УДК 528.71
DOI 10.33764/2618-981X-2022-6-258-263

Перестраиваемый интерферометр Фабри – Перо в качестве диспергирующего элемента в спектральных приборах

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Аннотация. В настоящее время, перестраиваемые оптические фильтры широко используются в оптических и оптико-электронных системах и комплексах. Например, они используются для перестройки длины волны в лазерах, которые применяются в волоконно-оптических линиях связи. Разработаный перестраиваемый интерферометр Фабри-Перо, представленный в данной статье, может найти применение в различных областях оптотехники. Конструкция предлагаемого перестраиваемого оптического фильтра, представляет собой перестраиваемый интерферометр Фабри-Перо на основе обратного пьезоэлектрического эффекта. Оптические характеристики фильтра будут зависить от оптических, электрических и физических характеристик компонентов, входящих в его конструкцию.

Ключевые слова: перестраиваемый интерферометр Фабри-Перо, поливинилиденфторид, пьезоэффект

Tunable Fabry-Perot interferometer as a dispersing element in spectral devices

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Annotation. Presently, tunable optical filters are widely used in optical and optoelectronic systems and complexes. Tunable optical filters are essential components in a wide range of optical systems. The developed tunable Fabry-Perot interferometer presented the article can be used in various fields of optotechnics. The design of the proposed tunable optical filter is a tunable Fabry-Perot interferometer based on the inverse piezoelectric effect. The optical characteristics of the filter will depend on the optical, electrical and physical characteristics of the components included in its design.

Keywords: tunable Fabry-Perot interferometer, polyvinylidene difluoride, piezoeffect

Introduction

The interferometer, or Fabry-Perot etalon, is currently the basic instrument in high-resolution spectroscopy. Its operation is based on the interference of a large number of rays obtained by multiple reflection of a light wave between two parallel flat mirrors (silver and aluminum films) with partial transmittance. Modern interferometers usually use multi-layer dielectric mirror coatings, which are deposited on optical glass or quartz substrates in vacuum. They provide high light reflection coefficients at low absorption losses. This paper proposes a study of tunable Fabry-Perot interferometer as a function of the electrical characteristics of polyvinylidene difluoride (PVDF) films of different thicknesses. The tunable Fabry-Perot interferometer can be used as a dispersing element in spectrometry, fiber optic sensors, spectroscopic gas analysis systems, biological, chemical, and vibration sensors, etc [1-4].

Problem

In this paper, the expected characteristics of a tunable Fabry-Perot interferometer with different thicknesses are considered. Two highly reflective mirrors are employed as bandpass filters.

Theory

Spectral devices mainly use a diffraction grating or prism as a dispersing element. The spectrum is scanned by rotating the dispersing element [5]. The use of tunable Fabry-Perot interferometer is complicated by the complexity of their designs. Fig. 1 shows the design of a known tunable Fabry-Perot interferometer.

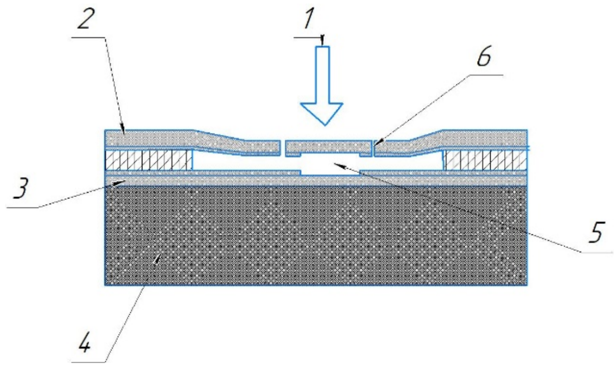

Fig. 1. Cross-sectional view of tunable Fabry-Perot interferometer

1 - incident radiation; *2* - upper mirror; *3* - lower mirror; *4* - substrate; *5* - air gap; *6* - membrane (thin-film) structure of the upper mirror

The tunable Fabry-Perot interferometer has an upper and lower mirror opposite each other with an air gap between them. When voltage is applied to the mirrors, an electrostatic force arises, which causes the air gap to change. To facilitate this action, the upper mirror has a membrane (thin-film) structure. If the air gap is $m\lambda/2$ (m is an integer), it functions as a filter transmitting a larger wavelength λ.

As the voltage between the mirrors increases, the air gap decreases under the action of the electrostatic force, causing the peak wavelength of transmission to shift toward the shorter wavelength.

In this paper, we propose the design of the dispersing element in the form of a tunable Fabry-Perot interferometer, Fig. 2.

The Fabry-Perot interferometer consists of two glass disks - 3, with applied mirror coatings - 2, having a reflection coefficient R. The two glass disks are separated by a film of polyvinylidene fluoride (PVDF) - 1, with a thickness d, which has an inverse piezoelectric effect. All elements of this design must be transparent in a certain range of the spectrum $\Delta\lambda$. Depending on the characteristics of the Fabry-Perot interferometer elements and the range of incident radiation Δλ, it works as a selective filter, the transmittance of which will be maximum for certain wavelengths: λ_1, λ_2, λ_3, etc. and is calculated by the formula [6]:

$$T = \frac{T_m^2}{(1-R)^2 + 4R\sin^2\frac{\delta'}{2}}, \tag{1}$$

where $\frac{\delta'}{2}$ - angle ($\frac{\delta'}{2} = 2\pi nd/\lambda$); T_m - transmittance of the mirrors; R - reflectance of the mirrors; n - refractive index of the PVDF film; λ - wavelength of the incident radiation; d - thickness of the PVDF film.

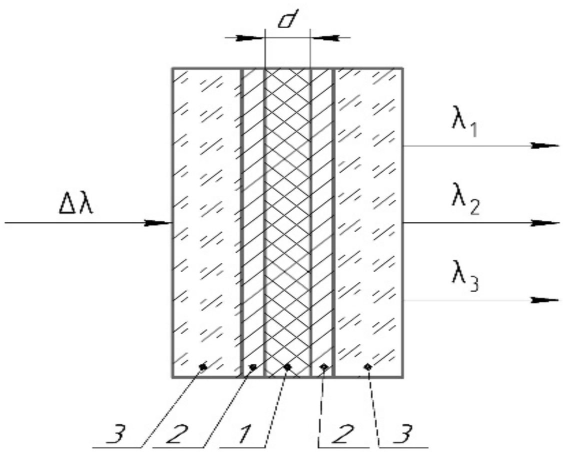

Fig. 2. Fabry-Perot interferometer

1 - PVDF film; 2 - mirror coatings; 3 - glass substrate; Δλ - incident radiation on the FPI; λ_1, λ_2, λ_3 - wavelengths of the passed radiation; d - PVDF thicknes

The Fabry Perot interferometer is reconfigured along the spectrum by changing the film thickness d by Δd by applying a voltage U to the PVDF film, which has an inverse piezoelectric effect [7], for example, to the metal mirrors of the Fabry-Perot interferometer. When the film thickness is changed by Δd, the maximum transmittance of the Fabry-Perot interferometer, in accordance with formula 1, will change for the initial wavelengths by $\Delta\lambda_1$, $\Delta\lambda_2$, $\Delta\lambda_3$, etc., Fig. 3.

The change in the thickness Δd of a PVDF film under the inverse piezoelectric effect can be calculated using the formula [8]:

$$\frac{\Delta d}{d} = -d_{31} \cdot E_X, \tag{2}$$

where E_X is the electric field strength in the PVDF film; d_{31} is the piezoelectric modulus of the PVDF film.

Fig. 4 shows the graph of transmission coefficient dependence in visible range on the incident radiation wavelength calculated by the formula 1: PVDF film thickness d=5 µm [9], mirror reflection coefficient R=0,9, mirror transmittance T_m=0,1, PVDF film refractive index n =1,55.

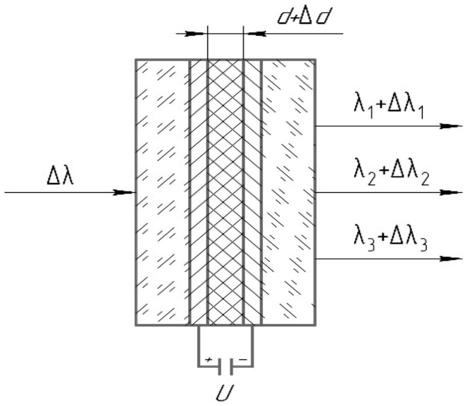

Fig. 3. Interferometer with modified thickness PVDF film

Δλ - incident radiation on the Fabry-Perot interferometer; $\lambda_1+\Delta\lambda_1$, $\lambda_2+\Delta\lambda_2$, $\lambda_3+\Delta\lambda_3$ - wavelengths of the passed radiation after the conversion of the Fabry-Perot interferometer; $d+\Delta d$ - PVDF thickness after applying voltage U to it

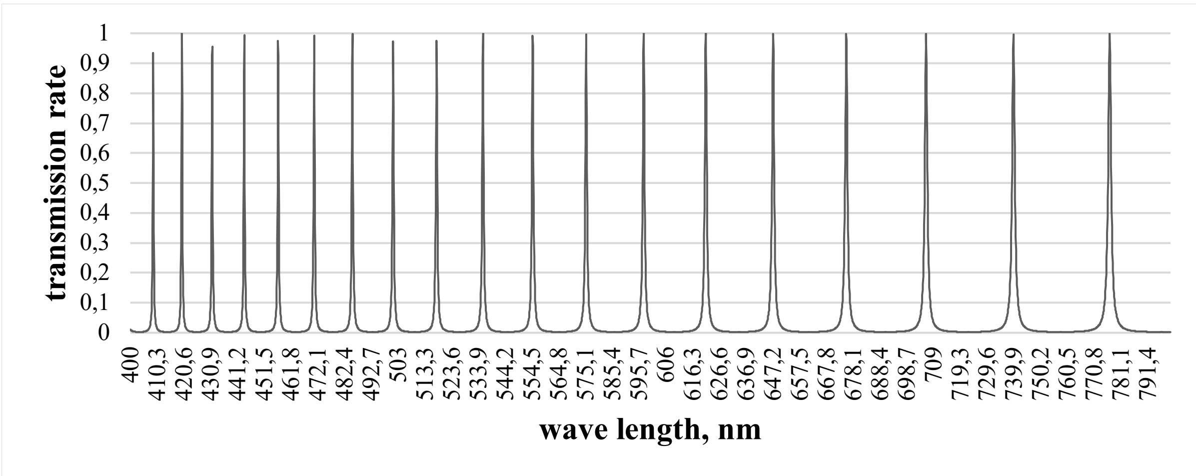

Fig. 4. Fabry-Perot interferometer transmission from the wavelength of the incident radiation

It should be assumed that the graph was plotted for an ideal Fabry-Perot interferometer: light absorption was not taken into account, the parallelism of the mirrors was ideal, and the refractive index of the PVDF film over the entire range of radiation was constant.

For a PVDF film having a piezoelectric modulus $d_{31} = 33 \cdot 10^{-12}$ m/V and a maximum intensity at which breakdown occurs E_X = 80 V/µm [9], from formula 2, the maximum change in thickness will be $\Delta d \approx \pm 13$ nm.

By changing the thickness of the PVDF film from its minimum (4,987 µm) to maximum (5,013 µm), the tuning range of the Fabry-Perot interferometer for the wavelength of the maximum transmission of the right peak will be 4 nm (from 772,6 to 776,6 nm). For the same peak we can calculate free dispersion area *G* - distance from transmission maxima of neighboring peaks (37 nm) and resolution δλ - peak width at half-height (1,3 nm).

To increase the tuning range of the Fabry-Perot interferometer, it is necessary to use a PVDF film with a larger piezoelectric modulus value. Increasing the film thickness will increase the resolution of the Fabry-Perot interferometer, but decrease the free dispersion area, Fig. 5.

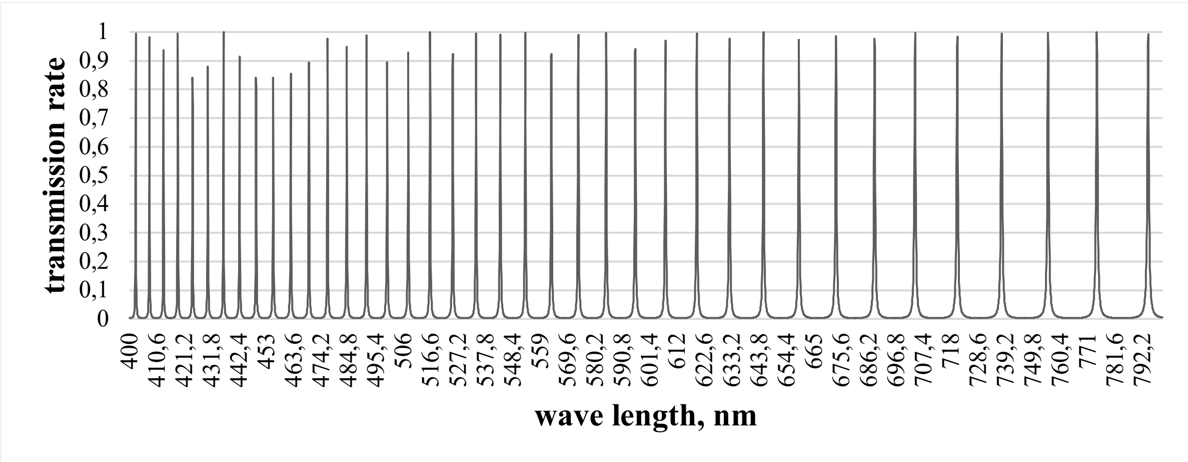

Fig. 5. Transmittance of Fabry-Perot interferometer from the incident radiation wavelength (*d*=10 μm)

Table 1 shows the optical characteristics of the tunable Fabry-Perot interferometer having different thicknesses of PVDF films.

Table 1

Optical characteristics of the tunable Fabry-Perot interferometer for incident radiation Δλ=400÷800 nm.

PVDF film thickness, μm	δλ, nm	*G*, nm
5	1,30	37,0
10	0,70	19,9
15	0,45	13,1
20	0,34	8,2
25	0,26	6,8
30	0,22	6,8

Conclusion

The presented interferometer is needed for the building of compact, inexpensive and efficient multispectral systems with tuning in the entire visible spectral range and high spectral resolution.

As a high-resolution spectral analyzer, the tunable Fabry-Perot interferometer is a useful tool for monitoring laser performance. Fabry-Perot interferometers can also be used in an educational setting, particularly as a method for observing HeNe resonator modes during HeNe laser warm-up, as well as for determining properties such as free spectral range.

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