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LASER FREQUENCY CONTROL PLANO-CONFOCAL INTERFEROMETER

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ABSTRACT

[illegible] discuss the practical aspects of a highly efficient compact plano-confocal interferometer arrangement. Using a spacing of about 19 mm between the two mirrors results in a free spectral range of about 2 GHz and a finesse of 160 was obtained in the wavelength range 535-635 nm. Experimental details about its design, fabrication, alignment procedures, thermal and mechanical stability and low cost FPI are presented.

INTRODUCTION

In the last years the development of lasers leads to the development of highly efficient Fabry-Perot Interferometers (FPI) necessary for laser frequency control, monitoring and scanning. In many institutes of laser research commerciall produced FPI are often used. Sometimes these types do not fulfil all the requirements of experimental work especially in the field of high resolution spectroscopy. Additionally these commercial [illegible] tend to be highly expensive. Many papers treat in detail the description of spherical mirror FPI's [1-6].

This paper describes a new specific instrumental design very suitable for laser frequency control, monitoring and scanning of tunable lasers. The motivation for developing the interferometer arises from the special design considerations which are not always achieved in the commercial designs. Some of these considerations are: compact size, ease of adjustement, laboratory driving electronics available, low production costs, high quality optical substrate and coatings suitable for the chosen wavelength range, along with thermal and mechanical stablility. Another consideration is that the dimensions of piezo driver must be selected according to the needed number of free spectral range (FSR).

PRINCIPLE OF OPERATION AND DEFINITIONS

The pure criterion for stability of optical resonator [7]:

$$0 \leqslant g_1 \, g_2 \leqslant 1 \qquad (1)$$

where $g_1 = \left(1 - \frac{L}{R_1} \right)$ and $g_2 = \left(1 - \frac{L}{R_2} \right)$

According to this relation Fig. (1) shows the stable and unstable regions for a resonator with mirrors of radius R_1 and R_2 respectively, and separated by a distance L. The high loss configurations are known as unstable resonator geometries. For a given resonator, the resonant frequency of a given mode is [7]:

$$f_{qmn} = \left(q + (m+n+1) \frac{\arccos \sqrt{g_1 \, g_2}}{\pi} \right) c/2L \qquad (2)$$

where q, the longitudinal mode order number, m and n are the transverse mode order numbers. The frequency difference between adjacent axial modes:

$$f_{q+1} - f_q = c/2L = (FSR)_{ax.} \qquad (3)$$

For the confocal resonator of two mirrors of the same curvature radius $R_1 = R_2$ and seperated by a distance $L = R_1 = R_2$, then $g_1\ g_2 = 0$ and the relation (2) can be written as follows:

$$f_{qmn} = \left(q + \frac{m + n + 1}{2}\right)\ c/2L \qquad (4)$$

here q,m,n, are numbers, then the spacing between the two adjacent resonance frequencies:

$$= c/4L \qquad (5)$$

This seperation is called transversal free spectral range $(FSR)_{tr}$. The seperation between two modes of the same value of q but differ in the indices m and n (the difference between m and n equal one) can be written as follows:

$$\frac{\arccos\sqrt{g_1\ g_2}}{\pi}\ c/2L \qquad (6)$$

If $L = R_1/2$ and $R_2 = \infty$ then, from equations (1,6):

$$\frac{\arccos\left(\left(1 - \frac{R_1}{2R_1}\right)\left(1 - \frac{R_1}{2 \cdot \infty}\right)\right)\ c/2L}{\pi} = \frac{\arccos\ (\ 1/2\ )}{\pi}\ c/2L$$

$$- \frac{\pi/4}{\pi}\ c/2L = c/8L \qquad (7)$$

This means four transversal mode seperations equal one axial mode seperation. From Fig. (1) and the previous calculations one conclude that:

(i) The stability and adjustments conditions of the confocal and plano-confocal optical resonator are considered as uncritical and quite suitable resonator types.

(ii) The frequency spacing between two adjacent axial modes depends only on the mirror spacing and is independent of the resonator type.

(iii) The distance between the resonant frequencies of the resonator modes by plano-confocal interferometer is perfectly equal to the distance in the confocal, Assuming the mirror spacing of the plano-confocal is equal to half the mirror spacing of the confocal system.

(iv) It is necessary that the radius of curvature of the spherical mirror of the plano-confocal resonator is equal to the radius of curvature of the spherical mirrors of confocal one. The advantage is, from confocal resonator we have plano-confocal one with the same resonant frequency spacing, but smaller physical size.

MATERIALS AND MECHANICAL DESIGN

Because the stability of the resonance frequency of an interferometer is determined through the stability of optical length n.L between the mirrors where n is the refractive index of the medium between the mirrors and L is the cavity length, therefore materials of very small thermal expansion coefficient

(α) must be used. As mirror spacer a tube of zerodur with thermal expansion coefficient $\alpha < 1.5 \times 10^{-8}$ / °c is used. This tube has internal diameter of 15 mm, external diameter 25.4 mm and length of 43 mm. For mirrors materials fused quartz substrate is very good suitable because of relative small temperature expansion coefficient. In our case a spherical substrate of diameter 12.7 mm, R = 38 mm and thickness of 6 mm is used together with plane-mirror substrate of diameter 10.5 mm and thickness of 5 mm. A broadband coating is made in the wavelength range between 535-635 nm, reflectivity of 99% for spherical mirror and high reflectivity for plane-mirror.

For frequency tuning and stabilisation a piezo-cermic type PXE-5 was used. This piezo material according to the industrial manual, has very good time stability and a high piezo-electric charge constant [8]. The piezo material is in the form of rectangular plates of dimensions 12 mm x 6 mm x 0.3 mm and has temperature constant of 9×10^{-6} / °c. Because of high temperature coefficient of the piezo material, the piezo-electric mirror translator can be clearly contributed for temperature dependence length instability of the resonator. To avoid this problem a new stable double concentric triangle mirror translator is constructed as shown in figure (2). It consists of two triangle tubes. The plates of the internal one has the dimensions 8 mm x 6 mm x 0.3 mm, while that of external tube has the dimensions 12 mm x 6 mm x 0.3 mm. One of these tubes is used as active part and the other used as passive part. The active part changes the length of the resonator according to the applied voltage and the passive one compensate the change of length of the active part due to temperature change. Informations details about the piezo construction are given in [9].

The mirror separation is determined entirely by the zerodur spacer and zerodur rings which were precisely prepared to have parallel and flat front surfaces. The interferometer is shown schematically in figure (2). It consists of three parts: spacer tube, piezo-head and plane mirror part, The piezo-head consists of the spherical mirror, the piezo translator and two zerodur rings. The external ring has, internal diameter = 15 mm, external diameter = 25.4 mm and thickness = 4.5 mm but the internal one has 8 mm, 10 mm, 6.8 mm. The piezo, mirror and zerodur rings are mounted together as in figure (2). The piezo head part is axially epoxied against the front surface of the spacer. The third part consists of a zerodur ring of internal diameter = 8 mm, external diameter = 14.8 mm and thickness of 7.5 mm, to which the plane mirror and the metal ring are mounted as shown in figure (2).

INTERFEROMETER ALIGNMENT

A schematic of the complete adjustement system of the interferometer used for the final precisely alignment construction is shown in figure (3). The incoming beam from He-Ne laser is defined through polarisation rotator and two diaphragm for the beam to be clearly located (sharp spot). A white card is used for observing the two back reflections. The first reflection comes from the plane-surface of the spherical mirror which has equal diameter as the incoming laser beam. The second reflection comes from the curved mirror surface with diameter greater than the incident laser beam. The great reflex must be precisely in the direction of the incoming beam, and small reflex must make very small angle with the incoming beam. The adjustment of the third part, and the exact length, controls the interferometer precision. To improve this precision, we used an electromagnet to carry the third part. The electromagnet (current 500-700 mA) is fixed on a mirror holder and positioned on a combination of three micrometer displacement tables prependicular to each other. Using this adjustement system, the mirror inclination and the distance from the spherical mirror can be adjusted in all directions independent from each other. The laser beam pass through the interferometer will be incident on a movable photodiode, where its signal amplified and connected to the Y-direction of an oscilloscope. The piezo is drived by a wobbel-generator with top voltage of 500 volt. Small ramp voltage from ramp-generator is connected to the X-direction of the oscilloscope. With this circuit the resonance frequency variation depend on the ramp voltage. Fine adjustment is then achieved by optimising the magnitude and the shape of the transmission maxima. One comes to this point, the plane-mirror must be fixed in the spacer tube through side holes of 3 mm diameter. After enough time we can make the electromagnet off. Figure (4) shows a picture of fringe pattern of the interferometer.

DISCUSSION AND CONCLUSION

Using electromagnetic method for alignment and adjustement operations, the adjusting mirror (plane-mirror) is separated without mechanical or chemical solvent, and therefore no distortion for the optical adjustment occurs. The fixing with epoxy of the plane-mirror part through side holes guarantee no changing in the adjustment precision, where forces due to drying of the fixing material tends to sides. Fixing at the end of spacer tube will change the mirror spacing and can destroy the alignment. The finesse of the interferometer is the key measure to resolve closely spaced lines: $F = (FSR)_{ax}$ / B.W., where B.W. is the minimum resolvable bandwidth. It depends on the lack of parallelism and/or planeness of the mirrors, mirror reflectivity of less than unity and diffraction losses arising from the finite aperature of the interferometer. The attainable result of finesse is 160 which exactly equal to the estimated value.

This etalon is located inside a compact air tight brass tube to maintain its temperature constant relative to the ambient. It mounted on mirror holder provided with two micrometer screws for adjustement inclination, and used actively in the laser work.

For stabilizing a He-Ne laser to the developed FPI resonance an electronic control system as shown in Fig. (5) is used. We have considered a case where the laser is oscillating in a number of modes, and the FPI serves not only as a frequency reference, but also as a filter to transmit a single laser frequency. The electronic system operates as follows: The laser output is mode matched into the reference FPI [10]. For the laser frequency to be stabilized on the center of the FPI response, a sinus form signal of ca. 10 kHz produced from lock-in amplifier is applied to the input of high voltage amplifier. The dc-voltage portion at the output of the HV-amplifier determined the position of the center frequency of the transmission maximum. This will wobbel with sinus form signal of ca. ± 5 MHz. The effect of this on the output power is monitored with a detector. When the laser output drifts to one side of the interferometer response, a proportional signal to the deviation from the center of the interferometer response is produced. This signal is suitably amplified by the HV-amplifier and used to control the frequency of the laser resonator so that the output is stabilized on the center of the FPI response. On the other hand this plano-confocal interferometer is used efficiently as laser frequency monitor and scanning.

The experimental results showed that for the resonance frequency change of about 1 FSR = 2 GHz, it is necessary a change of the length $\Delta L = 0.3$ um, this gives $\Delta v/\Delta\nu = 0.071$ v/MHz, where Δv is the electrical sensitivity of the resonator (the wavelength = 600 nm). Because of the small thickness of the interferometer piezo transducer a low dc-amplifier up to 500 volt is enough. This voltage generator can derive the interferometer for scanning up to 5.83 FSR = 11.66 GHz. These generators is available in each laboratory of research. Using Zerodur spacer, fused quarz mirrors and temperature compensated double concentric piezo translator, the experimental temperature dependance of resonance frequency is = 7.5 MHz/°c. In comparison with the commercial interferometers which are usually made from a low thermal expansion coefficient materials such as invar, a change of ambient temperature of 1 °c will change the frequency of laser oscillating in the visible region of the spectrum by about 500 MHz.

From the previous discussions one conclude that the developed FPI has the following characteristics: thermal and mechanical stability, high finesse, compact physical size, low cost, ease of alignment and efficiently suitable for frequency stabilization, monitoring and scanning of all comarin and rhodamin dye laser.

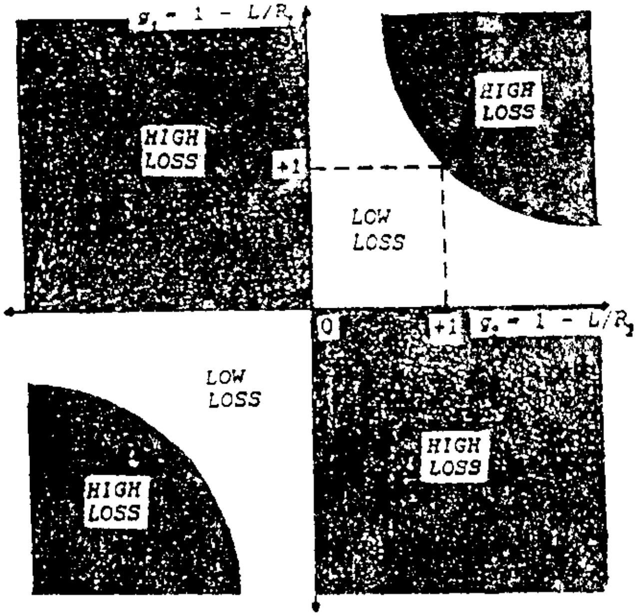

Fig. (1): Stability diagram showing stable and unstable values of mirror radius of curvature (R_1 and R_2) and mirror seperations

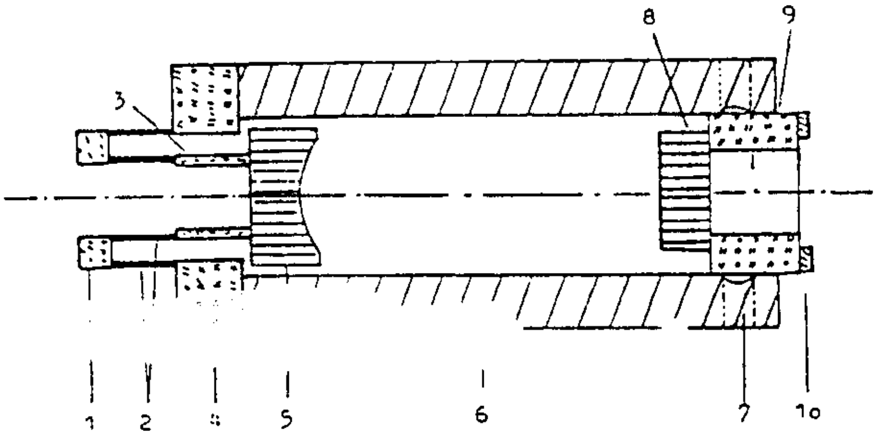

Fig. (2): Schematic diagram of the interferometer. 1.2.3.4.5 represent the piezo head (1.3.4 are Zerodur rings. 2 is the double piezo translator. 5 is a spherical mirror of R=38 mm), 6 is Zerodur mirrors spacer. 7 is side holes. 8.9.10 represent the plane-mirror part (8 is plane-mirror. 9 is Zerodur ring. 10 metal ring)

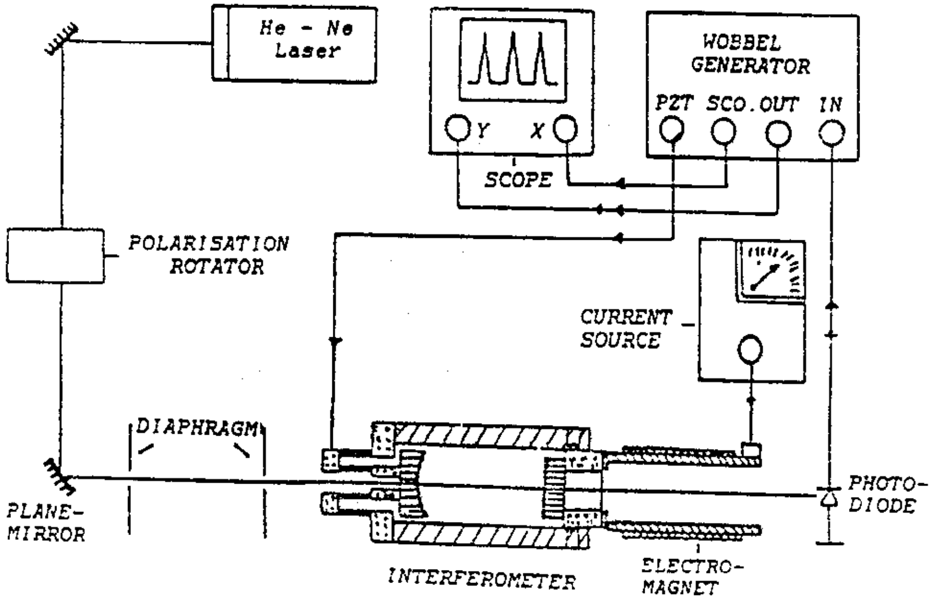

Fig. (3): The adjustment system used for construction

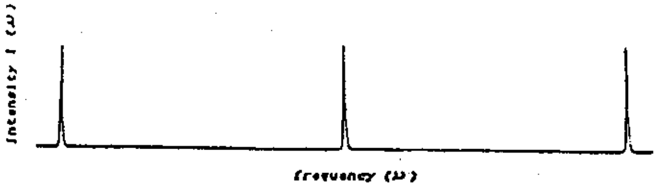

Fig. (4): Fringe pattern of the interferometer

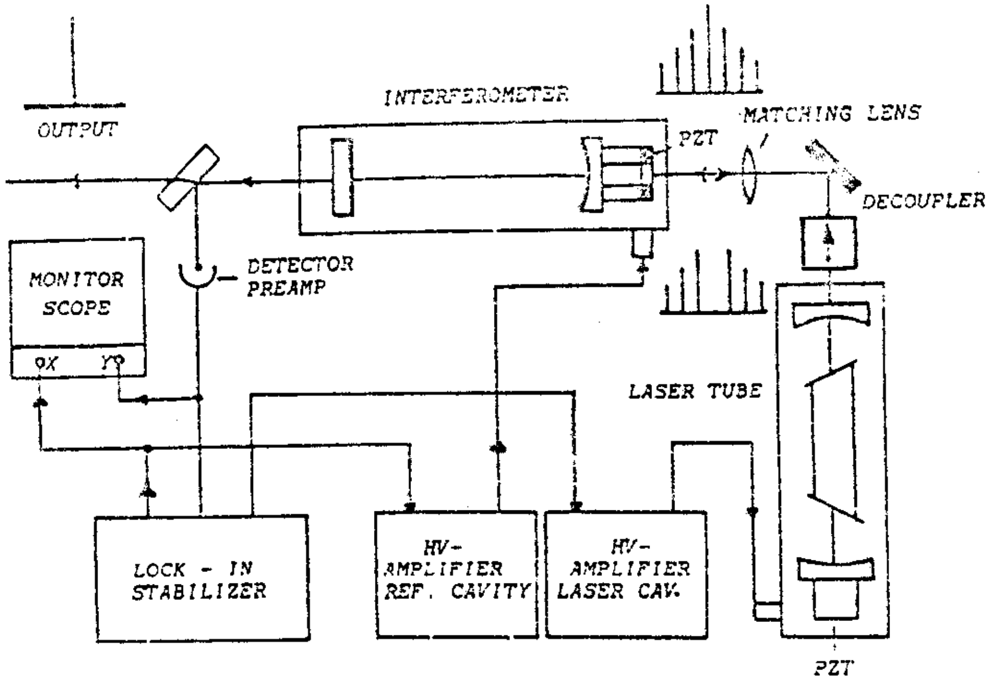

Fig. (5): Block diagram - Stabilisation scheme

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انترفيروميتر ذات مرايا مستوية ـ مقعرة للتحكم فى تردد الليزر

حسن الكاشف
قسم الطبيعة ـ كلية العلوم ـ جامعة طنطا
مصر

يستعرض البحث الواجهه النظريه والعمليه لتصميم وتركيب فابرى - بيروت إنترفيرو
صغر ذات مرآتين إحداهما مستويه والأخرى مقعره وتفصلهما مسافه مقدارها ١٩ مليمي
يلغ المدى الطيفى الحر للإنترفيروميتر ٢ ميجاهيرتز ودقه تحليليه قدرها ١٦٠ فى مدى ال
لموجى الممتد من ٥٣٥ - ٦٣٥ نانومبتر .

تم تركيب المرآه الكريه على بلوره بيزو مزدوجه الجدران فى شكل مربعين إحدهما
يوضع داخل الآخر السلبى ووظيفته تحاشى التغير فى البعد بين المرآتين بتغير درجة الحرا
سممت جميع أجزاء الإنترفيروميتر من ماده السريدور **zerodur** والتى تتميز بعدم تغير أبع
مع درجة الحراره . تم ضبط وتركيب هذا الإنترفيروميتر بإستخدام تقنيه لها مواصفات تمد
الدقه أثناء التصنيع النهائى له . وقد تم إختبار هذا المحلل عمليا كمراقب ومرشح للتردد الر
ليزر الهليم نيون وأثبتت النتائج دقته وفعاليته العاليه وأفضليته على فابرى بد
نترفيروميتر ذات المرايا الكريه . تفاصيل أخرى حول عملية التصميم والتصنيع والضبط وال
ميكانيكى والحرارى لإنترفيروميتر إقتصادى التكاليف تمت معالجتها عمليا .