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A pulsed argon ion laser and ring dye laser system

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A structure and performance of pulsed argon ion laser are described. The discharge conditions were optimized and the peak power of 20 W was obtained at 1 kHz repetition rate with excellent reproducibility. A structure of a single mode ring dye laser pumped by the argon ion laser is presented.

1. Introduction

Pulsed argon ion lasers have been investigated by many authors. Some aspects of plasma development, ion population, discharge parameters, optical properties of active medium are established [1–5], and different discharge circuits are described. In this paper a novel scheme of electrical system is presented. It allowed us to obtain rectangular high current pulses with variable duration using low voltage power supply. A systematic study of the laser output power against pressure, peak current and pulse duration was performed for all blue-green argon ion lines. Under optimal conditions 8 μs pulses of 20 W peak output-power were observed. In addition laser action on UV argon ion lines and several krypton ion lines was achieved.

Using this laser as a pump source, a ring dye laser operating with Abbé prism and Brewster angle optical diode was constructed. A single mode operation with reasonably high efficiency (8%) and very good stability in a wide tuning range were observed.

2. Pulsed argon ion laser

The laser tube was a commercial (Carl Zeiss Jena production) graphite sectioned column. The bore size was 3 mm and each section was 6 mm long. High current oxide-coated cathode was used. High voltage (~10 KV) is necessary to get breakdown in this class of plasma tubes. Single pulse systems with thyratron discharging capacitor [6], or systems using high voltage prepulse [7] are widely known. Essential disadvantage of these designs is that they necessitate the use of high voltage elements. High voltage pulses caused discharge instabilities due to the tube construction. Very frequently the discharge was started on the outer surface of the graphite segments. To avoid this shortcomings low voltage power system was used. The power supply diagram is shown in Fig. 1. A low current arc discharge was maintained as a *keep alive* discharge providing continuous preionisation of the active gas medium. The main discharge pulses were formed by the thyrystor *T* and the artificial delay line *F.C.*, with 3 Ω impedance, and 5 µs propagation time. This system allowed to obtain rectangular 10 µs current pulses with amplitude up to 250 A and repetition rate up to 1 kHz. Voltage-current characteristics of the main discharge for different argon gas pressures are given in Fig. 2. As the diagram shows, differential resistance of argon plasma is almost constant within 250–600 V range, and does not depend on the gas pressure. This feature ensures impedance matching of the argon plasma tube and the delay line.

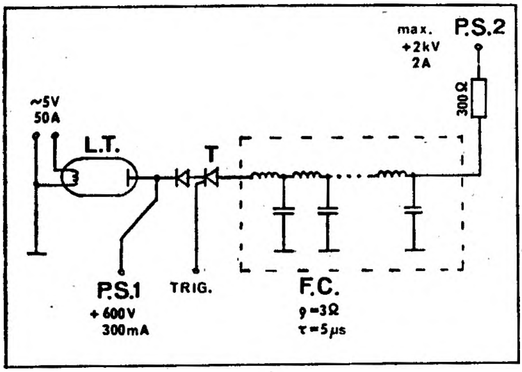

Fig. 1. Power supply diagram: *P.S.* 1 – continuous low current arc discharge power supply, *P.S.* 2 – main power supply, *F.C.* – pulse forming circuit, *T* – thyrystor, *L.T.* – laser tube

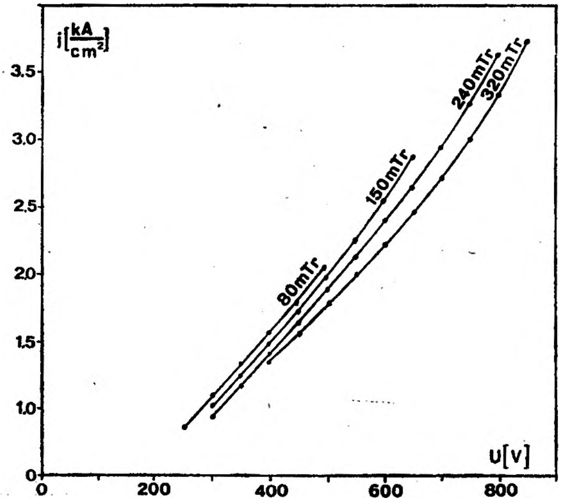

Fig. 2. Voltage-current characteristics of the main discharge for different argon gas pressures

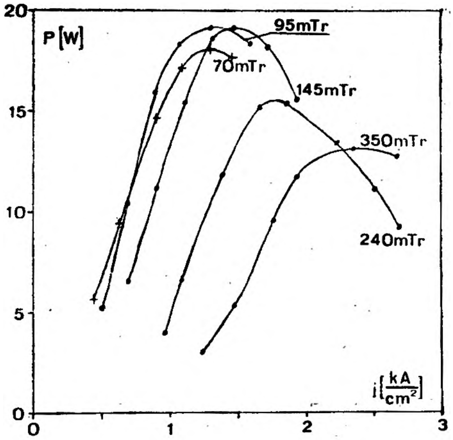

Fig. 3. Laser output power as a function of a current density for different gas pressures

Taking into account the maximum power which can be dissipated in a plasma tube and nonlinear characteristics of the tube discharge, it may be found that the efficiency of the laser is higher in pulsed regime. The current density in the pulsed laser tube can be increased in comparison with continuous operation, which increases the laser output. This fact is very important in case of high threshold laser lines when high output power is required.

Using 1.4 m long resonator with one fully reflecting flat mirror and the output mirror (curvature radius 5 m) with 5% transmittance, laser action at eight blue-green argon ion lines was obtained. No systematic attempt was made to optimize the output power, though a simple experiment with several different mirrors have shown that the optimum transmission is close to $5^0/_0$. Laser output power was studied in the case of all lines generation to determine its behaviour as a function of gas pressure and discharge peak current.

The results are shown in Fig. 3. The optimum pressure ranged from 90 mTr to 140 mTr when the discharge current density was changed from 1270 A/cm^2 to 1550 A/cm^2. Saturation of the output power at high currents was observed for all studied laser transitions. At pressures and currents near the optimum the time dependence of the laser pulse closely follows that of the current pulse. For higher pressures the lasing start is somewhat delayed with respect to the current pulse. This can be explained by a higher energy necessary to ionize larger number of argon atoms.

Small signal gain (SSG) measurements were made by inserting a tunable attenuator into the laser cavity and by increasing the attenuation until the laser threshold was reached. The measurements were made to establish SSG for the separate lines. The largest gain was attained for 488 nm line, its maximum value being about 7 dB/m. For the second strongest 514 nm line SSG was about 1 dB/m. These data are in a good agreement with the previously reported ones [4].

A weak ultra violet (351.4 nm, 357.7 nm) laser action was also achieved by using suitable mirrors. An attempt was made to generate laser oscillations with krypton as an active medium. Several lines (468.0, 476.2, 482.5, 520.8, 530.9, 647.1 nm) were observed. All these lines, however, were weak. This can be explained by the fact that the discharge current densities were much lower and the gas pressures much higher than the optima. As it was mentioned above the graphite bore did not allow high voltage and high current operation.

3. A single mode ring dye laser

The argon ion laser described above, working on all blue-green lines, was used to pump a rhodamine 6G dye laser in a ring cavity. Figure 4 shows the experimental set up. The resonator consisted of four mirrors ($M1$–$M4$), and an Abbé prism (P). Pumping beam after having passed through a flat mirror $M1$ transparent for all argon laser lines was focussed by mirror $M2$ on the jet stream J. Rhodamine 6G in ethylene glicol (concentration 0.87 g/l) was used, the velocity of the stream was equal to 18 m/s. Mirrors $M1$–$M3$ were fully reflecting in the range of 570–630 nm while the mirror $M4$ was used as on output coupler. The Brewster angle Abbé prism made of SF-59 glass allowed tuning of the laser. The crucial optical element in the ring laser is the *optical diode* (*O.D.*), the device which forces the laser to operate in a preferred direction. Without such a device the travelling wave could pick either direction resulting in a capriciouse operation.

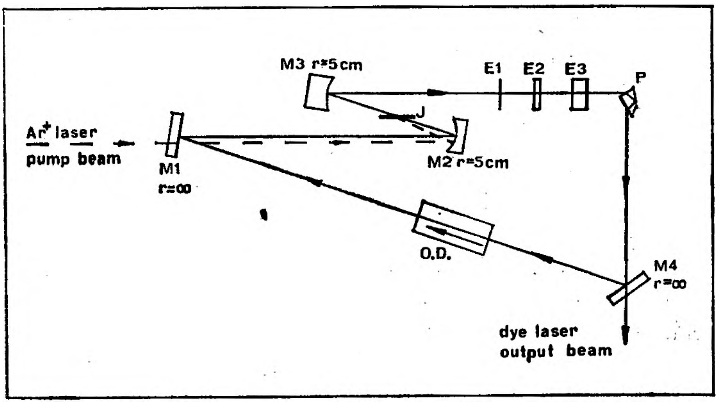

Fig. 4. Optical scheme of the ring dye laser cavity: *J* – dye jet, *M*1–*M*4 – mirrors, *O.D.* – optical diode, *E*1–*E*3 – etalons, *P* – prism

One direction operation is of great importance, since it eliminates mode competition removing the maximum pump power limit in a single mode operation. Moreover, the efficiency in a standing wave resonators is almost two times smaller.

The structure of optical diodes was similar to that described in [8]. It consisted of a Faraday rotator made from 18 mm long SF-2 glass rod, placed in the field of a cobalt-samarium magnets and crystalline quartz plate 0.1 mm thick.

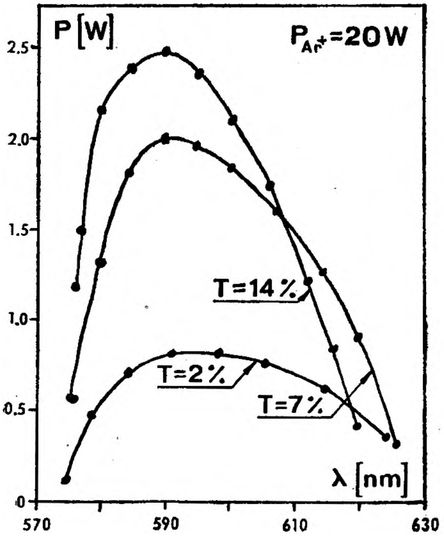

Fig. 5. Power output for different output couplings vs. wavelength

Both elements were inserted into the cavity at the Brewster angle. Each of them rotated a polarization of the laser beam by about 2.5 deg. For forward wave these two rotations cancel giving net effect; for the backward wave, these two rotations add and a net loss is greater due to the increased reflection by Brewster surfaces in the cavity. These additional losses were high enough to suppress completely the backward wave.

Tuning elements	P [W]	$\Delta\nu$ [GHz]	$\Delta\lambda$ [nm]
1	2.5	130	568–633
1.2	2.2	15	569–630
1–3	1.8	0.5	570–628
1–4	1.6	single mode	572–624

(1 – prism, 2 – ethalon 0.15 mm thick, 2 – ethalon 4.4 mm, 3 – ethalon 30 mm, pumping power – 200 200 W)

At the beginning the output mirror transmission was optimized against the power output and tuning range. The results are shown in Fig. 5. A $7^0/_0$ transmission was chosen as satisfying both criteria.

The spectral bandwidth with the Abbé prism as the only tuning element was about 1.5 Å. In order to decrease the linewidth three optional etalons ($E1$–$E3$) were added. All of them were dielectrically coated (single surface reflection $15^0/_0$). Intersection of the ethalons into the cavity produced the narrowing of laser line up to single mode operation. The results showing the maximum output power, linewidth and tuning range for different numbers of tuning elements are presented in the Table. Single mode dye laser efficiency was reasonably high (8%) and similar to those described in [8].

4. Conclusions

It has been found that pulsed argon ion laser is a very useful device, especially as a dye laser pump. The laser tube used in that experiment could supply continuous wave power up to 3 W, so it could be used as a pump for rhodamine 6G only. Under pulse excitation the peak power increased up to 20 W and the average power reached 160 mW at 1 kHz repetition rate. Such a laser can excite many different laser dyes operating from blue to red.

We have found, however, that segmented tube is not the best structure for pulsed operation for some lines. The discharge at low pressure and high current density tended to be unstable, that is why parameters of the UV laser lines were worse than expected. These problems can be avoided using capillary type tube.

The performance of the laser constructed was checked by using it as a pump for a ring cavity dye laser. Single mode operation of the dye laser was obtained with excellent reproductivity.

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Импульсный ионный аргоновый лазер и система лазер — циклический краситель

Представлены конструкция и свойства импульсного аргонового лазера. Были оптимизированы условия разряда и получена выходная пиковая мощность 20 Вт, с частотой репетиции 1 кГц и очень хорошей сходимостью. Описана, кроме того, конструкция лазера с циклическим красителем, работающего в единичном моде выемки, накачиваемого аргоновым лазером.

Перевела Малгожата Хейдрих