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COMPUTERIZED WAVELENGTH INDEPENDENT OPTICAL DIODE FOR UNIDIRECTIONAL BEAM IN RING LASER

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ABSTRACT

A computerized high precision adjustement of a new wavelength independent unidirectional device for using in ring dye lasers is discussed. The one way travelling wave operation of the laser beam is achieved without adding more optical elements in the resonator. The Optical diode consists of wedged Faraday rotator and special arrangement of three mirrors. The performance and the optimum adjustement precision for enforcing one perferred direction travelling wave are computer controlled. This leads to actively stable unidirectional high power laser beam.

INTRODUCTION

In the field of laser spectroscopy and laser applications, it is necessary to use time stable single frequency laser beam. This stable single mode operation can be obtained using linear or ring laser by a combination of many wavelength selective elements. In ring laser one find addationally optical devices for enforcing one perferred direction travelling wave operation. Without such devices the travelling wave could pick either direction, resulting in capricious and hence near useless operation [1]. The advantages of the ring laser in comparison with the linear one were discussed in early papers [2-4]. Some methods to produce one way travelling wave operation for ring dye laser were done [5-8]. The disadvantages of these methods and other design of an optical diode were discussed [1].

In general the optical diode consists of two components: (i) direction dependent polarisation rotation using Faraday effect [9]. (ii) direction independent polarisation rotation using one of the following possibilites: Crystal of optical active molecules, half wave plate, or fresnel prism [10,5,11]. The problems of operation of the previous components of the optical diode depend on wavelength. This dependence leads to limitations on the operating region and interacavity power levels.

The aim of this work is to design a wavelength independent optical diode efficiently suitable for enforcing one directional beam. The performance and adjustement precision of the optical diode are computer controlled.

DESIGN CONSIDERATIONS

The idea of the optical diode is based on selective production additional losses in the undesired direction of the laser beam. This is accomplished by rotation of the polarisation plane in the ring resonator. For the desired direction the rotation angle will be exact compensated.

Different designs of the optical diode have been applied in laser research institutes for achieving one way propagation in ring lasers. All these designs used wavelength dependent Faraday effect as the fundamental component of the optical diode. When a linear polarised light, passes through isotropic medium of length l (e.g. glass) where an external, homogenious and longtudinal magnetic field of magnetic flux density B is applied, the polarisation plane of the laser beam will rotate with a certain angle (α) according to the following emperically determined experission: $\alpha = V B l$, V is the factor of proportionality known as Verdet constant (in min/gauss/cm). The Verdet constant for a particular medium varies with both wavelength and temperature [9]. In this case the polarisation plane will always rotate in the same direction and independent on the incident direction. The selective direction of propagation of the laser beam is determined by the poles of the magnetic field.

By selection of the Faraday material as isotropic medium, important considerations must be taken into account e.g. low absorption losses, high Verdet constants, high optical quality and the desired rotation angle. On the other hand the alloy of the permenant magnet must contain high remenance and axially magnetised. Figure (1-a) shows the form of the used magnet (Firma vacuumschmelze Hanau aus Vacodil 170).

In order to eliminate the dependence of Faraday effect on the wavelength, a new form of Faraday rotator is used. Plane parallel plate (BK-7-Glass supplied by [13]) of thickness = 16.7 mm, a length of 20 mm is cutted under Brewster angle according to the relation:

$$d = 1 \cos (90° - \Theta_B) = 1 \sin \Theta_B$$

where: d = the glass plate thickness, 1 = length of glass rod, and Θ_B= Brewster angle which equal to 56.6° by a wavelength of 589.3 nm. The new form of the glass rod is shown in figure (1-b). This rod is inserted in a cobalt-samarium magnet of length L=20 mm, internal diameter of r = 11.5 mm and external diameter of R = 50 mm. The calculated rotation angle for one revolution equals ca. 1.93° at a wavelength of 600 nm (V = 0.016 in min/gauss/cm, B = 9000 gauss). The wedged Faraday rotator in Fig. (1-b) leads to the compensation of the wavelength dependence of Faraday effect. By displacing the Faraday rotator system perpendicular to the beam direction, the optical pathlength will be changed and accordingly the rotation angle. To eliminate the reflection losses of the incident surface, it is made under Brewster angle and the output surface is coated with antireflex layer of reflectivity = 0.2% (Fig. 1-b).

The second rotation of polarisation plane is direction independent rotation, i.e the polarisation plane of a linear polarised light wave will always rotate in the same direction of the beam. This can be realised by different methods [1]. Other direction wavelength independent special arrangement of three mirrors for the rotation of the polarisation plane of the laser beam was developed [12]. This rotation is achieved when one of these three mirrors is placed high or low out of the real resonator plane as shown in Fig. (2-a). The advantage of this method is that the rotation achieved by the same mirrors of the resonators without addition more optical elements in the resonator. In comparison with the other described methods [10,5,11], that its action is wavelength independent. The disadvantage is that the height of the mirror which placed out of the laser resonator is proportional to the angle of rotation of the polarisation plane. This height will be estimated and adjusted coarsely. This leads to high power losses and unstable undirectional beam.

In this work the previous disadvantage is avoided. A combination of the wedged Faraday rotator and the special arrangement of the mirrors is used to achieve the unidirectional operation of a ring laser. Both are components of the optical diode with action independent on the wavelength. A computer program is developed for exact calculation of the position of the laser beam in a plane high or low out of the laser resonators. The same program is used to control the change in the pathlength of the laser beam in Faraday wedge to achieve high adjustement precision of the optical diode.

THEORETICAL

Consider that the polarisation of the laser light is described by polarisation vector $\vec{P}$. It lies prependicular to the propagation direction. As the propagation of laser light realised in one plane, the polarisation vector of $\vec{P}$-polarised laser light lies also in this plane. For one revolution of the laser beam through the resonator, the polarisation vector $\vec{P}$ on every mirror appears as in figure (2-b) with phase change π due to refelction. This can be described by the relation [14]:

$$\vec{P}_i = \vec{P}_{i-1} - 2\,(\vec{P}_{i-1} \cdot \vec{n}_i)\,.\,\vec{n}_i \,. \qquad (1)$$

$\vec{P}_i$ = the polarisation vector after reflection by i-mirrors.

$\vec{P}_{i-1}$ = the polarisation vector before reflection by i-mirrors.

$\vec{n}_i$ = the normal vector on the i-mirror

The angle α between the polarisation vector $\vec{P}_o$ (start polarisation vector) and the polarisation vector $\vec{P}_m$ after one revolution in a resonator consists of m components, can be calculated as follows:

$$\alpha = \arccos \frac{\vec{P}_o \cdot \vec{P}_m}{|\vec{P}_o| \cdot |\vec{P}_m|} \qquad (2)$$

A computer program is developed to calculate the polarisation rotation angles due to the special arrangement of the mirrors and the wedged Faraday rotator. The program is carried out as follows: (i) The position vectors of the mirrors (x,y,z) in the resonator must be given as input values. (ii) The computer calculates the direction vectors $\vec{dv}$ between the mirrors: $\vec{dv}_i = \vec{ov}_i - \vec{ov}_{i-1}$. (iii) Normalization the direction vectors $\vec{dv}_i = \vec{dv}_i / |\vec{dv}_i|$. (iv) calculation of the normal vectors ($\vec{Nv}_i$) on the mirrors: $\vec{Nv}_i = \vec{dv}_{i+1} - \vec{dv}_i$. (v) Normalization of the normal vectors: $\vec{Nv}_i = \vec{Nv}_i / |\vec{Nv}_i|$. (vi) calculation of the polarisation vector ($\vec{Pv}$) behind the mirrors:

$$\vec{P}_i = \vec{P}_{i-1} - 2(\vec{P}_{i-1} \cdot \vec{Nv}_i) . \vec{Nv}_i$$

(vii) calculation of the angle α between $\vec{Pv}_i$ and $\vec{P}_o$:

$$\alpha = \arccos \frac{\vec{Pv}_i \cdot \vec{P}_o}{|\vec{Pv}_i| . |\vec{P}_i|} \qquad (3)$$

The program checks the input data of each mirror. On the other hand the data of Faraday rotator (the magnetic field strength, the length of wedged rod and verdet constant) must be given.

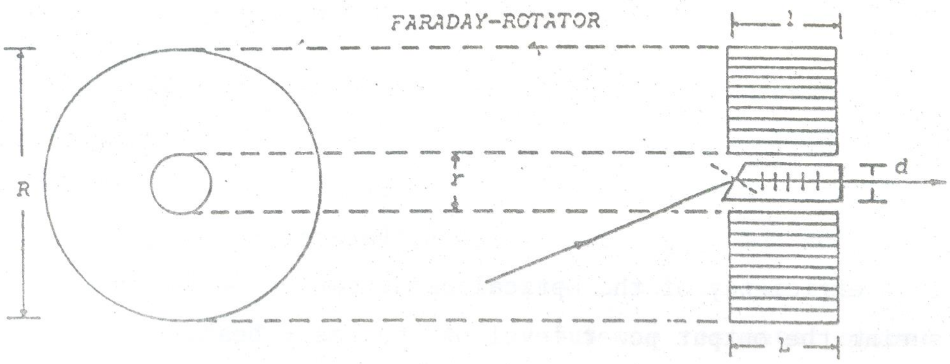
EXPERIMENTAL

Figure (3) shows a ring resonator with optical diode consisting of three mirror arrangement (M3 ,M4 ,M5) and the wedged Faraday rotator. The position vectors of the optical elements in the resonator are determined, where the original point (start point) is the dye jet stream. M1 ,M2 are concave mirrors with focal length 25 mm. At the mirrors M3 ,M4 ,M5 the polarisation plane is not in the incidence plane, where the mirror M4 find out the resonator plane. The rotation achieved in the distance M3-M4-M5. At small angles ψ, φ the rotation angle α is given approximately by $\alpha = \psi . \varphi$. The rotation angle α can by a given resonator geometry be adjusted through the height of the mirror M4. The asymmetrical rotation will be compensate for the desired laser beam direction by the wedged Faraday rotator. For the opposite laser beam direction the rotation is additive and results in a net loss due to increased reflection by the Brewster surfaces in the cavity. These losses suppress the laser oscillation in the opposite direction and one has stable one way propagation in the desired direction. The single mode operation achieved with the new development of Mach-Zehnder Interferometer [15] in combination with Lyot filter and the developed optical diode. Because the rotation angle due to Faraday rotator is proportional to the optical pathlength of laser beam through it, therefore it is mounted on micrometer displacement table. The displacement is proportional to the angle of polarisation rotation. On the other hand the hight of a mirror out of the resonator plane is proportional to the angle of polarisation rotation. This height is also precisely adjusted by a micrometer screw.

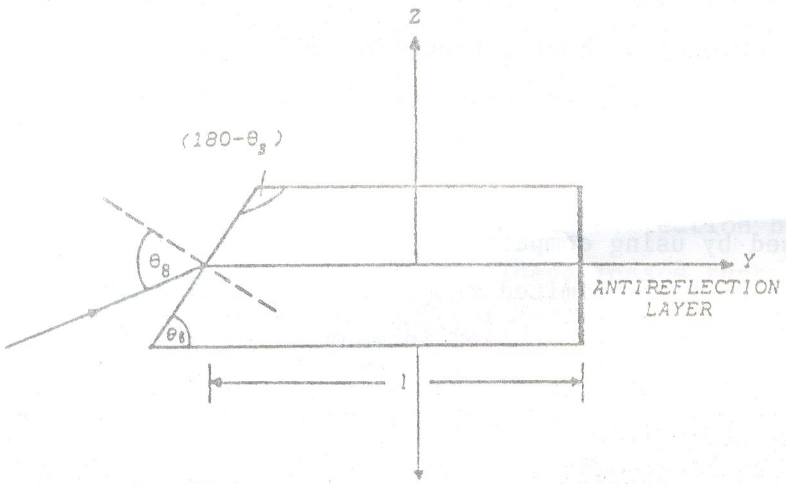
Using the developed computer program, the calculations of the polarisation angle due to the system of mirror arrangement are achieved firstly. Secondly the program calculates the compensation rotating angle caused by Faraday rotator. The optimum efficiency of the optical diode can be observed by measuring the output power level of the laser beam.

CONCLUSION

The developed new wavelength independent optical diode leads to stable unidirectional beam in ring lasers. This has been achieved without introducing additional losses in the ring resonators. The losses are limited only in the absorption of the wedged Faraday rotator material which is equal to 0.0015 cm^{-1} by λ = 580 nm. High power laser beam is realised by using computer adjustements program. In comparison with the limited range wavelength dependent optical diode which is applied in many laser research institutes, many advantages are achieved: complications in the adjustement are eliminated, the losses are minimised, simplicity of producing stable one way propagation independent of wavelength and high power laser beam.



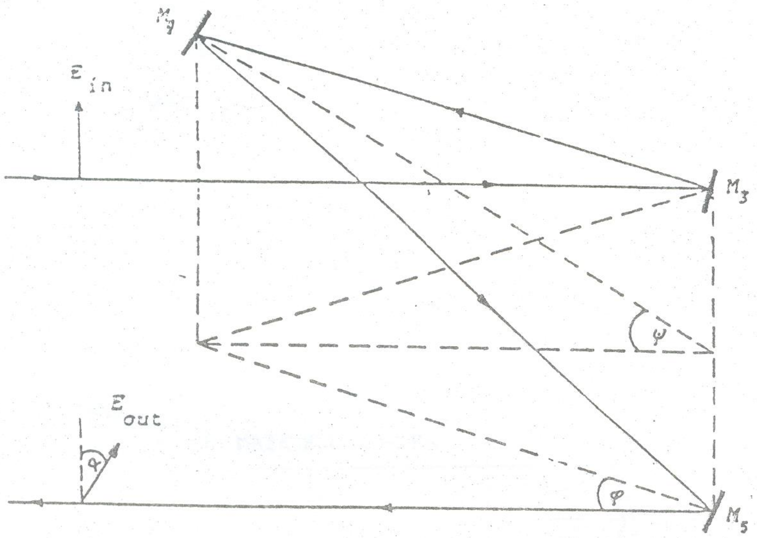
(a)



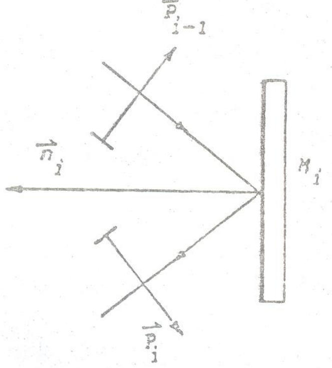
(b)

Fig. (1): a- The dimension of the used magnet and the wedged Farady rotator

b- The wedged form (BK-7-glass) Faraday rod.



(a)



(b)

Fig. (2) a- Rotation of polarisation plane by three mirror arrangement.

b- Reflection of polarisation vector for P-polarisation with phase change equal π .

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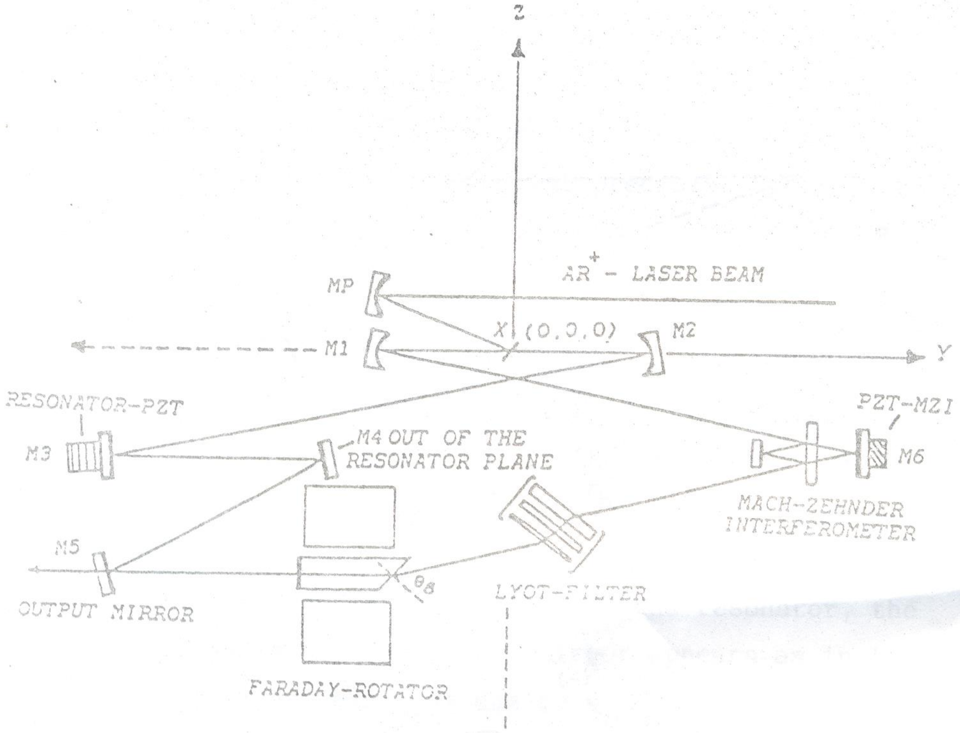

Fig. (3): The coordinates of laser resonator (jet is (0,0,0)).

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صمام ثنائى ضوئى يضبط بالكمبيوتر ومستقل عن الطول الموجى لتوحيد إتجاه شعاع الليزر الحلقيه

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يتناول هذا العمل بالبحث والمناقشه تطوير جهاز جديد " صمام ثنائى ضوئى " لتوحيد إتجاه شعاع ليزر الصبغات الحلقيه . يتكون الصمام من دوار فارادى " الإسفينى " ذات المسار الضوئى المتغير وترتيب خاص من ثلاث مرايا أحدهما يقع خارج مستوى متذبذب الليزر . يتم التحكم بالكمبيوتر فى أداء ودقة الضبط المثاليه من خلال تطوير برنامج كمبيوتر لفرض الإتجاه المفضل لشعاع الليزر . تتحقق عملية توحيد إتجاه شعاع الليزر بدون إضافة مزيد من العناصر الضوئيه فى المتذبذب مما يقلل من القدره المفقوده فيه بحيث أصبحت قاصره على الفقد الإمتصاصى الذى يبلغ ٠٫٠٠١٥ سم$^{-١}$.

بمقارنته بغيره من الصمامات الضوئيه المستخدمه فى الليزرات التجاريه نجد أن الصمام المطور مستقل فى عمله عن الطول الموجى ممايتيح إستخدامه على مدى واسع.كذلك تم التخلص من تعقيدات الضبط داخل المتذبذب مما يؤدى إلى الحصول على شعاع وحيد الإتجاه ومستقر وذو قدره عاليه .