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# Research on new type temperature-insensitive quartz filter☆

Fei Gao*, Wenlong Wang, Yong Kong

*Shanghai University of Engineering Science, College of Electrical and Electronic Engineering, Long Teng road 333#, 201620 Shanghai, China*

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ABSTRACT

A new type temperature-insensitive quartz filter is presented in this paper, which is composed of three polarizers, a quartz birefringent crystal and a quartz rotation crystal. Based on the principle that the fluctuations of the quartz birefringence and specific rotation have an opposite trend with the temperature change, the temperature effect on output center wavelength of this new type quartz filter is investigated in detail theoretically and experimentally. The theoretical and experimental results show that this new type quartz filter is indeed insensitive to temperature change. It will have a certain application in the stability output of optical filter when temperature change as we believe.



## 1. Introduction

Usually there are two traditional birefringent filters: Lyot [1,2] and Solc-type optical filter [3,4]. Compared with other optical filters, the unique advantage offered by this birefringence filter is the tenability to a desired wavelength, low insertion loss and wide field of view. So the birefringent filter is widely used in the fields of laser tuning [5,6], astronomy [7–9], dense wavelength division multiplexing [10,11]. Recently, a new polarization coherent spectral filter based on rotatory dispersion effect was proposed by C. Ye [12–14], compared with traditional Lyot and Solc filter, it not only can be adjusted by mechanical structure but also can be further adjusted by the applied voltage (if it having an active device, such as LC polarization rotator), and it does not require additional achromatic retarder.

For a optical filter, working in fixed transmission wavelength spectra is very important. For example, in the sunlight observation instrument applications, the change of output central wavelength caused by temperature fluctuation is unacceptable [9], The analysis of temperature effect on the output characteristic of the quartz birefringence filter has been investigated [15,16], but the analysis of temperature effect on output characteristics of the quartz rotation filter has not still been reported to our knowledge. In addition, the common techniques to compensate the temperature effect on the output center wavelength of quartz birefringent filter include the temperature feedback control method [17], rotating waveplate method [18], using different temperature coefficient birefringence crystal method [19]. For the first method, temperature control equipment is very complex. For the second method, through rotating the quartz wave plate to compensate the central wavelength change with temperature, and it is still not compact. For the third method, it is sometime difficult to select a suitable temperature coefficient birefringence crystal.

In this article, we propose a new type quartz temperature insensitive filter, which is composed of three polarizers, a quartz birefringent crystal and a quartz rotation crystal. Based on the principle that the fluctuations of the quartz birefringence and specific rotation have an opposite trend with the temperature change, through numerical analysis and experiments research, the central wavelength temperature stability of this filter is investigated in detail, which provides an adaptive temperature compensation method for the application of output wavelength stability of quartz filter with temperature change.

## 2. Numerical simulation

### 2.1. The transmissivity of quartz rotation filter

As shown in Fig. 1, a rotation dispersion polarization filter is composed of two Glan prisms $P_1$, $P_2$ and a quartz wave plate $L_1$. The azimuth angle of two polarizer prisms is parallel to the azimuth angle of $Z$-axis, the quartz optical axis is perpendicular to its surface,

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* Corresponding author.
*E-mail addresses:* hi4455707@163.com (F. Gao), ky7757@163.com (W. Wang), kkyy7757@yahoo.com.cn (Y. Kong).

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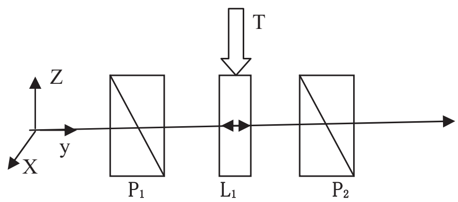


**Fig. 1.** The schematic diagram of a quartz rotation filter.

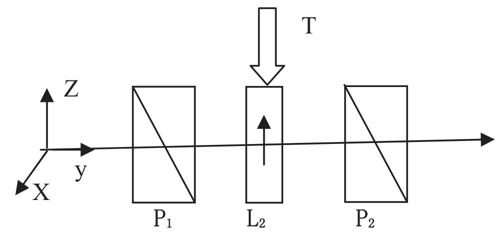


**Fig. 2.** The schematic diagram of the quartz birefringent filter.

and $T$ is the temperature which is applied to the quartz optical rotation filter.

The Mueller matrix of $P_1$, $P_2$ and $L_1$ can be expressed as follows [20]:

$$M_{P_1} = M_{P_2} = \frac{1}{2}\begin{bmatrix} 1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \quad (1)$$

$$M_{L_1} = \begin{bmatrix} 1 & 1 & 0 & 0 \\ 0 & \cos\ 2\theta & \sin\ 2\theta & 0 \\ 0 & -\sin\ 2\theta & \cos\ 2\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

where $\theta$ is the angle of rotation of the quartz crystal [21],

$$\theta = \alpha d_1 \quad (3)$$

here, $d_1$ is the thickness along the optical axis direction of the quartz crystal, the unit is mm; $\alpha$ is the optical rotation coefficient of the quartz crystal, the unit is°/mm. the value of $\alpha$ is related to the wavelength, properties of the material, temperature, [22] and so on.

With changing of temperature, the relationship between optical rotation coefficient of quartz crystal and the wavelength is given by [22]:

$$\alpha = A + \frac{B}{\lambda^2 - C} - D\lambda^2 \quad (4)$$

where $A$, $B$, $C$ and $D$ are the temperature coefficient, $\lambda$ is the wavelength of the incident light, the unit is mm. The expressions of $A$, $B$, $C$ and $D$ are [22]:

$A = -311.87457 - 2.75492T - 0.35441T^2 + 0.01061T^3 - 7.99432 \times 10^{-5}T^4$,

$B = 1.76092 \times 10^8 + 5.31675 \times 10^5 T + 7.1668 \times 10^4 T^2 - 2.090 \times 10^3 T^3 + 15.35985T^4$,

$C = 1.04049 \times 10^5 - 130.6369T - 22.26345T^2 + 0.62473T^3 - 0.00442T^4$,

$D = -1.57039 \times 10^{-4} - 3.42124 \times 10^{-6}T - 4.1859 \times 10^{-7}T^2 + 1.2732 \times 10^{-8}T^3 - 9.75758 \times 10^{-11}T^4$,

At the temperature range of −10 to 60 °C and wavelength range of 470–600 nm, using the formula (3) and (4), the specific rotation of quartz crystal for any wavelength and temperature in the range of −10 to 60 °C and 470–600 nm can be obtained easily.

Linear expansion factor of the quartz crystal along the optical axis direction is $\gamma = 7.97 \times 10^{-6}\,°\mathrm{C}^{-1}$. The thickness variation should be also taken into account when the quartz rotation crystal is heated or cooled, namely:

$$d_1 = d' + \gamma \Delta T \quad (5)$$

$d'$ is quartz thickness at 20 °C, if the incident light is the nature light $I_0'$, its Stokes parameters is:

$$S_0 = I_0' \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad (6)$$

Stokes parameters of passing through a single-stage quartz rotation filter is:

$$S_1 = M_1 M_2 L_1 S_0 = \frac{I_0' \cos^2[\alpha(\lambda)d_1]}{2} \begin{bmatrix} 1 \\ 1 \\ 0 \\ 0 \end{bmatrix} \quad (7)$$

here $I_0'$ is the incident light intensity, ignoring the inserting loss of light of each element, considering the output light intensity of $P_1$ is $I_0 (I_0 = I_0'/2)$, then the normalized transmittance of the quartz rotation filter is:

$$T = \cos^2[\alpha(\lambda, T)d_1] \quad (8)$$

### 2.2. The transmissivity of quartz birefringent filter

As seen from Fig. 2, a single-stage Lyot birefringent filter is composed of two Glan prisms $P_1$, $P_2$ and a quartz wave plate $L_2$. The azimuth angle of between each polarizer prism and the azimuth angle of $Z$-axis is 45°, optical axis of $L_2$ is parallel to its own surface.

Quartz dispersion birefringence can be described as follows [23]:

$$10^3 \times \Delta n = 8.86410 + 0.107057\lambda^{-2} + 0.0019893\lambda^{-4} - 0.17175\lambda^2 - 10^{-3}T\left(1 + \frac{T}{900}\right)(1.01 + 0.2\lambda^2) \quad (9)$$

Linear expansion factor of the quartz crystal perpendicular to the optical axis direction is $C = 1.337 \times 10^{-5}\,°\mathrm{C}^{-1}$. The thickness variation should be also taken into account when the quartz birefringent crystal is heated or cooled, namely:

$$d_2 = d''[1 + 1.337 \times 10^{-5}(T' - T)] \quad (10)$$

The unit of $\lambda$ is μm, $T$ is the temperature, there it is 20 °C, $d''$ is the quartz's thickness at 20 °C. The normalized output light intensity is:

$$T = \cos^2\left[\frac{\pi}{\lambda} n(\lambda, T)d_2\right] \quad (11)$$

### 2.3. The transmissivity of quartz birefringence rotation filter

In this paper, we propose a new structure combined by quartz birefringent and quartz rotation crystal filter, which is showed in Fig. 3.

As shown in Fig. 3, the new type filter is composed of three Glan prisms $P_1$, $P_2$, $P_3$ and two quartz wave plates $L_1$, $L_2$. The azimuth