. Serious limitations appear if the laser operates at a high stored energy and/or high repetition rate regime. This problem is due to a progressive degradation of the insulating surface, mainly because of heating. To authors knowledge, this fact can not be easily overcome and, because of that, this spark-gap model can not be used in this case. In a low repetition rate, low stored energy values regime condition, no heating is detected. The laser operated during several months at a 2 pps repetition rate — 0.35 J stored energy condition without any modification on the spark-gap insulating body and/or increasing instability in laser

![Graph](image_url)

**Fig. 7.** — Δt_{laser} (ns) behaviour as a function of N₂ pressure (mbar). 1, 2, 3 and 4 correspond to NSG + [L (μH) = 7.2]; CSG + [L (μH) = 7.2]; NSG + [L (μH) = 10.4] and CSG + [L (μH) = 10.4] condition, respectively. In all cases, NSG makes the system to produce shorter laser pulse width values.
power output. The only required maintenance was to clean the spark-gap chamber every 10^5 pulse interval.

The observed time interval between trigger and spark-gap pulses was only a function of trigger pulse characteristics and remained constant if compared with spark-gap lifetime.

The pulse to pulse laser output characteristics fluctuation was below 5 %. If no changes are introduced on trigger and/or spark-gap electronic plus geometric conditions, this value is a constant in the limit of the 10^5 pulse interval.

Conclusions.

By changing the design of the spark-gap it is possible to obtain electric pulses with larger amplitude in the high frequency components.

Applying this new spark-gap design to an N_2 TE UV laser, peak power output increases in 60 % while Δt_{laser} (FWHM) value reduces in 40 %. A laser discharge tube having 70 cm length gives a peak power output of 0.21 MW with a temporal width of 1.65 ns. This result corresponds to the laser operating with a high L value (10.4 μH) so that results are more consistent with the time resolving power of the detection system. When the laser operates with L = 7.2 μH, we measure 1.45 MW peak power output — 0.6 ns Δt_{laser} (FWHM) values. The latter results involve Δt_{laser} (FWHM) value differences almost equivalent to the uncertainty of temporal measurements.

It is important to mention that there exists a possibility of over heating and consequent damage of the insulating body, in high repetition rate regimes. For a low repetition rate, low stored energy condition, this problem has no significance. In the present case the laser operates at a 2 pps repetition rate and we dismantle and clean the spark-gap every 10^5 pulse interval.

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