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Fabrication of a pulsed Ar^+ laser

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Abstract. A pulsed Ar^+ laser, providing about 150 W peak power, in the visible region is fabricated, using indigeneous materials The laser is excited by D.C. voltage applied to the electrodes through an artificial transmission line. The influence of various parameters like tube voltage (700–3000 V), peak currents (200–1400 amps) and pressures (10–25μ of Hg), on the output power was studied extensively. The optimum conditions for a tube of 6 mm. dia. and one meter discharge path length are : current, 550–650 amps; Argon fill pressure 15 μ of Hg; and electrodes, Kovar for anode and Indium cathode. The peak output power and its distribution among the various wavelengths stays invariant as the pulse width is changed from 30 μsec to at least 250 μsec.

1. Introduction

Though laser action in pulsed argon ion discharges was observed long back (Bridges 1964, Convert 1964, Bell 1964), with the development of cw Argon ion lasers on the one hand and the powerful N_2 molecular laser on the other hand the pulsed Argon ion laser has not received much attention This laser is however a very convenient tool for studying transient phenomena in the microsecond time scale. The output pulse width could be varied from about 10 μsec. to as long as few milliseconds without any loss of peak power and so the total energy of excitation can be easily tailored to suit individual requirements. This laser can be also built comparatively easily with indigeneously available materials. This paper is a result of a study on the performance of the laser and presents in a readily usuable form, the details of the fabrication and parameters for optimum performance.

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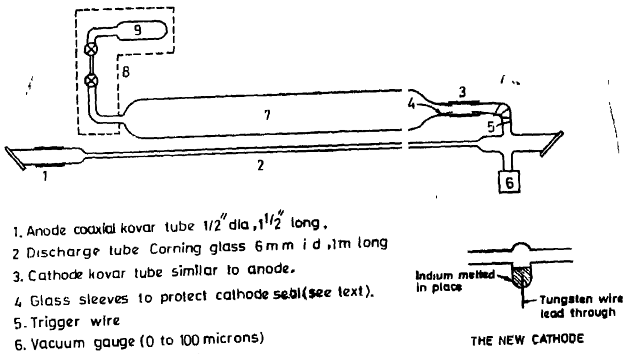
2. Details of Fabrication

A. *Plasma Tube*

The laser tube constructed in the present work is shown in Figure 1 and is made of commercially available *corning* glass. It consists of a discharge tube of 6 mm inner diameter and about 1 meter length, terminated on either side by quartz windows set at Brewster's angle (55°30′). (An accuracy of the order of about one degree is tolerable in fixing these windows M-seal, super bond, manufactured by Dr. Beck and Co is used in our laboratory for fixing the windows, but an adhesive which can withstand temperatures of about 300°C would be preferable). This discharge tube is connected on one side to a ballast tube of 2″ diameter and 30″ length. Two Kovar tubes (about 0·5″ i.d. and 1·5″ length) are joined to the tube co-axially by ordinary glass-to-metal seals to form the electrodes. The anode is placed co-axially to the main discharge tube while the cathode is placed on a side tube connecting the discharge tube to the ballast tube. Such co-axial placement of the cathode seems to be very important for the proper and reliable operation rather than the choice of the cathode material (Al, W, Mo, Ni). Further, it was found necessary to provide inner glass sleeves (as shown in Figure 1) to protect the cathode to glass seal from positive ion bombardment This bombardment causes localized and intense heating, which, if allowed to take place on the seal region leads to its damage We have recently experimented with an Indium cold cathode (Simmons 1970) and found the performance to be very good. This is formed simply by surrounding a usual tungsten wire lead-through con-



1. Anode coaxial kovar tube 1/2″ dia, 1 1/2″ long.
2 Discharge tube Corning glass 6 mm i d, 1m long
3. Cathode kovar tube similar to anode.
4 Glass sleeves to protect cathode seal (see text).
5. Trigger wire
6. Vacuum gauge (0 to 100 microns)
7. Ballast tube 2″ dia, 30″ long.
8. Argon refilling system (suggested).
9. Argon gas reservoir.

Figure 1. The Plasma Tube

tained in a glass cup, by Indium and melting it in place so as to make good electrical contact with it. This cathode has large current capability as well as long life. Experiments are presently being conducted in our laboratory to find out whether any other metals (Bi, Sn, etc.) with low melting points could also be used similarly. The parametric study being reported here is however done using the coaxial cathode only, and a preliminary report of this data was presented earlier (Ramasastry 1976) The gas pressures are monitored by a Pirani guage (Vacuum Instruments Co.) and it is advisable to connect the vacuum gauge permanently to the laser as shown in Figure 1.

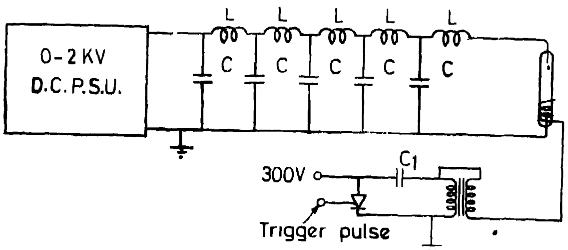
The laser operates at a comparatively low pressures of the orders of 10–30μ of Hg and thus the effect of any impurities is rather pronounced on the performance All parts of the structure must be thoroughly cleaned using distilled water, dilute hydrofluoric acid and acetic acid prior to being connected together. The laser tube must be evacuated to about 1×10^{-6} torr of Hg and baked at 350°C for about 48 hours while taking care to see that the window seals do not get affected during the heating. Heating tapes covered with asbestos are very convenient for this, but any suitably designed simple oven arrangement would be adequate. However, even after the baking, the laser discharge itself dislodges several atoms from the walls of the discharge tube and the electrodes, leading to significant contamination of the gas. The effect of these impurities is sought to be minimized by diluting them using a large volume of ballast gas. This problem is particularly severe in the initial stages and the lasing would stop after a few hundred pulses This can be avoided by taking the laser through three or four fill-operate-evacuate-fill cycles, operating each time for a few thousand shots. No baking is necessary during this process. Further cleaning by a getter is advisable, but we have not tried it. During the subsequent operation of the laser however, the gas pressure drops as a result of the Argon atoms getting absorbed by the walls of the discharge tube. This leads to a drop in the output power and in a severe case, to erratic firing. For this reason it is advisable to incorporate a gas reservoir (filled at 1 atm). connected to the discharge tube through suitable valves and fine capillary The lasers made in our laboratory had a usuable life of about 100–150 hours after which they could be evacuated and refilled again and operated.

B. *Resonant Cavity*

The resonant cavity of the laser is formed by two multilayer dielectric-coated mirrors of radius of curvature 2 meters, placed about 1·5 meters apart. These were supplied by the M/s. Spectra Physics (USA). The mirrors are held in simple mirror mounts of the so called 'two plate design'. The reflectivities of the two mirrors are 99·5 percent and 96 percent.

C. *Power Supply and Trigger System*

The laser is excited by D.C. voltage pulses of 750–3000 V coupled to the discharge tube through an artificial transmission line made up of several L.C. sections as shown in Figure 2. The capacitance (C) to be used is determined by the amount of energy desired to be fed to the laser. The inductance (L) value is chosen such that the characteristic impedance of the artificial line Z_0, given by $Z_0 = \sqrt{\frac{L}{C}}$ matches the ohmic resistance of the discharge tube. Since Z_0 is usually not known 'a priori', the value has to be chosen by trial and error. For the 6 mm i d. tube used, five sections each with, $C = 2\mu F$, $L = 16\mu H$/section



L=12 μH , C = 2 μF , C1 = 0 2 μF
T = Trigger transformer

Figure 2. Schematic of the transmission line and the trigger circuit.

resulted in good flat pulses of 50 μsec width. The use of a transmission line to feed the laser results in a flat rectangular shape for the current pulse, as well as the light pulse which is desired for many applications Further, if the laser is fed from a capacitor only, the time evolution of the current is controlled only by the stray inductances Typically, the current pulse has a steep rise and an exponential fall with a time constant of about 5 μsec under such circumstances. This results in a very poor efficiency for light generation, since typical ion laser plasmas do not attain useful electron temperatures (Klein 1970) in times less than about 20 μsecs. The width of the pulse W is equal to $2n\sqrt{LC}$, where n is the number of L–C sections, and determines the number of L–C sections to be used It is to be mentioned, however, that reasonably flat pulses can be obtained (Glasoe 1948) only with more than three sections Further, it is important to form the required inductances as sections of a single continuous coil (wound on a single former) rather than as separate coils, for attaining reasonably flat pulses (Glasoe 1948) The inductance, used is : a single layer air core inductor of 2·5 cm diameter and 20 cm length wound with 14SWG enamelled copper wire.

Total number of turns is 150; inductance is 80 μH, and inductance per section is 16 μH. The dimensions required for other values of the inductances can be calculated by consulting the relevant tables.

The trigger voltage ($\sim$20 kV) is applied to the tube through a capacitive coupling from a wire, wrapped around the tube near the cathode The trigger pulse transformer is wound on ferrite core (No. U1, 58-HP 28) manufactured by the Central Electronics Ltd. The primary of the transformer contains 40 turns of 18 SWG copper wire. The secondary contains 8000 turns of 38 SWG copper wire with 2 ml thick mylar sheet for interlayer insulation, and is impregnated with high voltage araldite after winding

3. Excitation Mechanisms

Gordon and co-workers (Gordon 1964) were the first to propose a model for the production of population inversion in Ar^+ lasers In this model, the upper laser level is excited by an electron collision with an ion in the ground state. This ion is supposed to have been created by an electron collision with a neutral atom in the ground state. So the two stages in which, the upper laser levels got populated, are

$$Ar+e \rightarrow Ar^+ + 2e \text{ and } Ar^+ + e \rightarrow (Ar^+) + e.$$

In an alternate model proposed by Bennett and co-workers (Bennett 1964), the population inversion occurs in a single step, the ionization of the neutral atom and the excitation of the ion to the upper lasing level occurring simultaneously. This type of operation occurs under very high E/P (Electric field/pressure) values. The observations of Rudko and Tang (Rudko 1966) indicated the existance of yet another mechanism, namely; the atoms are directly excited to some levels higher than the upper laser levels, from where they decay to the upper laser levels by radiative cascade processes.

4. Parametric Studies (Time Evolution)

Two different kinds of operation exist in pulsed Ar^+ laser, namely, short pulse and quasi CW operations. The short pulse operation occurs, when the current pulse is shorter than about 10 μsec, as well as, during the first 10 μsec. of wider pulses. At such short times, a definite electron temperature is not established but a significant number of fast electrons are present. These electrons are energetic enough to excite the Argon atoms to upper laser levels in a single step and lead to emission at 4765, 4965 and 5145 Å while the transition at 4880 Å is absent. Of these, the emission at 4765 Å is more predominant and also increases monotonically as the E/P value is increased. The emission at the other two wavelengths (4965 and 5145 Å) however falls off after some optimum value of E/P. Thus, a short pulse operation at a high E/P value should be chosen to get pure

4765 Å emission from this laser. Figure 3 shows the variation of the laser light intensity of 4765 Å line with peak discharge current. The currents are measured by the voltage drop across a low inductive resistor (0·39 Ω) inserted in the cathode lead. The peak power however depends on the pulse width also. The power obtained with pulses of 1 μsec width is considerably smaller than that with pulses of 5 μsec width.

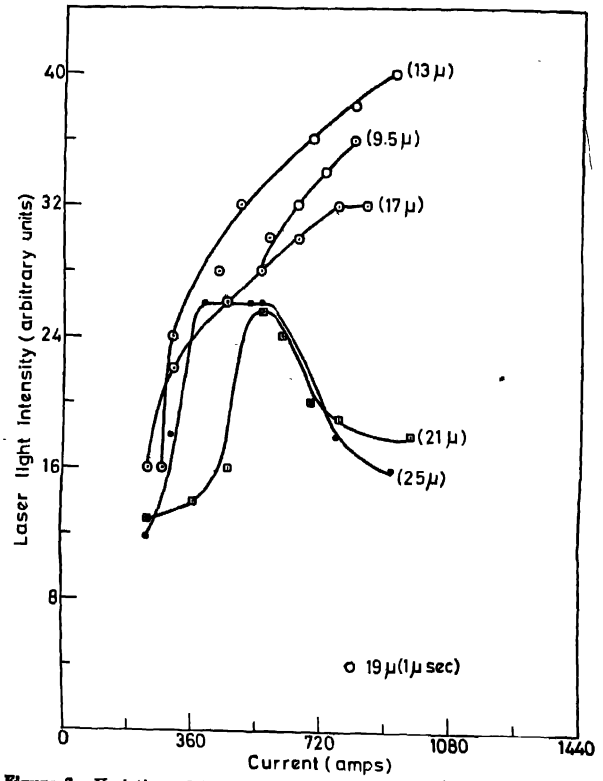


Figure 3. Variation of laser light intensity of 4765 Å line with peak discharge current.

No fast electrons are present in the discharge after about 5 μsec. and the electron energies are more suitable for two-step excitation. This is similar to the situation that exists in cw lasers and thus this mode is called quasi cw operation. In this mode of operation, the emission at 4880 Å and 5145 Å are predominant. In the present work it is seen that this behaviour continues for pulses of at least 240 μsec. duration. Figures 4, 5 and 6 show the variation of laser light intensity of 4880, 4965 and 5145 Å lines with peak discharge currents. Figure 7a shows the time evolution of the output at 5145 Å which exists during both modes of operation. Figure 7b shows the emission at 4880 Å which exists only in quasi cw operation. It is seen that the emission exists for the full duration of the current pulse only at low pressure. As the pressures is increased, the emission is quenched for an increasing fraction of the duration of the current pulse due to decrease in population inversion (Cheo 1965, Demtrodder 1966). Hence it is important to operate the laser at the optimum pressure, so as to get the maximum energy output.

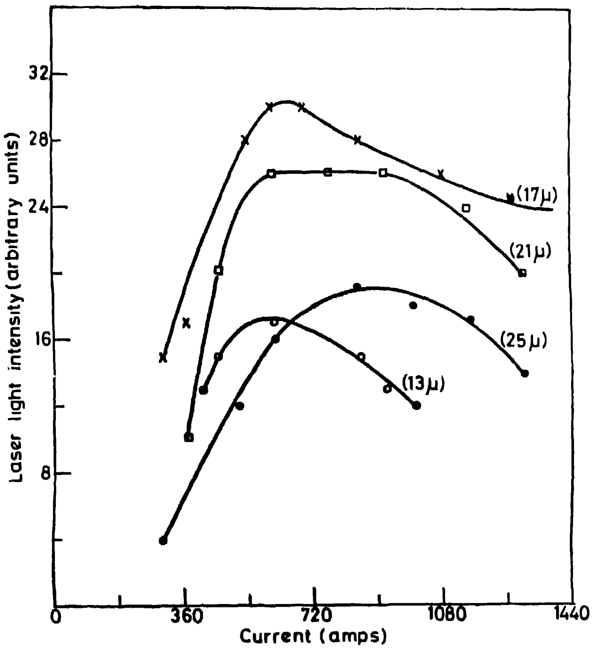


Figure 4. Variation of laser light intensity of 4880 Å line with peak discharge current.

From the Figures 3-6. it can also be seen that there is a definite, though broad, range of peak currents, for which the emission is maximum and for the tube of 6 mm i d. it ranges between 550-650 amp. The value of the optimum current changes only slightly for different wavelengths and also different pressures At higher currents, several processes, which tend to destroy the population inversion, (Cheo 1965, Hattori 1966) come into paly and reduce the output power. The present observations are in complete conformity with the theoretical and experimental results of the earlier workers (Cheo 1965, Hattori 1966, Demtroder 1966).

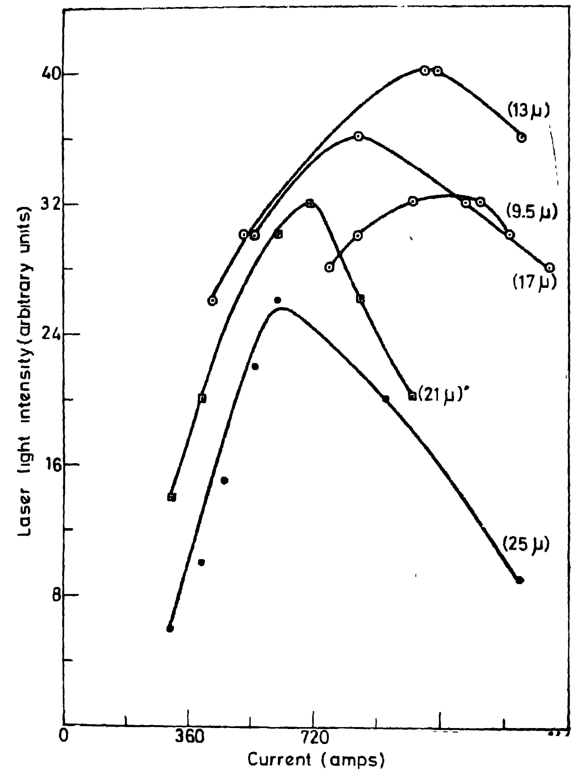


Figure 5. Variation of laser light intensity of 4965 Å line with peak discharge current.

With tube of 6 mm diameter, the peak power (all lines together) obtained in the quasi c w. mode is estimated to be about 200 W, while the optimum current and pressure are about 600 amperes, and 15 μ of Hg respectively. This peak power stays invariant as the pulse width is changed from 300 μsec. to at least 240 μsec. Some observations are also made with a tube of 4 mm i.d. For this tube, the optimum pressure is about 20 μ of Hg and the peak output power obtained is about 50 W.

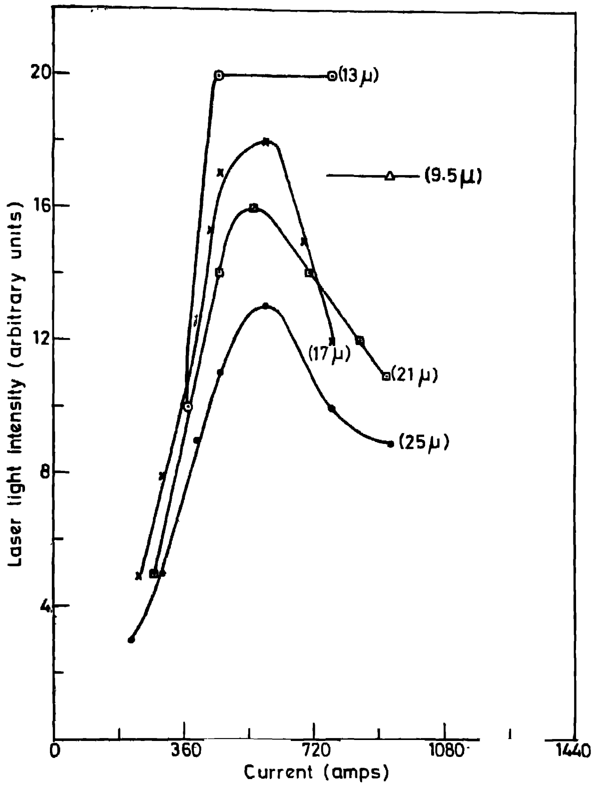
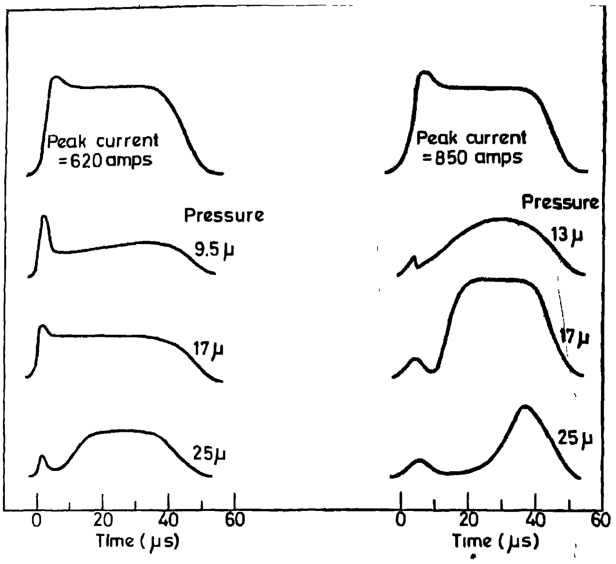


Figure 6. Variation of laser light intensity of 5145 Å line with peak discharge current.



(a) (b)

Figure 7(a) Time evolution of the output of 5145 Å line which exists in both short pulse and quasi continuous operations.

Figure 7(b) Time evolution of the output of 4880 Å line which existis in only quasi continuous operations.

5. Conclusions

A pulsed Argon ion laser can be built very easily with inexpensive materials and the pulse width can be varied in a comparatively simple manner. From the parametric observations made on the individual lines, it can be seen that the maximum energy output is obtained at a pressure of about 15 μ and a current of about 600 amps. The total maximum peak output power obtained is estimated to be of the order of 200 W for a tube of 6 mm i.d. The peak laser output power increases with pulse width for widths upto 30 μsec and stays constant for longer pulse durations, at least upto 240 μsec. If needed, very sharp (1 μsec.) pulses at 4765 Å can be obtained by reducing the pressure to about 13 μ of Hg. The output of this pulse can increase monotonically with input voltage.

The same discharge tube and PSU can also be used to obtain pulsed lasing in Kr and Xe also. The usefulness of this type of laser can thus be increased several fold by an integrated system consisting of the discharge tube a vacuum system and a row of gas bulbs containing Ar, Kr and Xe.

Acknowledgments

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