

A three-stage blumlein-circuit to generate transversely excited atmospheric nitrogen laser by using three spark gaps

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Abstract

In this research constructed N₂ laser system by use developed method of electric discharge. In this method used four step of electric discharge by using four capacitors, three spark gaps, high tension power supply varying in range from 12kV to 24 kV and three resistors, this method called three stage blumlein circuit. The breakdown time delay of these parallel spark gaps cement strong ultraviolet preionization in the laser channel, thus the result of these amendments the laser output is many doubled and is more increasing than that obtained using the one and two stage blumlein circuits. This system has been designed and operated to give pulse laser with wavelength at 337.1 nm. This laser system can operate without mirrors and optical resonator. The best result of energy was about (20.2 mJ) at electrode separation (3.5 mm) with flow rate (13 L/min) and applied voltage (24 kV). With this conditions of electric discharges the pulse duration was (6.65 ns) then the peak power was (3.04 MW), the efficiency of convert the electric energy to optical energy was (0.93%) and The divergence of laser beam at optimal condition was (0.348 mrad). The results of fabricated system indicate the output characteristics can be significantly improved by improving the discharge characteristics.

Key words

Gas lasers, TEA nitrogen laser, time delay, highly efficiency.

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دائرة البلوملين ذات ثلاث مراحل لتوليد ليزر النيتروجين المتهيج بالطريقة المستعرضة عند الضغط الجوي باستخدام ثلاث فجوات قرح

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الخلاصة

في هذا البحث قمنا ببناء منظومة ليزر نيتروجين باستخدام طريقة مطورة للتفريغ الكهربائي، استخدمنا اربعة مراحل من التفريغ الكهربائي باستخدام اربعة متسعات، ثلاث فجوات قرح، مجهز قدرة للفولتية العالية في مدى من 12 كيلوفولت الى 24 كيلوفولت وثلاث مقاومات، هذه الطريقة تدعى دائرة البلوملين ذات ثلاث مراحل. ان زمن التأخير في عملية الانهيار بواسطة فجوات القرح تؤدي الى توليد تأين اولي للأشعة فوق البنفسجية في قناة الليزر. لذلك تكون الطاقة الناتجة مضاعفة مقارنة بدوائر البلوملين ذات المرحلتين والمرحلة الواحدة. ان هذه المنظومة صممت للعمل لانتاج ليزر نبضي بطول موجي 337.1 نانومتر. ان هذه المنظومة الليزرية تعمل بدون مرايا. ان افضل نتيجة للطاقة كانت 20.2 ملي جول عند بعد بين الاقطاب (3.5) ملليمتر مع معدل لتدفق الغاز 13 لتر لكل دقيقة وفولتية مجهزة للنظام 24 كيلوفولت، مع هذه الشروط كان زمن النبضة 6.65 نانوثانية لذلك قمة القدرة كانت 3.04 ميغاواط، وكانت كفاءة تحويل الطاقة الكهربائية الى طاقة بصرية حوالي 0,93% اما انفرجعية شعاع الليزر فكانت 0.348 ملي راد. ان نتائج النظام المصمم يوضح تحسن في النتائج المستحصل عليها من خلال تحسين خصائص التفريغ المستخدمة.

Introduction

N_2 laser considered as important example of vibronic laser. It has important oscillation at 337.1 nm, and belongs to the class of self-terminating lasers. The laser action occurs through transition called second positive system i.e., through transition ($C^3\Pi_u \rightarrow B^3\Pi_g$), which transition from (C – State) to (B-state) [1]. Fig.1 shows the energy level scheme for the N_2 molecule, the excitation of the C state is believed to engender from collision between electron impact and ground state N_2 molecules. Because both C and B states are triplet states then transitions from the ground state are spin forbidden. According Franck-Condon principle, can expect that the

excitation cross section to the $v=0$ of the B – state will be smaller than the $v=0$ level of the C-state. Comparison to the ground state shown that the potential minimum of the B –state to be tends to greater inter nuclear separation than of C state. The lifetime of the B- state is 10 μs while the lifetime (radiative) of the C- state is 40 ns. Because the condition ($\tau_1 < \tau_{21}$) is not satisfied in N_2 laser then these laser cannot operate as continues mode (CW), so N_2 laser can be excited on a pulsed basis provided the electrical pulse but with shorter than 40 ns. Laser action occur predominantly on many rotational lines of transition [2, 3]

$v''(0) \rightarrow v'(0)$ at ($\lambda = 337.1$ nm).

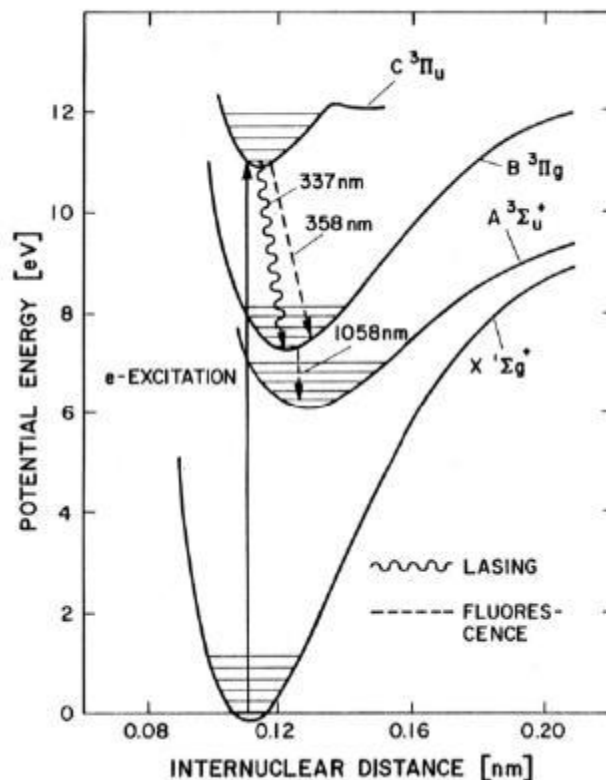


Fig.1: Energy levels of the N_2 molecule [2].

N_2 laser can be utilized for many applications such as pump dye laser, spectroscopic applications, and high speed photography and for the purpose of fluorescence study. To arrive to the best results of N_2 laser must studying

different theoretical and experimental aspects. For reliability and suitable efficiency of N_2 laser, the optical and electrical parameters of system need to be addressed neatly. The blumlein circuits represented important method

or charge transfer circuit to get electric discharge diatomic N₂ molecules. The Blumlein line circuit and charge transfer circuit properties were measured [4]. The high efficiency of a N₂ laser depends very considerably on a fast electric discharge circuit to provide a big overvoltage through the laser channel prior to its breakdown, which usually occurs at voltages several times the constant breakdown voltage [5]. This overvoltage is necessary to provide a regular electric discharge as well as a fast discharge excitation of the N₂ laser in which the

upper laser lifetime is rather short, about sub nanoseconds depending on the gas pressure. In a parallel-plate, Blumlein-driven N₂ laser, it has been shown to increasing the spark gap inductance with decrease the output energy [6], thus an airtight spark gap has often been used[5-8], in particular for N₂ lasers at atmospheric pressure. An group of parallel spark gaps which have a low switch inductance was shown to rise the output power of N₂ laser than driven by Blumlein system [9].

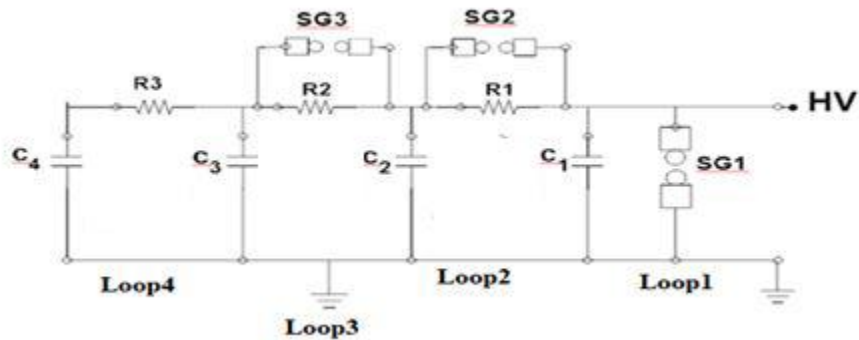


Fig.2: Three stage Blumlein circuits.

Experimental set-up

The system consist of electrical arrangement with four discharge loops shown in Fig. 2, in our three stage Blumlein circuit for TEA-N₂ laser. These circuit consist from four capacitors and three spark gaps, these capacitors represented by C1, C2, C3 and C4 and with values 2.7 nf, 1.85 nf,

1.56 nf and 1.47 nf respectively, are each constructed using copper foil as upper plate and lower plate from copper foil as a common ground with thick 33 μm. Between these top foils and lower plate layer of 1.5 mm thick glass and glue which called (epoxy resin fiberglass substrate) as a dielectric insulation showed in Fig. 3.

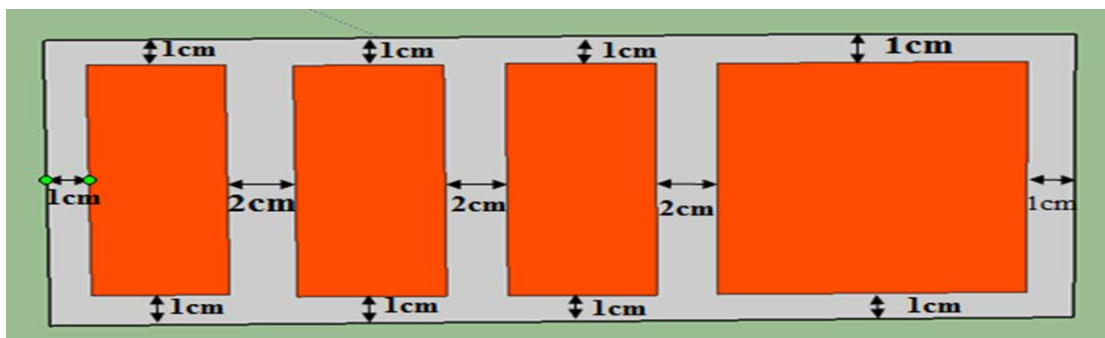


Fig.3: Board of capacitors.

The electrodes in this research are made of Brass metal, which is in the form of parallel rectangles with dimensions (26 cm x 6 cm x 1.5 cm), which contain a bump outside the dimensions of the mentioned space, which is in the shape of half circle with a radius of about (3.5 mm) as shown in Fig. 4.



Fig.4: Shape of electrodes.

The circuit of the high voltage power supply that showed in Fig.5, consists of important three stages, bridge rectifier to convert the alternating current to direct current and filter circuit to provide the +12 V dc voltage to operate timer circuit which used 555 timer and third step the Flyback transformer driver to rise the voltage which is based on MOSFET. The power supply give high-tension voltage varying from (12-24) kV that operated at constant frequency about 16 kHz with constant values of resistors at 3 kΩ by depend about equation [10]

$$f = \frac{1}{\ln(2) (R_1 + 2R_2)C} \quad (1)$$

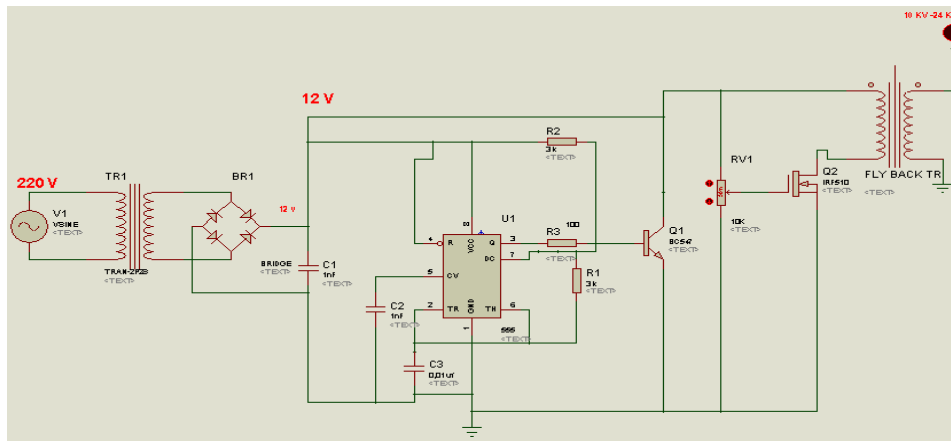


Fig.5: High-tension power supply circuit.

The connection of all system parts N₂ laser showed in Fig.6, first spark gap SG1 and first capacitor C1 which has connected to a high tension power supply, the other end of the SG1 has connected to the common plate, when a high voltage is applied to the blumlein circuit all capacitors C1, C2, C3 and C4 are charged at the same voltage during the resistors R1, R2 and R3, no potential difference exists during the laser channel at this time. When the SG1 arrived the breakdown voltage, it is triggered and the charges in the upper plate of capacitor C1

begins to landing. The charged voltage in capacitors C2, C3 and C4 stays the same because the process is very quick so as that the resistors R1, R2 and R3 impedance becomes so high that it impedes any crossing of current through itself. In this way, as capacitor C1 full discharges at this time the C2 discharged by SG2 with continual charged of C3 and C4, when C2 become totally discharged the C3 discharge across SG3, the breakdown time delay in the SG3 Availability a larger voltage to be created across the laser channel.

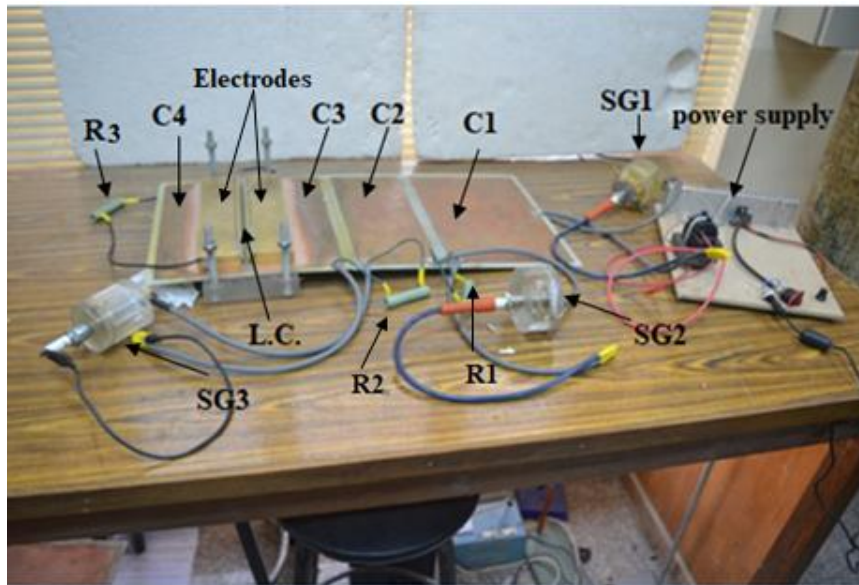


Fig.6: N₂ laser system.

Experimental results

The energy of output laser depend on several factors, these factors are the applied voltage for the system as well as the change in the flow rate N₂ gas through the laser channel. Fig.7 and

Table 1 show the change in the voltages for each value of the flow rate, so that the distance between the two electrodes is constant at the best value (3.5 mm).

Table 1: The change in the voltages for each value of the flow rate.

| Flow Rate (L/min) | Voltage (kV) | Energy (mJ) |
|-------------------|--------------|-------------|
| 5 | 12 | 1.1 |
| | 16 | 2.9 |
| | 20 | 3.3 |
| | 24 | 3.8 |
| 7 | 12 | 2.1 |
| | 16 | 4.3 |
| | 20 | 6.5 |
| | 24 | 7.1 |
| 9 | 12 | 2.4 |
| | 16 | 6.8 |
| | 20 | 10 |
| | 24 | 11.3 |
| 11 | 12 | 4.1 |
| | 16 | 8.2 |
| | 20 | 11.4 |
| | 24 | 14.7 |
| 13 | 12 | 3.4 |
| | 16 | 6.9 |
| | 20 | 12.1 |
| | 24 | 20.2 |
| 15 | 12 | 3.1 |
| | 16 | 5.3 |
| | 20 | 11.2 |
| | 24 | 18.3 |

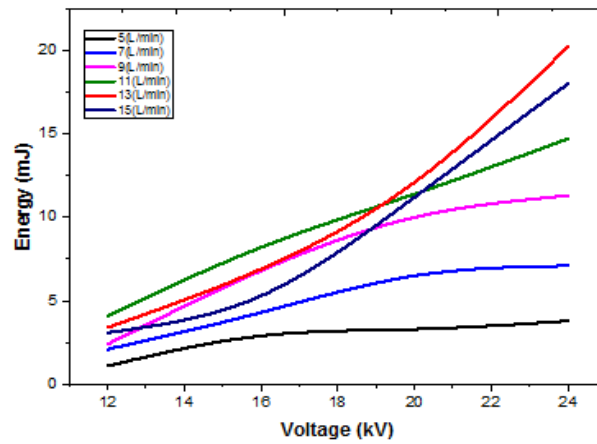


Fig. 7: Dependence of the laser pulsed energy on the charging voltage where inerelectrode distance (3.5 mm).

The increase in voltages increases energy, this means that the energy increases with the increase of the stored voltages in the capacitors (1/2 CV²) but this does not occur with the increase in flow rate due to the influence of several factors including the speed of particles as well as the number of collisions and the first ionization section obtained.

The output power depends only on the charge stored in the capacitor and on the energy distribution of electrons in the plasma. The energy is proportional to output power according to relation (2) [11].

$$p = \frac{E}{\Delta t} = \frac{\text{Energy per pulse}}{\text{pulse time}} \quad (2)$$

The change of energy with the change in the applied voltages is associated with the best value of the N₂ gas flow between the electrodes. From Fig.7 the relation that obtained is not linear, whereas some previous research stated that the relationship between the voltages and the resulting capacity or the energy produced is linear [12-14] depending on the relationship (3)

$$W_P \propto \varnothing(l,t)N_o \quad (3)$$

where W_P represents the resulting power, N_o represents the density of gas molecules available for excitation, and $\varnothing(l, t)$ represents the density of

the photons formed along the laser channel over time.

(W_P) of the relationship (3) is directly proportional to N_o, and N_o is directly proportional to N_e by relation (4) [15].

$$N_o \propto \bar{\sigma}(T_e) N_e \quad (4)$$

The resulting power is proportional to the electron density (N_e) and the cross section of the electrons in the upper and lower laser levels $\bar{\sigma}(T_e)$. The resulting power increases linearly with the electron density and the electron density depends on the current passing through the laser channel, this means that the output power increases linearly with the applied voltages.

The reason for the lack of nonlinear relationships in Fig.7 is that the voltages depend on the temperature of the electron (T_e) and that the temperature of the electron can be calculated from the following relationship (5) [16]

$$K T_e = 0.11 (E/P)^{0.8} \quad (5)$$

K- Boltzmann constant, E- electric field and P- gas pressure.

The output energy increases with increasing gas flow rate for voltages 12kV and 16kV until flow rate arrived (11L / min), this mean, they reach saturation limit, While the laser output to be Stable of the voltages between 20 kV to 24 kV until the pumping rate

(13L / min) is the saturation limit for them (this means that the photons emitted from the excitation molecules began to absorb from non-excitation molecules within the gap).

From Fig.7 the energies are low when the flow rate is minimum value at (5) L / min. This means that the number of N₂ particles available for excitation is low.

While the energies at low values when the flow rate is minimum value at (5 L/min), this means that the number of N₂ molecules available for excitation is low and at the same time the energy increases with the increase in voltages, i.e. the number of electrons increases lead to an increase in the number of collisions. As well as increasing the electric field caused by the breakdown of gas within the laser channel. The increasing in the flow lead to increasing the output energy, because increasing the flow rate leads to an increase, thus providing chances of collisions with free electrons and thus increase the laser output. The increase in the voltage difference increases the density of the current passing through the laser channel, thus increasing the density of the free electrons according to the relation (6)

$$J_e = N_e e v_d \quad (6)$$

J_e - current density, e - electric discharge, N_e - electron density and v_d - average drift velocity of electrons.

The increase in the voltage difference will increase the flow of electrons according to the relationship (7)

$$v_d = \mu \cdot E \quad (7)$$

where: μ is the mobility of the electron. E is the electric field, this means that the velocity of the electrons increases and the number of possible collisions between electrons and N₂ molecules increases, which leads to an increase in the number of excited N₂ particles which increase the laser output due to

the increase in the number of particles at the higher levels leading to the reverse distribution. The best value of energy was at the flow rate (13 L / min) at 24 kV where the energy was 20.2 mJ, this means that the best value for electrons and molecules is that there are enough excited molecules with enough electrons to excite the gas molecules. The increase in the energy at this value from the flow rate did not start from the beginning at the low voltages, but the increase was slow at the beginning of the charging of the voltages, i.e., the excitation of N₂ molecules was minimum, but with the increase of the voltages, the excitation process started increasing rapidly at the value of 18 kV. While the decrease in energy it was obtained when the flow rate increased to a rate of (15 L / min) Because exceeded the saturation limit in the gas molecules (saturation excitement) within the laser channel and discharge process within the laser channel becomes irregular. The velocity of the particles increases, thus decreasing the number of collisions, as well as decreasing the chance of passing the first ionization, The output will be reduced even to the excited molecules, which will require the increase of the rated voltages to exceed this limit as shown in the flow rate (11L / min) of the 12kV and 16kV volts where the amount of energy produced decreases when the flow rate is increased to 13L/min. While increasing the same flow rate when increasing voltages to 18 kV or 24 kV. The efficiency of any N₂ laser system does not exceed 1 % and from Table 2 can see the best efficiency is not necessarily with the best energy because the efficiency depends on the energy of the resulting laser as well as the energy stored in the capacitors (1/2 CV²), depending on the applied voltage to the system as well as the capacity of capacitors.

Table 2: Change the efficiency with applied voltage for each flow rate.

| Flow Rate(L/min) | Voltage (kV) | efficiency |
|------------------|--------------|------------|
| 5 | 12 | 0.00202 |
| | 16 | 0.00299 |
| | 20 | 0.00218 |
| | 24 | 0.00174 |
| 7 | 12 | 0.00385 |
| | 16 | 0.00443 |
| | 20 | 0.00429 |
| | 24 | 0.00325 |
| 9 | 12 | 0.0044 |
| | 16 | 0.00701 |
| | 20 | 0.0066 |
| | 24 | 0.00518 |
| 11 | 12 | 0.00751 |
| | 16 | 0.00845 |
| | 20 | 0.00752 |
| | 24 | 0.00673 |
| 13 | 12 | 0.00623 |
| | 16 | 0.00711 |
| | 20 | 0.00798 |
| | 24 | 0.00925 |
| 15 | 12 | 0.00568 |
| | 16 | 0.00546 |
| | 20 | 0.00739 |
| | 24 | 0.00825 |

Fig.9 shows that the optimum efficiency was 0.93 % at 24 kV with flow rate 13 L / min, and inerelectrode distance at 3.5 mm, However, with a flow rate of less than 13 L/min, there is a slow increase starting at applied voltage 14 kV and then decreasing after a value of 18 kV,

while at flow rate 13 L/min the efficiency increasing rapidly with increased applied voltages, because the output energy to be with large increases compared with stored energy in capacitor but the efficiency increases slowly when the flow rate is greater than 13 L/min.

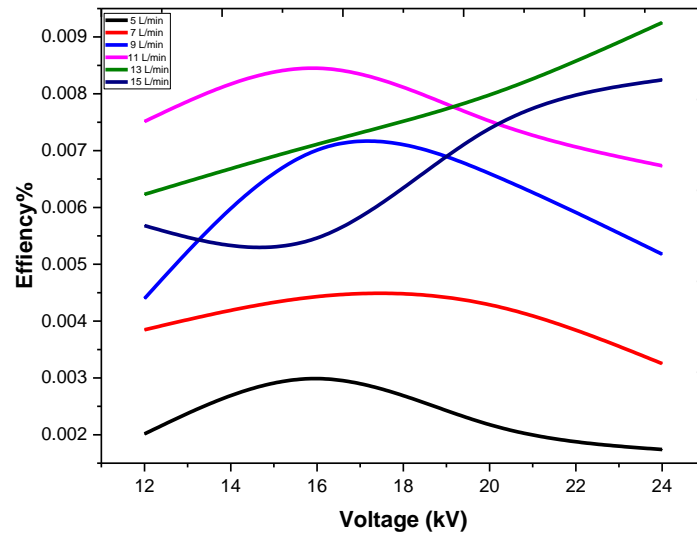


Fig.9: Dependence of the efficiency on the charging voltage.

The beam laser divergence was measured by measure the size width of the beam spot at difference distance that showed in Fig.10, at 25 cm from the source the width of beam spot was 3.2 cm and at 50 cm was 4.3 cm, then the divergence was 0.384 mrad.

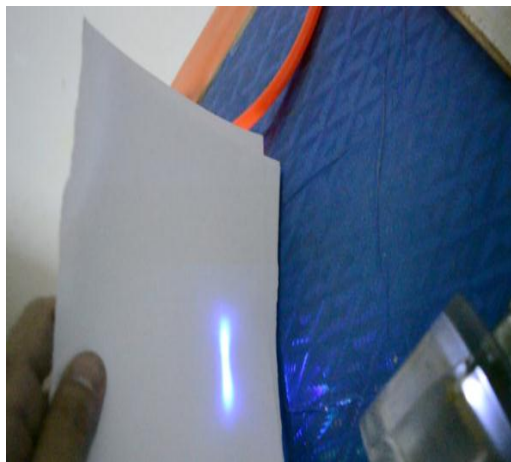


Fig.10: Spot of beam laser.

The laser pulses showed in Fig.11 were recorded with an FDS010 detector with a 100 MHz oscilloscope HAMEG (HM1004-3) which was surrounded by the shield to reduce the noise, the pulse duration was about 6.65ns, then the total inductance of the circuit that measured by following equation $T=2\pi(LC)^{1/2}$ was $L=0.147$ nH.

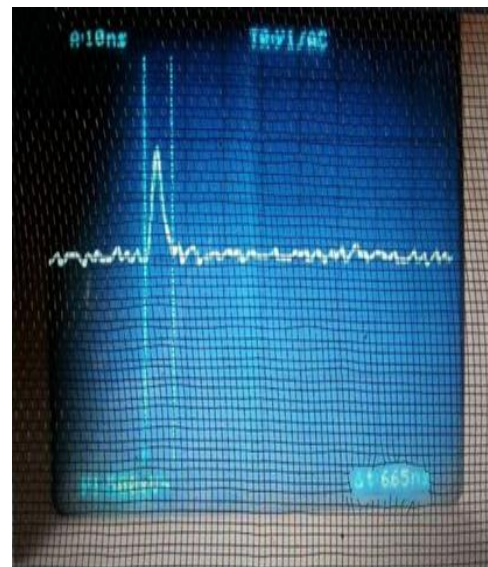


Fig.11: Shape of pulse duration.

Conclusions

A maximum output energy (20.2mJ) was arrived because ultrafast exciter by use three stage blumlein circuit that have three spark gaps represented as a free running switching and acted as a time delay for uv preionization of the laser channel, in addition third spark gaps is given Additional energy to the laser channel, hence improving the discharge locative uniformity and lead to best reproducibility of the laser output. A uniform glow discharge has been accomplished at considerably lower

height above the surface corona discharge compared to the earlier reports. The energy in our research increased with increase in applied voltage to the system but these increases was different by depend upon the flow rate values ,and showed that the best result of energy did not give with highest flow rate value.in this research the value of efficacy dose not to be with highest value of energy.

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