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Numerical Investigation of the Non-Uniformity of the Electric Field Distribution by Injection of Net Electron Charge in TE CO_2 Laser

Nader Morshedian[1,*], Majid Aram[2], Ahmad Mehramiz[3], and Nahid Jahanian[1,2,3]

[1] Plasma and Fusion Research School, NSTRI, North Kargar Ave., Tehran, Iran.

[2] Photonics & Quantum Technologies Research School, NSTRI, North Kargar Ave., Tehran, Iran.

[3] Department of Physics, Faculty of Science, Imam Khomeini International University, Qazvin, Iran.

*Corresponding Author's Information: nmorshed@aeoi.org.ir

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ABSTRACT

In this report, the distribution and deviation of electric field in the active medium of the TE CO_2 laser has been investigated due to the injection of net electron charge beam as a plasma generator. Some parameters of system have been considered, such as density and mean-free-path of injected charge beam. The electric potential and electric field distribution have been simulated by solving the Poison's equation using the method of successive over relaxation (SOR) numerical method. The electrode potential and the number of injected charged particles are respectively considered to be +75 kV and 10^8 mm^{-3}. In these conditions, the maximum energy of the electrons beam would be at the order of 1-2 eV. Deviation of the electric field with different mean-free-path of electrons beam with Gaussian density distribution has been numerically calculated. It has been concluded that if the net charge density is increased then the field deviation would grow. Moreover, if the mean-free-path of the electrons is decreased, subsequently, the electric field deviation is increased.

1. INTRODUCTION

The CO_2 lasers were first introduced in 1968. At the beginning, the output energy of these lasers were at the order of Joule and then the technology of this laser developed very fast and its energy reached up to kilojoule [1]. Therefore since then, many research works have been concentrated towards increasing the output energy of this type of laser. Having high CO_2 laser energy, necessitates whatever larger active medium with as much as uniformity in the excitation of CO_2 molecules [2].

Apart of the electrical discharge as the main source of plasma creation and formation of excited molecules and creation of population inversion, the complementary methods such as pre-ionization methods, net charge injection [3] and configuration of the electrodes geometry [4], have been useful ideas in order to perform uniform glow discharge and thus having better population inversion in the active medium.

In this report, we have theoretically investigated the uniformity of electric field in the gas-plasma discharge when the net charge (electrons) injection method is employed. The electrons beam is assumed to be injected perpendicular to the optical axis of the laser.

2. THEORETICAL METHOD

The SOR method is considered for numerical simulation of the electric potential in a discharge medium. In this method, if the computer memory does not limit us, there would be no other restriction for the numerical processing.

Also, this method has the benefit of reducing the calculation approximations. According to Fig.1, the solution of the potential equation at each point is based on the potential value obtained at that point for the previous stage, plus the averaging of the four potential values of the points in the vicinity of intended point.

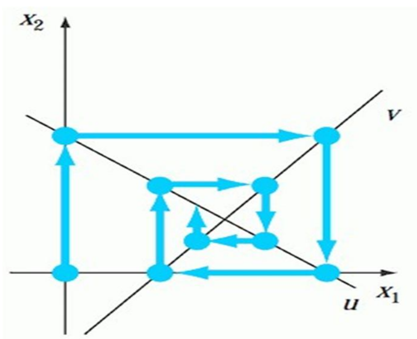

Figure 1: The path of the successive calculation for the potential of each point.

The relation (1) is generraly defined for the potential value for each point [5];

$$x_i^{(k)} = (1-w)x_i^{(k-1)} + \frac{w}{a_{ii}}\left\{ b_i - \sum_{j=1}^{i-1} a_{ij}x_j^{(k)} - \sum_{j=i+1}^{n} a_{ij}x_j^{(k-1)} \right\} \quad (1)$$

where, $x^{(k)}$ is the response vector or scalar that here it means the potential variable, $i=1,2,...n$, which n is the number of iteration, w is the scaling factor (w= 0-2) and if w=1 the above relation is converted to the Guass-Siddle equation.

Also, a_{ij} is the matrix array of coefficients, b_i is the constant value of the equation and $x_j^{(k-1)}$ is the potential value obtained for the previous stage. Thus the final value of the potential is resulted by iteration, provided that the solution is converged by estimation of the scaling factor (*w)* to a specific value.

Indeed, the Poison's equation according to the relation (2) is numerically solved using this method.

$$\nabla^2 V = \frac{\rho}{\varepsilon_0} \quad (2)$$

which V is the potential, ρ is the charge density and ε_0 is the vacuum permittivity. Here, it should be mentioned that equation (1) should be redefined for potentials in a medium with different permittivity at the boundary conditions which are shown schematically in Fig. 2,

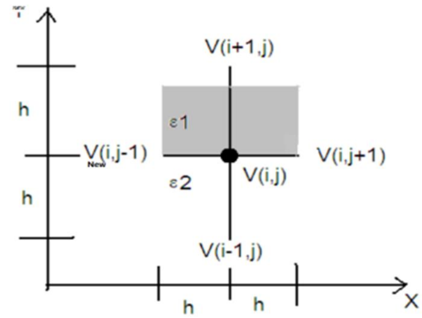

Figure 2: Showing a point with four vicinity points of potential and different permittivity at the boundary.

Relation (3), is redefined in accordance with relation (1) based on the SOR method [6].

$$\begin{aligned} V_{new}(i,j) = {} & (1-w)\times V(i,j) + \\ & \frac{w}{4}((V(i,j+1)+V_{new}(i,j-1) \\ & +(\varepsilon_1 V(i+1,j)+\varepsilon_2 V(i-1,j))/(\varepsilon_1+\varepsilon_2))+ \\ & 1/((\varepsilon_1+\varepsilon_2)/2)\times\rho(i,j)\times d^2 \end{aligned} \quad (3)$$

Where, ε_1 and ε_2 are the permittivity of two media at the boundary, $V(i\pm1, j\pm1)$ is the four potential values at the vicinity of the concerning point, $V_{new}(i, j-1)$, is the potential value obtained for the previous stage, $\rho(i,j)$ is the net charge injected and d is the distance between the two successive points of the mesh. The distribution function of the net charge injected is as follow;

$$\rho = en\,exp(\frac{-x}{L})^2 \quad (4)$$

Where, e is the electron charge, n is the number charged particles which here assumed to be $10^8/mm^3$, L (mm) is the mean-free-path of the electrons or is the distance where the charge density decay to $1/e$ of its initial value. If the value of L is increased then the density of charges in the active medium becomes comparatively more uniform. The values of the electric field are calculated using the potential values which are resulted through numerical simulations, according to relations (5) below,

$$|E_x| = \frac{V_2-V_1}{x_2-x_1}, |E_y| = \frac{V_2-V_1}{y_2-y_1}, E = \sqrt{E_x^2+E_y^2} \quad (5)$$

Where, V_1, V_2 are the potential values of two consecutive points and $E_{x,y}$ is the electric field along the *x, y* axis. Here, it we can define the field deviation (*FD*) as;

$$Field\ Deviation = \frac{\Delta E}{E_o} * 100 \qquad (6)$$

in which E_0 is the electric field of the central or symmetrical point of the system and ΔE is the electric field difference between the central point and the point at the edge of the electrode. The cross section of the electrode, geometry of the active medium and the boundaries are all shown in Fig. 3.

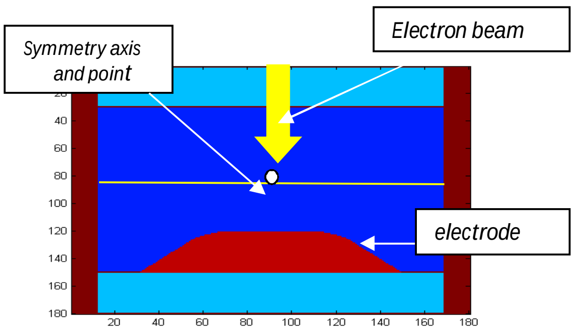

Figure 3: The geometry of the system.

Indeed, the two cones of the electrode are bowed with a radius of about 2 mm and each four external sides are grounded. The beam is injected transversally i.e., normal to the optical axis and perpendicular to the electrode.

3. Results and Discussion

Using MATLAB for programming and the SOR method for numerical simulation, the experimental conditions and system parameters have been considered as follows; the electrode is connected to a potential supply with +75 kV voltage and as mentioned before, all the external boundary edges are set as zero potential or grounded. The special value of the electrode voltage is an optimized value in order to obtain the practical value for reduced-electric-field (*E/N*) and having a good performance for CO2 laser operation. Each laser has its own optimized *E/N*, and for CO2 laser, this value is about $4\times10^{-16} V.Cm$ [1]. In this condition, the electrons distribution is maximized for 1-2 eV energy with different mean-free-paths. As mentioned before, in the SOR method, the initial potential for each point is calculated based on the previous value in the iteration process and averaging of the four vicinity points. By definition, the field deviation is computed using the potentials obtained at the edge of the right and left hand sides of the active medium. This is relative to the potential at the symmetry distance (here, 5 mm) measured from the symmetry center. The field deviation is a criterion for the uniformity of electric field in order to reach a suitable glow discharge in the active medium. It means that, in this condition it is possible to prevent the generation of sparks and/or arcs in the discharge. Table 1 shows the dielectric permittivity constant of the gas mixture with different rate mixing and the corresponding field deviations [8].

Table 1
K and ε Values for Different Gas Mixture and the Corresponding FD

CO_2:N2:He	*K* $(\times10^{-18} c)$	$\varepsilon = \frac{c}{N.mm^2}$	FD
1:1:1	1.0007	8.8565	0.9970
1:1:8	1.0006	8.8557	0.9970
1:1:3	1.0007	8.8560	0.9970

Moreover, the field deviation data in terms of different values of mean-free-path and constant density of charged particles beam has been given in Table 2.

In Figs. 4 and 5, the 3D potential and electric field distribution have been illustrated by solving Laplace equation i.e. without any charge injection. It should be pointed that, the field deviations in different mixtures of gases are approximately the same as those given in Table 1.

Table 2
Mean- Free- Path and FD

L	$\rho(\times10^{-11} \frac{C}{mm^3})$	FD
0.025	-1.6000	0.6946
0.05	-1.6000	0.7539
0.5	-1.6000	0.7555

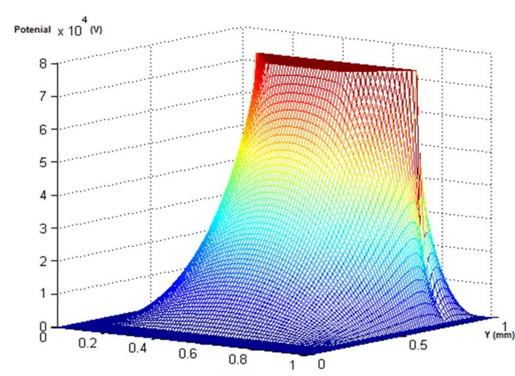

Figure 4: The 3D potential distribution without beam injection (electriode potential 10 kV).

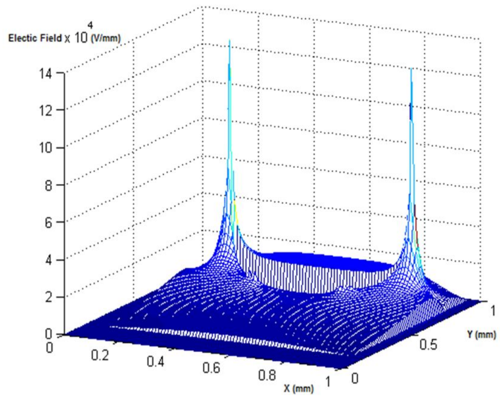

Figure 5: The 3D electric field distribution without beam injection (electriode potential 10 kV).

By injection of the electron beam and solving the Poison’s equation, the potential and electric field distribution have been obtained as illustrated in Figs, 6 and 7.

It is obviously apparent that the field deviation is reduced by injection of net charge. By increasing the electron density in the medium, the potential is increased and it should be noted that, due to increasing of the mean-free-path of the beam larger than the symmetry distance of the system (5mm), the field deviation would increase.

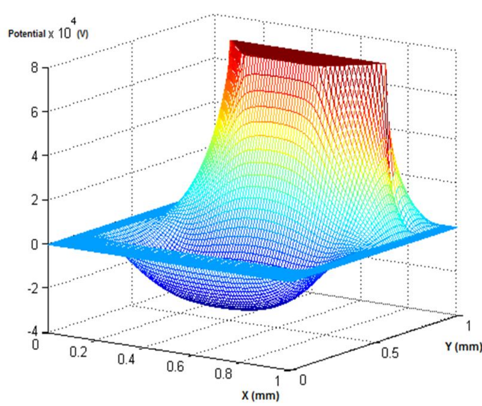

Figure 6: The 3D potential distribution with beam injection (electriode potential 10 kV).

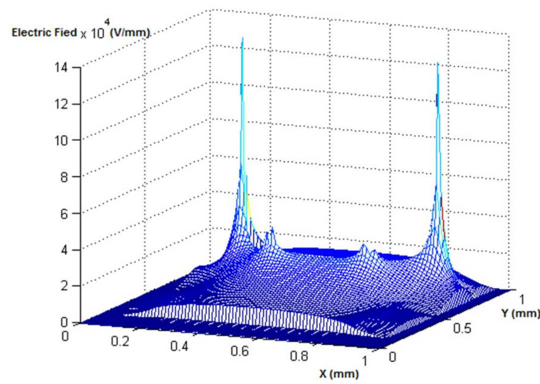

Figure 7: The 3D electric field distribution with beam injection (electriode potential 10 kV).

4. Conclusion

The generation of pre-plasma is generally important for a uniform discharge medium and also for preventing arcs and/or sparks in the active medium. One of the methods of producing such conditions, is external charged beam injection in order to achieve a glow discharge and uniform pumping for population inversion. It is resulted that, there are two basic parameters i.e., electron beam density and mean-free-path of the beam injected which should be optimized for having much less electric field deviation in the active medium of the laser. The results show that by increasing the value of the electron density, the field deviation is increased. Furthermore, if the mean-free-path of charged particles is decreased, the field deviation would grow.

5. Acknowledgment

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BIOGRAPHIES

The Authors' photographs and biographies not available at the time of publication.

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