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Research Note

A Compact Simple Structure TEA CO_2 Laser with Dielectric Corona Preionization

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In this paper, a compact simple structure, a TEA CO_2 laser with dielectric corona preionization, is introduced. This structure is suitable for a high repetition rate (transverse gas flow) or sealed-off operation of the laser. The cathode of the laser is a copper Ernest profile electrode. For the anode, a Pyrex plate is sandwiched between two stainless steel meshes, where one of the meshes are used as the anode of the laser. In this structure, the anode and the cathode electrodes are parallel, as in all other TEA lasers. To produce preionization, the other mesh of the Pyrex plate is connected to the cathode electrode by a copper strip. For this simple structure (a single discharge TEA CO_2 laser in a 1.2 cm electrode gap with low CO_2 concentration), the output energy per unit volume obtained is more than 20 J/l.

INTRODUCTION

The term "corona discharge" refers to phenomena, which occur in a gaseous medium in the vicinity of conductors with a small radius of curvature subjected to high voltage. The high electric field along the surface is usually non-uniform and produces a partial breakdown of the surrounding gas. When a dielectric plate is subjected to a high electric field, a similar situation may arise. The field polarizes the dielectric plate and a high field is present at its surface. Then, a corona discharge may be produced in the surrounding gas near the dielectric plate [1]. This mechanism has been exploited in several different laser constructions [2,3]. Ernest and Boer [4-6] used two suitable dielectric sheets parallel to the optical axis and perpendicular to the electrodes. Then, closely approaching the anode, the dielectric plates were subjected to a very strong electric field. In the method used by R. Marchatti [2], electrodes were installed in a suitable circular dielectric tube (Pyrex), surrounded by a stainless steel mesh connected to the cathode and the corona is produced on the surface of the dielectric tube. Bahrampour and co-workers added an additional mesh under the cathode and inside the laser tube to increase the energy deposition into the corona plasma and UV-light intensity [7]. In this work, a new construction and its performance is reported. In this structure, a Pyrex plate is sandwiched between two stainless steel meshes. One of the meshes is used as the anode of the laser tube and the other mesh is connected by a copper strip to an Ernest uniform electric field distribution copper cathode electrode. The corona plasma is produced on the anode surface. Similar to all previous dielectric-corona preionization structures, this configuration is also suitable for a sealed-off operation. In previous dielectric-corona, preionization TEA CO_2 laser, the UV preionization photons are emitted from the sidewalls. The lasing gas flows longitudinally and the heat transfer that restricts the laser repetition rate is slow. In the structure described in this paper, the sidewalls are completely removed, hence, the transverse gas flow can provide fast heat transfer and a high repetition rate operation is possible. These lasers are suitable for industrial photochemistry applications.

CONSTRUCTIONAL DETAILS

Figure 1 shows a cross section of the laser tube perpendicular to the optical axis. The cathode is an Ernest uniform electric field distribution and is fabricated according to the following analytic expressions [8]:

$$x = u + k_0 \sinh(u)\cos(\nu) + k_1 \sinh(2u)\cos(2\nu),$$

$$y = \nu + k_0 \cosh(u)\sin(\nu) + k_1 \cosh(2u)\sin(2\nu), \tag{1}$$

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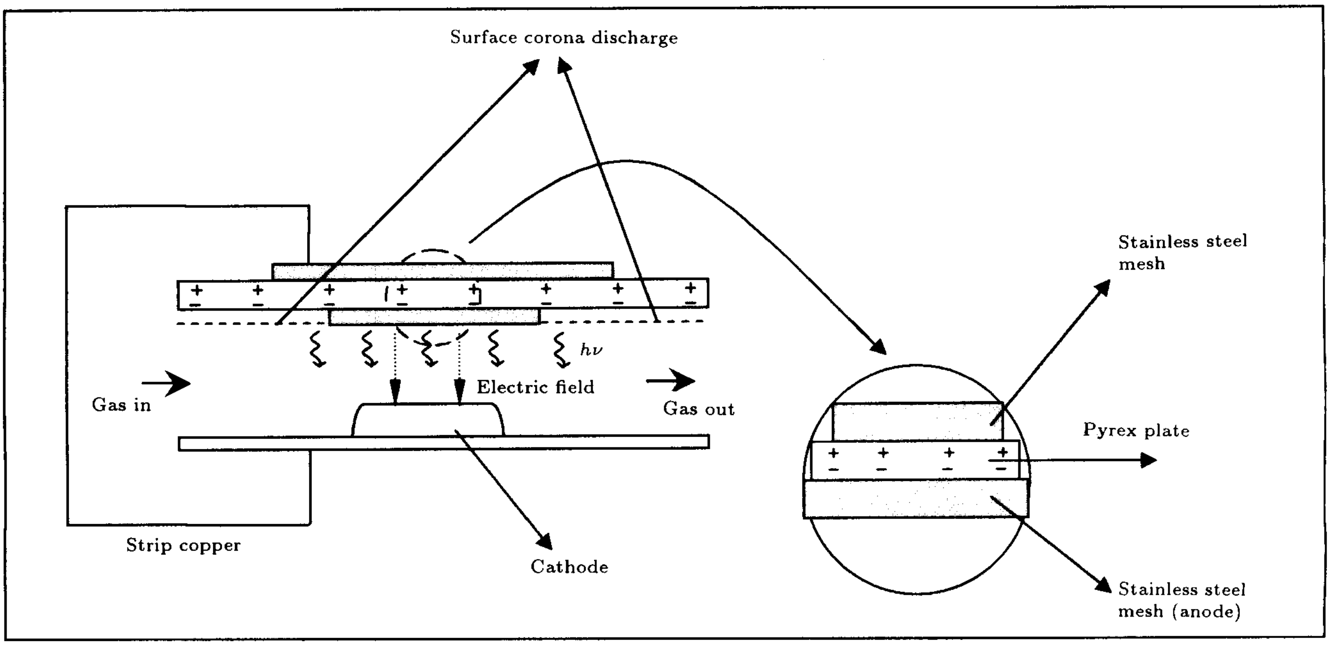

Figure 1. Schematic drawing of a cross section of the laser tube perpendicular to the optical axis.

where x and y are the space coordinates and u and ν are the flux and potential functions, respectively. For each value of $\nu(|\nu| < \pi)$, the above equations correspond to the equipotential surfaces and u is the running variable for these surfaces. This profile is symmetric, with respect to the y axis and the equipotential surfaces ($+\nu$ and $-\nu$) are images, with respect to the x axis, which are prerequisites for a uniform field electrode. Three independent variables, k_0, k_1 and ν determine the form of the profile, as well as the electric field strength distribution. Once k_0 has been chosen as an independent variable, k_1 and ν can be used to optimize the electric field strength distribution over the surface. From the above discussion, it can be seen that the profiles are not uniquely determined [7]. For an electrode gap of 1.2 cm, k_0 is chosen as 0.015 and k_1 and ν are determined as 0.28×10^{-4} and 1.5707, respectively.

The anode is a stainless steel mesh with a Pyrex plate sandwiched between the anode mesh and the other mesh, which is connected to the cathode electrode. The optical cavity consists of a planar, total reflecting, Brillion copper mirror and a concave, 60% reflecting, coefficient coated ZnSe mirror, with a 30-meter radius of curvature as the output-coupling mirror. The length of the profiled electrode is 32 cm and its width is 2.3 mm.

The physical principles involved in producing uniform preionization in the laser are explained with the aid of Figure 1. A high voltage pulse is suddenly applied between the electrodes through an electric circuit. Thus, a high electric field with a rapid rise appears as a strong electric field. They become polarized with surface charges, as shown in Figure 1. The high voltage in the surrounding gas produces a surface corona discharge. The ions formed in the surrounding gas are attracted by the Pyrex plate and the electrons are easily pulled from the gas layer by the strong electric field at the intersection of the Pyrex and the anode mesh. Once sufficient electrons are presented in the gas layer, steamers are formed and rapidly develop into avalanches. Because of the non-conductivity of the Pyrex, the surface discharge is uniform in the direction of the optical axis [9,10] i.e. perpendicular to the electric field (Figure 1). The plasma produced near the Pyrex plate forms a uniform channel for the passage of current, which, in turn, emits the Ultra Violet (UV) photons. The light emission from current surface-spark discharge has been extensively studied by Beverly [1].

The spectral investigation of the corona discharge at different gas compositions has been studied by Bob Cock [11]. The UV photons emitted by this uniform electric corona discharge illuminate the electrode gap uniformly in the direction of the optical axis. However, it is affected by the gradient in the direction perpendicular to the optical axis and the current direction. The widths of the anode mesh and preionization mesh determine the field uniformity between the electrodes and, also, the gradient in the direction perpendicular to the optical axis and to the main current direction.

Figure 2 shows the burn patterns of the output laser for several values of the anode width (A). For large anode width to cathode width (K) ratio, the population inversion near the optical axis is less than the sided regions. This effect causes low amplitude for

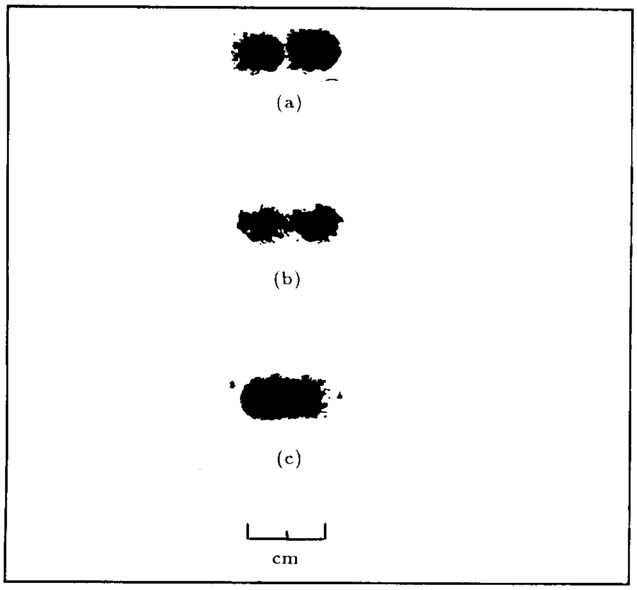

Figure 2. Spatial burn patterns of the laser output, 10 cm far from the output coupler, for anode widths; a, b and c, corresponding to 5 cm, 4 cm and 3.3 cm, respectively.

the TEM_{00} mode relative to the higher order modes and this effect can be obviously observed in Figure 2.

The output energy of the laser, versus the anode width to the cathode width ratio, are measured and shown in Figure 3. As expected, there exists an optimum value, which maximizes the laser output energy.

Figure 4 shows the output energy variation versus the width of the preionization mesh (P) to the cathode width (K) ratio and, as expected, the optimum value of this ratio is greater than that of the anode value. Beverly showed that the initial rate of energy input into the surface discharge channel and its light emission is largely determined by the initial rate change of

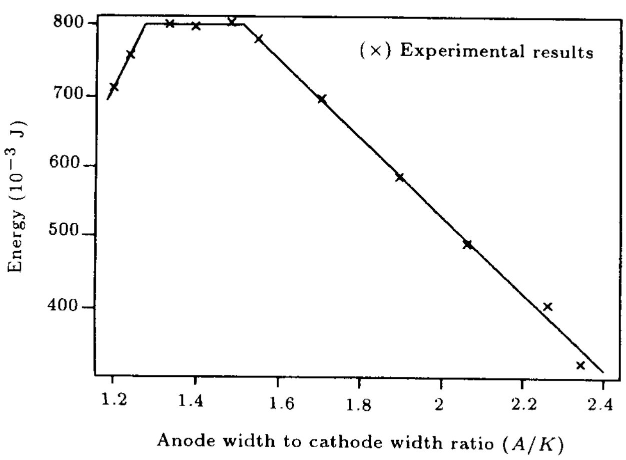

Figure 3. The output energy of laser versus the anode width (A) to the cathode width (K) ratio for a 1:1:7, CO_2: N_2: He mixture. Main capacitance and voltage are 40 nF and 15 kV, respectively.

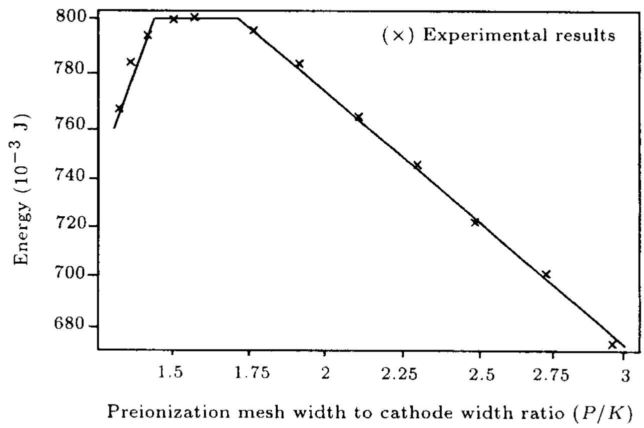

Figure 4. The output energy of the laser, versus the preionized mesh width (P) to the cathode width (K) ratio for a 1:1:7, CO_2: N_2: He mixture. Main capacitance and voltage are 40 nF and 15 kV, respectively.

the current with time [1]. A rapid change of current requires a low inductance driving circuit, because the initial current rise is ($\frac{di}{dt} = \frac{V}{L}$), where V is the imposed voltage and L is the inductance of the circuit. On the other hand, the discharge time is proportional to the square root of the inductance of the circuit. The long discharge time causes thermal-free running and sparking will occur [10,12], hence, this structure is strongly sensitive to the inductance of the discharge circuit. The peaking capacitor is also the capacitance between the anode and the preionization meshes. It is shown [13] that the output energy per unit volume of the active medium has an optimum value, with respect to the peaking capacitor, which has a relatively large value (nearly 3 nF in our conditions). The capacity of the capacitor between the meshes is inversely proportional to the thickness of the Pyrex plate. This means that the displacement current and, consequently, $\frac{di}{dt}$ increases with a decrease in the thickness. This, in turn, affects the energy deposition into the corona plasma and the UV light intensity. However, thickness reduction and voltage increase is limited by formation of the surface arc at the time of increasing the corona current [1]. The optimum condition is obtained for a 2-mm thickness Pyrex plate and a 3.3 cm width anode. Of course, an external 2.7 nF ceramic capacitor is used to produce the optimum condition, with respect to the peaking capacitor [13].

Figure 5 shows the variation of the output energy for a CO_2: N_2: He = 1:1:7 mixture as a function of the capacitance of the main capacitor up to a certain voltage, which depends on the pressure of the gas and gas mixture when a normal uniform corona is observed. As the voltage is further increased, the regime of surface sparking is reached. The sparking threshold voltage is rather low for pure helium, however, nitrogen and carbon dioxide increase the threshold level of surface sparking. As expected, this threshold increases with

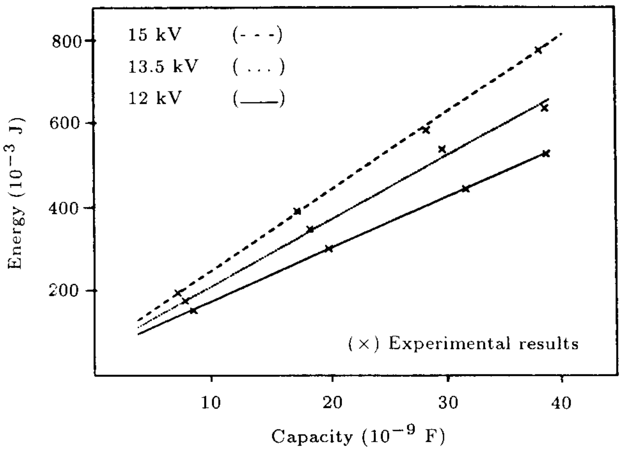

Figure 5. Output energy as a function of the main capacitor for a 1:1:7, CO_2: N_2: He mixture. The supply voltage has been used as a parameter and a, b and c correspond to 12 kV, 13.5 kV and 15 kV, respectively.

gas pressure. The UV light, produced by the corona for constant voltage, decreases as pressure increases. The reason is, when pressure and constant voltage increase, the current change, $\frac{di}{dt}$, decreases. The greater the $\frac{di}{dt}$ the more intense is the UV radiation. The uniformity of glow discharge strongly depends on the roughness of the Pyrex plate.

Figure 6 shows the variation of the output energy for the authors' previous conditions as a function of pressure. The output energy was measured by a "AN 20" model Russian Joule Meter. Its maximum was 800 mJ for supply voltage 15 kV and a high, free-running frequency, homemade, 40 nF, main capacitor. The output energy of the laser is limited from above by the volume sparking in the laser tube. The width of the output beam is measured by the burn pattern of the pulses on a fax paper. To increase precision, measuring has been done after more than

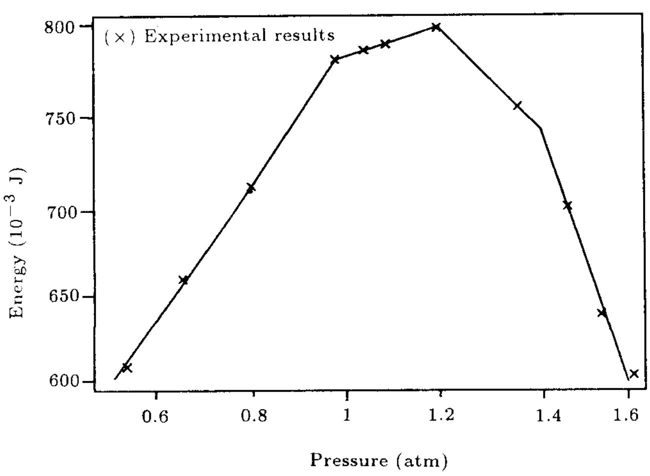

Figure 6. Output energy as a function of the pressure for 1:1:7, CO_2: N_2: He mixture. Supply voltage and main capacitance are 15 kV and 40 nF, respectively.

a ten pulse irradiation. The width appears to be 1 cm, which means an active volume of 38.4 cubic ml and an output energy per unit volume of 20.8 J/l. The calculated efficiency for a 4.5 J input energy is 17.7%. Lastly, in this investigation, a laser tube has been made with a cathode structure similar to its anode, which has been described in this article. The preionization mesh corresponding to the cathode electrode is connected to the anode mesh and the preionization mesh of the anode electrode is connected to the cathode mesh. Only a uniform glow discharge is obtained around the edges of the electrodes and no discharge in the volume is observed. In the future, the authors' investigation will continue to obtain a uniform glow discharge in the large volume of this structure.

CONCLUSION

In this work, a simple preionization, single discharge, high-output energy per unit volume dielectric corona, with high efficiency, is introduced. This structure is suitable for sealed-off operations and can also be used for transverse gas flow operations in high repetition rate lasers, which are attractive in photochemistry research and industries. In this structure, the glow discharge is extra uniform for lasers with small electrode gaps.

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