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Three – Mirror Laser Design to Calculate Some Plasma Parameters

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ABSTRACT

In this project, a new design have been suggested to use three – mirror laser as an interferometer by coupling a laser cavity with on other passive one containing low – density cold plasma. The aim of coupling is to study some important parameters of the plasma via a simply gained broadening technique.

The parameters in question are the plasma refractive index (μ), and the electron concentration (n_e). The design was appearing to be successful when some numerical calculations were held and compared to previous experimental works.

Keywords: Atomicand molecular collision, plasma and laser physics, Enerquhestribution functions.

Introduction

It is known that a single – cavity laser consists of two high reflective, identical mirrors placed parallely some distance a part which is called physical length of the cavity. ,d, The modified structure of this laser is accomplished by putting a third mirror which has some how high reflective index, to be discussed later, which is called the "coupling mirror". This mirror is fixed some where between the two original mirrors producing two nearly equil cavities in length. This mirror acts as an interacting source between the laser cavity and the other "passive cavity".

The act of interaction will offer a lot of informations about the nature and parametric instabilities of the second cavity, since laser characteristics are well known and identified simply.

Also the coupling mirror should be partially transparent in order to diffuse few percentage of the incident radiation.

The schematic diagram of TML, is short, is shown in fig. (1).

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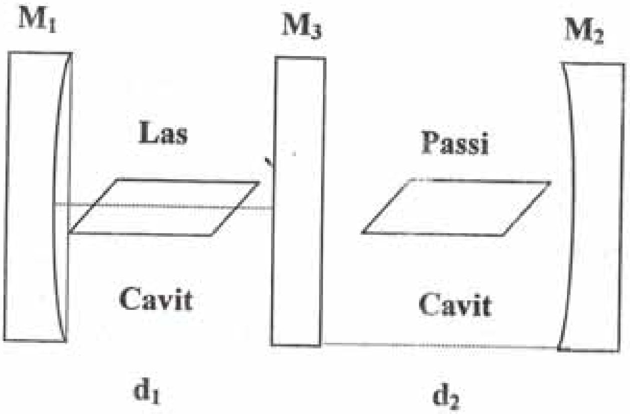

Fig. (1) Geometric description of "TML"

In this design, M_1, M_2, and M_3 are the input, the output and the coupling mirrors respectively, d_1 and d_2 are the physical lengths of 1st and 2nd cavity respectively. The laser cavity contains a mixture of "Helium and Neon" neutral gases with ratio of 8; 1 [He: Ne] in volume and the total pressure of (3 torr) approximately.

[1 torr means of 1 mm.Hg]. Of course the wave length of the output beam is 632.8 nm. On the other hand, in our design the passive cavity contains a low – electron, cold plasma, having average temperature of about 2000 K°.

The usual family of plasma material are:

Argon, Krypton, Xenor,……etc.

Theory:

Langmuir in 1926 [1], when he was intensively working on high temperature discharge tubes, defined "plasma" as highly ionized gases, which are good conductors of electricity. He stated that the charged particles in such a gas, interact with the local electro-magnetic field which can produce both electric and magnetic fields separately which is called the "field – free" regions of the gas where positive and negative space charges are nearly balanced.

We are now in a position to confine our selves to the details about cold – plasma considerations which has temperatures ranging between [$1.5*10^3$ and $3*10^3$] K°. By low electron density wee mean the plasmas which have nearly about 10^{18} to 10^{20} electron in one cm^3.

1- Plasma Electron Density

Plasma is the resultant of long studies about electron-dynamics. Classically [2] we know that if a charged particle moves in an electro - magnetic field ,then it will act as "dipole-oscillation" model. If the frequency of oscillation is such that it could be compared to the frequency of electromagnetic radiation, then it is called plasma-oscillation [3].

Alfven [4] had studied the nature of inter action between these particles and the field interacting with them and could find that their natural frequency [wp]is directly proportional to the density of electrons [ne] in the sample and formed the relation as:

$$w_p = \left(\frac{4.\pi.\, n_e\, e^2}{m_e} \right)^{1/2} \text{..................}(1)$$

where n_e is the density , e and m_e are charge and mass of electron respectively.

The details of mechanism about processing equation (1) will be discussed later, since both wp and n_e are very difficult to be calculated separately. Equation (1) could be re-written as:

$$n_e = \left[\frac{m_e}{4.\pi} \cdot \frac{w_p^2}{e^2} \right] \text{.........(2)}$$

2. Plasma Refractive Index

Plasma dynamics is looking much likely as dispersion of an elector –magnetic wave in a dielectric medium. Analysis show that propagation of a mono-chromatic radiation beam with some degree of coherency, result complex index of refraction of the medium.

We are not dealing our selves with detail of this process, but the tendency is rather towards the real part of this index.

Landau [5] has treated the problem by relating the natural frequency of the radiation and the plasma frequency in some way.

He said that the difference in square – value of them is proportional with squar of the velocity of light, i.e.:

$$w_L^2 - w_p^2 \alpha \cdot c^2 \quad \text{or}$$

$$w_L^2 - w_p^2 = c^2 . \text{[constant]}$$

The constant of proportionality was finally determined by Lifshit [6] "a collaborator with Landau" and he said it is similar to the propagation constant "K" of the plasma frequency:

$$\therefore \quad c^2 \cdot K_p^2 = w_L^2 - w_p^2 \text{ ....(2)}$$

but $K_p = 2.\pi / \lambda_p = c / \text{v}$ and $c = w/K$

arranging these terms in (2) we get:

$$\therefore \quad \mu^2 \cdot w_L^2 = w_L^2 - w_p^2 \quad or$$

$$\mu = \left[1 - \frac{w_p^2}{w_L^2} \right]^{1/2} \text{............(3)}$$

Equation (3) is a non trivial one, since w_p is a non – measurable quantity with out any know ledge about (μ).

The TML Characteristics

As we have mentioned earlier in the introduction, the TML is used to couple a laser cavity with one other passive one for which characteristics are an known.

This idea was firstly announced by Spencer and Lamb [7], who described the theory of two coupled laser. In their approach, "a transmitting window" was used for coupling. The parameters given to this window were transmittance and reflectance as:

$$T = \frac{4}{\Lambda^2 + 4} \qquad and \qquad R = \frac{\Lambda^2}{\Lambda^2 + 4}$$

where Λ is a characteristics dimensionless parameter which is the function of space as:

$$\varepsilon_{(z)} = \varepsilon_{(0)} [1 + \Lambda . \delta(z) / K] \text{ ....(4)}$$

here: $\varepsilon_{(z)}$ the E. field intensity at z

$\varepsilon_{(0)}$ the E. field intensity at $z = 0$

and K is the propagation vector [$K=2.\pi/\lambda$]

In TML, Jones and Leck [8] suggested that the transmitting window may have more parameters to be discussed such as: Loss and coupling coefficients, these are: $\Gamma = \sigma / \varepsilon_0$ and $M = c.d / \eta$ where Γ is the Loss factor, σ is the fictitious conductivity of the window material, η is a new parameter [relative excitation] defined by:

$$\eta = N / N_T \text{ ....(5)}$$

where N and N_T are relative, normal and threshold population – Inversion densities of the laser medium.

These parameters are very useful when plasma – calculation are considered. Also laser polarizability plays its own role when intention is to wards atomic – polarization of plasma – particles.

TML – Plasma Design

Interaction between laser and plasma have been studied as extension of interaction between radiation and matter, since the laser birth [9] where Lamb has considered that the laser frequency detuning as a perturbation of the 2nd order.

In this design, M_3 is a partial – reflector mirror where few percentage of radiation intensity leaks to the passive cavity where the plasma is embedied as in fig.(2).

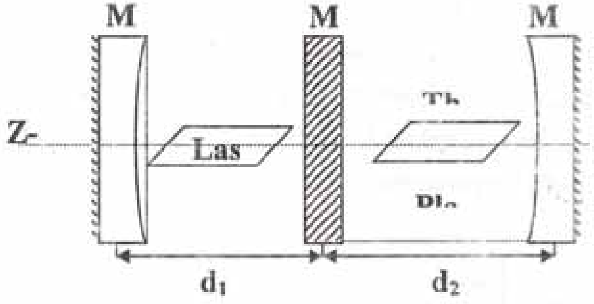

Fig.(2) The laser – plasma design

The plasma discharge tube have a relatively low temperature and pressure, in order to avoid glass destroying.

The laser is almost a mixture of Helium and Neon atoms having the ratio of He; Ne as 8/1, in volume. The operating wave length of radiation is the traditional output of 632.8 nm. The power output is ranging between [1 and 50 mw]. Other parameters are given to the plasma are shown table (1).

Table (1): Some plasma characteristics

Parameter	Value
1- Av. Temperature	2000 K"
2- Length of the plasma tube	21 cm
3- Structure	krypton gas
4- Total pressure	3 mm Hg
5- Volume	76 cm³

The Plasma Refractive Index Using TML

Traditional laser oscillation is obtained using equation of resonance, Smith [10], had proven the case as:

$$2\,d = n\,\lambda_L \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

where d is the physical length of laser resonator, n is an integer, and λ_L is the laser wave length.

This is called a single mode oscillation case when the laser is irradiated to the plasma, many modes will oscillate and the axial ones has proper positions rather than the transverse ones.

Gordon and Hee [11] have showed, without derivation, that:

$$\gamma_{lmq} = \frac{c\cdot[2q+(l+m+1)]}{4.L} \ldots\ldots\ldots\ldots\ldots(7)$$

where L is the resonator length of the plasma tube l, m, and q are mode indices along x, y, and z directions, simplified.

When the laser is coupled to the plasma, two factors are arised, as:

$$\begin{aligned} g_1 &= 1\text{-}d_1 / R_1 \\ g_2 &= 1\text{-}d_2 / R_2 \end{aligned} \qquad \ldots\ldots\ldots\ldots(8)$$

R_1 and R_2 are radii of curvature of the 1st and 2nd mirror.

These are called g – factors and they are characteristics of the input and output mirror. For conveniency, we choose:

$$R_1 = R_2 = d_2 / d_1\,[d_1 + d_2] \ldots\ldots\ldots\ldots\ldots(9)$$

Also we make the approximation:

$\mu \approx d_2 / L$, where d_2 is length of the 2nd resonator and L is length of laser discharging tube. Having confessing these:

$$\frac{2\mu\cdot d_2}{\lambda_o} = q + \left[\frac{1}{\pi}(1+l+m)\cdot\cos^{-1}\left(1-\frac{d_1}{d_2}\right)\right]$$

...(10)

from eq. (3) is $w_p \ll w_L$, where w_L is the laser a regular frequency; then:

$$\mu = \left[1-\left(\frac{w_p}{w_L}\right)^2\right]^{1/2} = 1-\frac{1}{2}\left(\frac{w_p}{w_L}\right)^2 \ldots\ldots.(11)$$

Introducing the value of μ, from (11) into (10) and making one round trip of the radiation ,then l, m, and q will be replaced be Δl, Δm and Δq as:

$$\frac{2L}{\lambda}\left(\frac{w_p}{w_l}\right)^2 = -\left[\Delta q + \frac{\Delta l + \Delta m}{\pi}\cos^{-1}\left(1-\frac{d_1}{d_2}\right)\right]$$

…………(12)

rearranging:

$$\left(\frac{w_p}{w_L}\right)^2 = 1 + \frac{\lambda_o}{2L}\left[\Delta q + \frac{\Delta l + \Delta m}{\pi}\cos^{-1}\left(1-\frac{d_1}{d_2}\right)\right]$$

…………(13)

Where Δq, Δl and, Δm could be calculated from equation (6), applied for all indices.

Practically, the order changing will be achieved throughout a time charge [τ = 2d / c] in microseconds where (c) is velocity of light.

This figure means that through each 0.1 μm change in d_2 the intensity fluctuates many times between (100 – 150) depending on the scale of reduction.

Zigler and Zmora [13] tried to put on improvement in the situation by connecting the plasma electron density with the refractive index discussed in the previous section they used a grating of ultra high sensitivity about [10^5 ruling/mm].

They said that around trip of the radiation results a change in intensity fringes as:

$2(\mu - 1)\, d_2 = N.\, \lambda_o$ ………………(15)

where N is the no. of fringes passing through the grating for each unit change in d_2. [from equation 6]. λ_o is the laser wave length.

Having found this relation, we have to extract $2(\mu - 1)$ from equation (11) as:

$w_p = w_L\, [2\, (\mu - 1)]^{1/2}$ ………………(16)

Eliminating $2(\mu - 1)$ from these equations and putting the value of w_p from (1), we get:

$$n_e = \frac{4 \cdot \pi \cdot N \cdot m_e \cdot \lambda_o}{d_2 \cdot e^2} \quad \text{………………(17)}$$

This means that the cold plasma electron density depends on the length of plasma cavity and intensity change in laser radiation.

Thus the two parameters μ and n_e could be calculated from equations (11) and (17).

Numerical Example

Let us begin with some examples for numerical purposes concerning both laser and plasma. As we have said earlier, if the resonator lengths are kept nearly equal, then the length of plasma tube for conveniency kept at 21 cm.

The krypton gas has ionization potential of 13.996 ev. Thus using a discharge of H.V. and ~ 7 kv.

Few milli-amperes converts the gas into plasma.

a- For plasma refractive index: [equation 11] $\Delta q = 1$, $\Delta m = \Delta l = 6.97*10^4$, L=21 cm. These parameters are substituted in to (11) to get μ of [1.12].

b- For plasma electron density:

The above parameters are kept constant, in addition [eq. 17] $N=1.3*10^4$ fringe/mm the result is that $n_e = 4.12*10^{18}$ electrons cm^{-3}.

Variations in μ and ne

Having identified the above parameters, it is clear that they charge with both Δd and N.

Fig.(4) and (5) shows the n_e – N and μ - Δd variations in the limit of Exp.

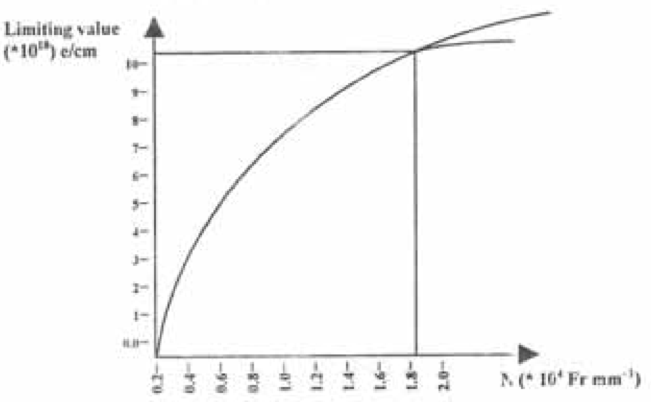

Fig.(4) (n_e) variation with N

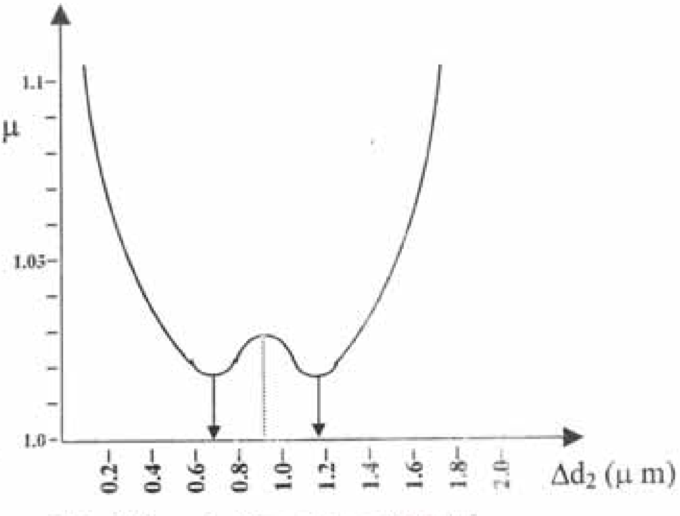

Fig.(5)variation of μ with Δd_2 .

From these diagram it is clear that both μ and n_e are non-linear functions of N and Δd_2 respectively. The limiting value of these are identified by the extensions to the -x- and -y- axis. The optimum value for them are used in different parametric experiments [18].

Results and Conclusion

TML have variety of applications. In our study we focused on two important plasma characteristics, μ and n_e. These are parameters which have intensive role for laser – plasma fusion. The results obtained from calculation are of high precession. Since they were compared with standard values and tables.

Les Houches [14] has stated in his paper that cold plasma are good sources of diagnostic and atomic spectroscopy. So our approach to wards these calculations was a good idea and could be extended in future to use TML as a high – resolution tool for parametric measurements, since the TML interferometry is a sensitive technique improvement in future, can be done through out utilizing the closely spaced resonance of optical cavities and spherical mirror.

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دەزگای لێزەری سێ ئاوێنە بۆ پێوانی هەندێ خۆماڵی لە پلازمادا

دلشاد عمر عبدالرحيم

بەشی فیزیا / كۆلیژی پەروەردە/ زانكۆی سەلاحەدین / هەرێمی كوردستان- عیراق

پوختە

لەم توێژینەوەیەدا، دەزگایەك ئامادە دەكرێ بە بەكارهێنانی لێزەری سێ ئاوێنە وەكو ئامێری بەیەك داچوونی تیشك بە لكاندنی لێزەرێكی سادەو ناوەندێكی نادیار كە لەوانەیە پلازمـا بێت. لێرەدا دوو خۆمـاڵی پلازمـا دەپێورێـت كـە ئـەوانیش هاوكۆلكەی شكاندنەوەكەی وچڕی ئەلەكترۆنن.

ئەكتیناری ئیشەكەش بریتییە لە گۆڕانكاری لە سروشتە درێژی ناوەندی پلازماكەوە بـەكارهێنانی درێـژی لێزەرەكـە وەك ئامێری بەیەك داچوون، بۆ هەردوو ئەو خۆماڵییانە ئەنجامەكان زۆر لۆژێك ونزیك لە پراكتیكە ئەنجامەكان بوون.

تصميم ليزر ذي ثلاث مرايا لحساب بعض المعالم في البلازما

دلشاد عمر عبدالرحيم

قسم الفيزياء / كلية التربية / جامعة صلاح الدين / أقليم كردستان - العراق

الخلاصة

لقد تم في هذا البحث تصميم ليزر ذي ثلاث مرايا كمدخال لاضوء الخارج مـن الليـزر الاعتيـادي مع وسـط البلازما الذي يعتبر وسطاً مجهولاً بالنسبة لوسط الليزر.

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