ANALYSIS OF TRANSVERSELY ELECTRICAL EXCITED ATMOSPHERIC (TEA) NITROGEN LASER AND DIFFERENT PARAMETERS OF HOMEMADE IGNITION SYSTEM

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ABSTARCT: We report a theoretical and experimental investigation of transversely electrical excited at atmospheric pressure (TEA) nitrogen laser and homemade ignition system. The voltage oscillation in the spark gap, laser cavity and in the Blumlein circuit has been described briefly. The laser pulses at central wavelength of 337.14 nm with pulse duration of 1.5 ns at atmospheric pressure are obtained from the constructed prototype laser. The optimization of the spark gap, variation of the inductance and resistance of the spark gap, geometry of the discharge channel of laser, observance of beam spot and electric field to pressure in the discharge channel of laser are measured and calculated. The investigation about the discharge channel voltage, current and their dependence upon the time dependent inductance, time dependent resistance of spark gap for different resistive phase period has been investigated for the optimization of the constructed TEA nitrogen laser system.

Keywords: Gas lasers, TEA Nitrogen Laser, Inductance of Spark gap, Resistance of Spark Gap

1. INTRODUCTION

Nitrogen laser is a coherent source of high power and short ultraviolet pulses at 337.1 nm center wavelength. Nitrogen lasers can be employed for the purpose of fluorescence study, dye laser pump source, high speed photography and for spectroscopic applications. For the optimization of nitrogen laser, different theoretical as well experimental aspects have been extensively studied. For reliability and proper efficiency of nitrogen laser, the electrical and optical parameters of system need to be addressed carefully. The Blumlein line circuit or charge transfer circuit configurations are employed for the electric discharge nitrogen molecules.

The Blumlein line circuit and charge transfer circuit characteristics were measured. Fitszimmons *et al*. [1] concluded that the Blumlein line based nitrogen laser has higher efficiency than charge transfer circuit based. Godard [2] reported the travelling wave based schemes nitrogen laser whose efficiency was nearly 1%, while 0.2% efficiency of Blumlein line based nitrogen laser was reported [3, 4]. The efficiency 0.11 %, of the nitrogen laser has been reported [5, 6] to be based on the charge transfer circuit. Oliveria *et al* [7] presented an amazing result about the nitrogen laser efficiency of 3% built on Polloni arrangement.

The reported work, described the designing and construction of homemade prototype TEA nitrogen laser along with the constructed regulated high voltage pump source. The constructed prototype high voltage power source is a flyback transformer based which output direct current range is in mA with a regulated high voltage up to 20 kV. In the present prototype TEA Nitrogen laser transverse arrangement of electrodes is used for the discharge of air because of its efficient, extraordinary power deliverance and rapid rise time of the voltage. An ignition system in the form of spark gap is conventionally used to short the Blumlein line circuit. The optimization of the geometry of spark gap, and effects of spark gap resistance and inductance during its resistive phase period on the performance of laser system is optimized and calculated numerically.

2. THEORY

In the Figure (a) the Blumlein line circuit is shown which consists of two parallel plate capacitor C1 and C2 interconnected through an inductor of inductance L. The spark gap is connected though high voltage source to capacitor C1. The equivalent Blumlein line circuit has drawn to understand the operational nature of Blumlein line arrangement whose functioning depends upon the inductance and resistance of spark gap as shown in Figure (b) which has two parts, the part of ignition system named I and the laser discharge channel portion named II having inductances L1 and L2 and resistances R1 and R2, respectively. The nature of inductance and resistance of part I is time dependent. The electric discharge is achieved in the laser discharge channel by keeping the C2 intensively charged while rapid discharging of C1 simultaneously.

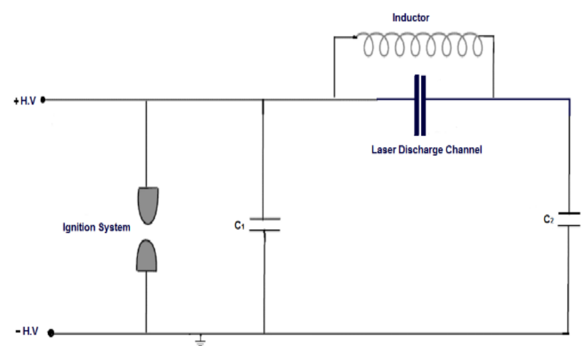

Figure (a). Blumlein Circuit.

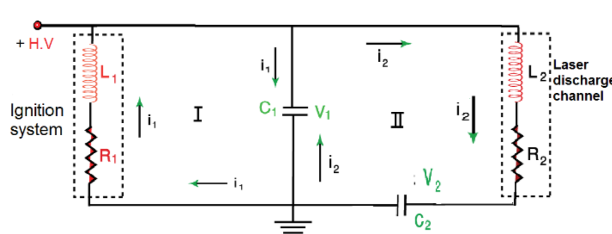

Figure (b). Equivalent Blumlein circuit

The output of the DC high voltage source is applied across the ends of spark gap which attached to the mutual plate of both the capacitors and to C1 which charged the capacitors to their extreme values through identical polarization concurrently while initially the potential difference between the spark gap is at extreme value and minimum across the laser cavity (discharge channel). The capacitor C1 gets short across the spark gap as it fires, the voltage breakdown occurred between the spark gap ends. At the same time the inductor offers a huge impedance to C2, which retains it highly charged, therefore a huge potential difference is build up between the electrodes. Because of this enormous potential difference very energetic electrons move from high potential to low potential and make elastic collisions with the air molecules. The air molecules absorb the electric energy and get excited, when de-excited results stimulated emission of photons in the UV range.

If the inductance and resistance of a discharge circuits are in series, the simulation of discharge occurring in discharge can be drawn. A current i1 is arisen across the portion I when spark gap fired and discharge channel of laser is still inactive at the same time. As the difference of voltage between V2 and V1 exceeds the threshold limits, the current i2 will appear across the II portion and the discharge channel of laser become effective. The oscillatory nature of current and voltage are evident from the experimental results and [9] presented the estimated elucidation of such complications.

The Blumlein line circuit performance is distributed into twofold phases, in phase one the portion II persevere its ineffective state while portion I exhibits its oscillatory behavior as spark gap fired. In the second phase, the portion II of equivalent circuit exhibits its effectiveness and the discharge channel of laser appeared as an operative. The voltage of both the portions is expressed as

$$V(t) = Ae^{-\mathbf{b}t}\,\mathrm{Cos}\,\boldsymbol{\omega}_1\mathbf{t} + B\,e^{-\mathbf{c}t}\,\mathrm{Cos}\,\boldsymbol{\omega}_2\,\mathbf{t} \qquad (1)$$

Where $\boldsymbol{V}_0 = A + B$, if $\mathbf{b}=\mathbf{c}$ then the system will oscillate with a constant value of damping at $\boldsymbol{\omega}_1$ and $\boldsymbol{\omega}_2$. The oscillations of the system continue after every lapse of the time period which results corresponding pulses. The spark gap resistance and inductance are described as $\boldsymbol{R}1=0.23*\boldsymbol{Z}*(\mathbf{t}p/\,\mathbf{t})^{3}$, $\boldsymbol{L}1=2.0*10^{-8}\,\boldsymbol{d}*\log((\mathbf{t}p/\,\mathbf{t})^{3})^{1/2}$ respectively. Where $\boldsymbol{Z}$ is the total transmission line impedance, $\boldsymbol{d}$ spark gap separations, $\mathbf{t}p$ is spark gap resistive phase period and $\boldsymbol{K}$ is the coefficient which is dependent on spark gap variables that taken subsequently [8,10,11].

3. EXPERIMENTAL SETUP OF TEA NITROGEN LASER

The diagram of constructed TEA nitrogen laser setup is presented in Figure (c) that is composed of four main parts, spark gap of free running nature, arrangement of parallel pair of electrodes, a coil and a pair of flat parallel capacitors. A transparency sheet of dielectric constant 2.26 used as a dielectric of thinness 100 μm between foil of aluminum and pair of plates of aluminum which constitute the capacitors.

A pair of parallel plate capacitors C1 and C2 of total capacitance 25.0 nF are formed from the two aluminum plates and a common foil of aluminum. The laser discharge channel is designed between the parallel plate capacitors by employing a pair of aluminum electrodes that are constructed to tolerate the heating effect, oscillatory nature of current and voltage which are connected through a coil. To obtain the identical and uniform electric discharge between the electrodes, the alignment of the electrodes and the edges are optimized up to micro level. In order to get lasing unidirectional, electrode separation is kept 1.45 mm at tail end while 1.50 mm on the front end.

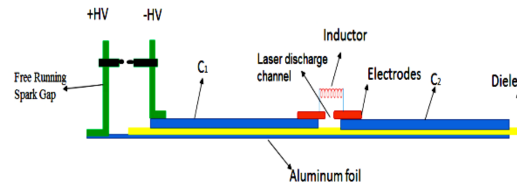

Figure (c): Schematic design for TEA Nitrogen laser.

The parallel plate capacitors are electrically connected through an inductor of 5.40 μH. A high DC voltage source is connected to the capacitors through spark gap and charged concurrently by inductor because of its low impedance to DC. The geometry of regulated free running spark gap optimized by employing various shapes of brass screws, i.e. square ends, elliptical ends, triangle shapes, whose one terminal is connected to the common aluminum foil while second terminal to upper plate of capacitor C1. As the input voltage exceeds the threshold value of breakdown across spark gap, the discharge occurs across the spark gap which short the capacitor C1 while at the same time the inductor opposes the rapid change in voltage that keep the capacitor C2 highly charged. Therefore a huge potential difference appeared between the electrodes which produced intense electric field. The nitrogen molecules from the air absorbed the electric energy and population inversion is created between the $C^3\Pi u$ upper level and $B^3\Pi g$ lower level. The coherent ultraviolet pulses obtained as the electron gets de-excited from $C^3\Pi u$ to $B^3\Pi g$.

4. RESULTS AND DISCUSSIONS

The homemade prototype high voltage dc power source used as an electrical pump source while spark gap of free running nature used as an activator.

Figure (d): Observance of fluorescence on yellow butter paper.

The optimization of spark gap is quite precarious for the proper operation of prototype constructed TEA nitrogen laser. If the gap between the spark terminals are quite less, population inversion can't build up because of the inadequate excitation of air molecules, on the other hand, for large gap separation between the terminals of spark gap, build huge amount of voltage that surpassed the critical limit of dielectric, therefore constructed prototype nitrogen execution may terminate. The prominent and proficient lasing achieved at input of 15 kV and spark gap separation of approximately 3 mm. The voltage variations between spark gap terminals, along the laser discharge channel observed is of oscillatory nature.

The confirmation of lasing among nitrogen molecules is perceived by measuring the spectrum of pulses with 337.1 nm central wavelength [12]. The observance of fluorescence on yellow butter paper is observed 50 cm from laser source (Figure (d)) as an indicator of the nitrogen laser in UV region. The central part exhibits more fluorescence than its surroundings which is the clear signature of more coherence of UV photons at central portion of the beam. In the reported constructed prototype nitrogen laser, the threshold spark gap terminal separation at which lasing achieved is 2.6 mm. The electrodes optimization of te discharge channel of laser and pre-corona ionization of air molecules is quite critical when atmospheric air used as a lasing medium. The pre-corona ionization is obtained by clamping electrodes on the parallel plate capacitors by keeping a distance of 1.45 mm at rear end and 1.50 mm at the front end between electrodes which constitute the laser cavity. As the nitrogen molecules have sufficient gain, therefore the reflecting mirrors are not employed in the formation of laser cavity.

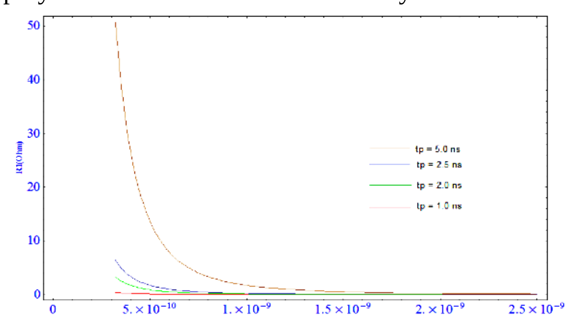

Figure (e): Time dependent resistance of spark gap for different resistive phase period.

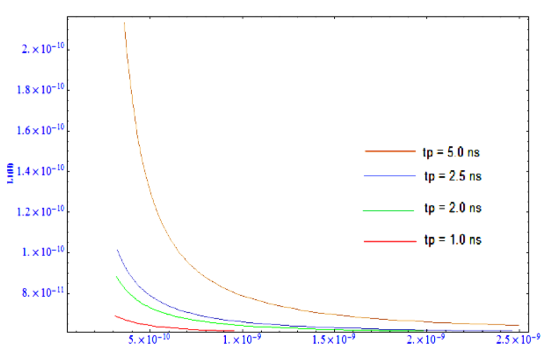

Figure (f): Time dependent inductance of spark gap for different resistive phase period

The time dependent resistance and inductance for a different resistive phase period of spark gap for nitrogen molecules have been observed at atmospheric pressure as plotted in Figure (e) and Figure (f). As the discharge occurred across the terminals of spark gap, very high resistance posed by the spark gap to voltage which rapidly decreased within few nanosecond of the resistive phase period of nitrogen molecules in air. A notable shifting of curves for time dependent resistance and inductance for different resistive phase period have been observed with the slight shift of phase in every curve. Also, the time dependent resistance and inductance spark gap for large value of resistive phase period are higher corresponding to smaller value of resistive phase period which is clear indication of non-smoothness impedance of the spark gap.

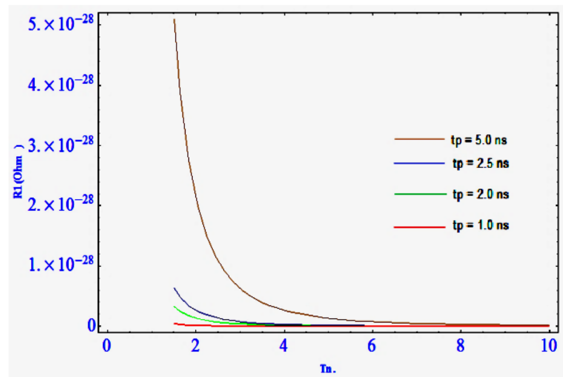

Figure (g): Time dependent resistance of spark gap along normalized time for different resistive phase period.

The time dependent resistance of spark gap along normalized time for different resistive phase periods is explored as plotted in Figure (g) which has similar behavior as that of resistance and inductance along with the resistive phase period. The findings of our constructed prototype systems regarding the effect of inductance and resistance on the oscillatory nature of current, voltage and power of laser system are fairly equivalent as described by Twati Mohamed [13]. A uniform and steady glow discharge in the discharge channel of laser is obtained at a height of 1.0 mm above the surface corona discharge. This design of surface corona distance is reasonably lower than reported [12, 14, 15] one which makes the system more operative and steady.

5. CONCLUSION

In the present report, the homemade prototype TEA nitrogen laser and spark gap are designed, fabricated and optimized. The optimization of laser discharge channel and spark gap terminals configuration, time dependent inductance and resistance of spark gap for a different resistive phase period are computed which shows a spark gap resistive period is inversely related to current and directly to voltage in the discharge channel of laser. The laser discharge channel,voltage is decreased by the decrease of resistive phase periods, while the laser discharge channel and spark gap current is increased by the decrease of resistive phase periods. These investigations are the clear signature of the non-smoothness impedance of spark gap.

REFERENCES:

[1] V.A. Fitszimmons, L.\V. Anderson, E.E. Riedhauser, and J.M. Vrtilck, "*Experimental and Theoretical Investigation of the Nitrogen Laser",* IEEE Journal of Quantum Electronics, vol. QE-**12**, no. 10, pp. 624-633 (1976).

[2] B. Godard, "*Simple high-power large-efficiency n//2ultraviolet laser",* IEEE Journal of Quantum Electronics, QE**-10** (2 Part 2), pp. 147-153. (1974).

[3] Ch. Iwasaki and T. Jitsuno, "*An Investigation of the Effects of the Discharge Parameters on the Performance of a TEA N2 Laser",* IEEE Journal of Quantum Electronics, vol. QE-**18**, no. 3, pp. 423-427. (1982).

[4] E. E. Bergmann, "*Compact TEA N2 laser",* Review Scientific Instruments, vol. **48**, no. 5, pp. 545-546 (1976).

[5] A.A. Serafetinides, *"Improved excitation by double discharge and semi conductive preionisers - electrodes in T.E.A. UV and IR lasers*", Optics Communications, V.**72**, p.219. (1989).

[6] F. E. Sanz, and J. G. Perez, "*A high power high energy pure N2 laser in the first and second positive systems",* Applied Physics B, **52(1)**, 42-45. (1991).

[7] D. Oliveira dos Santos, E.E. Fellows, J .D. d Oliveira e Souza, and C.A. Masan, *"A 3% efficiency N2 Laser"*, Appl. Phys. B **41** 241 (1986).

[8] A.D. Papadopoulos and A.A. Serafetinides, *"Characteristics of doubling circuits used in gas laser excitation - Application study of N2 laser",* I.E.E.E. Journal of Quantum Electronics, Q.E.**26**, p.117 (1990).

[9] Bassam Hanna Habib, "*A Simple Model of SparkGap Discharge Phase"*, Eng.&Tech.Joumal, vol. **31**, Part (A), No.9, (2013).

[10] Hasibur Rahaman, "*Investigation of a High Power, High-Pressure Spark Gap Switch with High Repetition Rate"*, PhD thesis, Universita Erlangen Numberg,(2007).[11] Eric Worts, *'Theoretical investigation of a laser triggered gas spark gap"*, M.Sc. thesis, University of Missouri-Columbia, (2005).

[12] M. Hussain and T. Imran, "*Design and Construction of prototype transversely excited atmospheric (TEA) nitrogen laser energized by a high voltage electrical discharge",* Journal of King Saud University – Science **27**, 233–238 (2015).

[13] Twati, Mohamed. "*A full distributed parameter model of a Blumlein-line laser circuit including the effect of time varying spark-gap inductance and resistance.*" Electrical and Computer Engineering (CCECE), IEEE 27th Canadian Conference on. IEEE, (2014).

[14] S.Sarikhani and A. Hariri, "*Modification of nitrogen Townsend ionization coefficient in a N2 laser with a weak corona preionization and high gas pressure using laser output power measurement",* J. Opt. **15**, 055705 (9pp),2013.

[15] A. Hariri, M.Tarkashvand, and A. Karami, *Corona-preconized nitrogen laser with variable pulse width.* Rev. Sci. Instrum. **61**, 1408 (1990).