Theoretical calculation of the thermal induced depolarization in high power lasers

الحساب النظري لانعدام الاستقطاب الحراري المحتث في الليزر عالي القدرة

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Abstract:

This research aimed to study the thermal induced depolarization in system consist of two optical elements separated by quartz. The Mathcad 14 program used to calculate the results. The theoretical suggestion model has solved and shown the effect of different parameters on value of induced depolarization .The depending of induced depolarization on type of the used elements was studied with calculating the optical anisotropy property (ζ) of the two optical elements. The effect of rotator of quartz element (θ_r) that separate between two optical elements has been investigated. The effect of circular birefringence on the induced thermal depolarization with using different values of ratio of normalized powers in the first and second elements was studied. In this research the results showed which parameter strongly effect on thermal depolarization .The reduction of thermal induced depolarization is important for laser system for best operating to avoid loss in power.

Keywords : Thermal induced depolarization, Faraday isolator, Photoelastic effect, High power lasers.

الخلاصة:

يهدف هذا البحث إلى دراسة انعدام الاستقطاب الحراري المحتث في نظام يتكون من عنصرين بصريين مفصولين بالكوارتز. باستخدام برنامج (mathcad14) تم حل النموذج النظري المقترح وأظهر تأثير معاملات مختلفة على قيمة انعدام الاستقطاب المستحث حراريا .اعتماد انعدام الاستقطاب المستحث على نوع العناصر البصرية المستخدمة تم دراسته من خلال حساب خاصية التباين البصري (ζ) لعنصرين بصريين . تأثير دوران عنصر الكوارتز (θr) الذي يفصل العنصرين البصرين على انعدام الاستقطاب المحتث حراريا تمت دراسته . تأثير الانكسار الدائري δ_c على الاستقطاب الحراري المستحث باستخدام قيم مختلفة لنسبة القدرات الحرارية المتولدة في العنصرين البصرين الأول والثاني تمت دراسته. في هذا البحث أظهرنا اي من المتغيرات لها تاثير قوي على انعدام الاستقطاب المحتث حراريا. إن تقليل انعدام الاستقطاب المحتث حراريا مهم جدا لنظام الليزر لكي يعمل بشكل مناسب لتجنب فقدان الطاقة.

الكلمات المفتاحية: انعدام الاستقطاب المحتث حراريا، عازل فاراداي ،التأثير الضوئي المرن، ليزر عالي القدرة .

1.Introduction

The rate of solid state laser power has increased significantly over the past 17 years. The main problem is the manufacture of lasers operating at a power equal to 100 kW so the study of the thermal effect on the absorption of laser radiation in the existence of optical elements of optical devices is very important. The Faraday's isolator is highly dependent on these phenomena because its visual elements are comparatively long [1-3].

At present time, there is growing interest in high-power solid state laser systems . This interest is due to the wide applications of this type of laser, there are applications in the field of industry and in the scientific field[4-5], and in the study of the behavior of materials when applied an external optical field[6]. By the progressing in the production and manufacture of laser devices, there are currently lasers operating at a power of one or ten kilowatts[7]. In 2010 this type of laser operated with a power equal to 100 kW continuously for six hours. The optical equipment in its work depends on the non-inverse rotation of the polarization plane, for example the Faraday rotation, which works on radiation isolation, which regulates the paths of the laser amplifiers. This rotation is used in the dual refractive evaluation of the beam in the laser elements. The most important in the work of these devices is the ocular element placed in a stable magnetic field. Faraday instruments which are used in high-power laser devices[8-9], the magnetic optical material must be contain special specifications[10-12].

One of the most important optical elements is terbium gallium garnet because it has a high Verdet constant , high thermal conductivity and has low absorption losses in wavelength between 500 to 1100 nm. The work in which rotation of Faraday was identified and the temperature reliance of the Verdet constant in terbium gallium garnet ceramics was showed in 2007[9]. In any case of the kind of the sources of heat , their occurrence in the optical elements of the laser device caused unfavorable thermal influence. The temperature of the elements will increase, leading to a change in the spectrum rate. The optical and mechanical properties of the element in the laser system will change as a result. The spectrum lines diverge and expand and the cross sections of the transition levels will decrease, the refractive index and the temperature gradient change, In addition, the synchronization angles are lower, the frequency of the Faraday devices will decrease and the thermal conductivity will decrease. The gradient in the temperature shown in the visual elements shows that all the variables of the elements depend on the temperature and become dependent on the coordinates. Therefore, the lack of homogeneity in the element appears and leads to mechanical exertion. Mechanical exertion leads to a change in the optical properties of the elements, so the refractive index of the material changes due to the effect of photoelastic [8]. The main cause of thermal phase deformation that occurs involves the adoption of the refractive index on the temperature, the dependence of length on temperature which is known as linear expansion, and the adoption of refractive index on mechanical stress. The deformation of the phase obtained depends on the mutual co-ordination of the radiation polarization, crystal coordinates, and the direction of exertion [9, 10].

The thermal phenomena in the active medium of the high-power laser can cause a significant loss of power through the lack of polarization, if the active medium without the self-double light refraction has been used and the optical resonator has an element with high losses for one of the polarization directions. The gradient heat in the active medium causes the mechanical stress and thus a double refraction of light occurs towards the local axis through the cross section of the beam. As a result, the original linear polarization state distorted and the losses appear in the power[13]. There are negative consequences resulting from the lack of thermal polarization, the most important of which is the loss of the ability of polarized radiation, which is equal to the degree of non-polarization, and the change in the transverse pattern of the radiation because of the formation of amplitude and phase associated with the lack of homogeneity of the lack of polarization, which leads to increased loss due to dispersion and makes it difficult to work with elements it radiation polarized. depolarization is the process by which polarized radiation converts to non-polarized radiation. The degree of non-polarization is the ratio of non-polarized radiation power to total radiation power. The medium used to reduce the lack of thermal depolarization is glass[14-16], ceramic[17] and single crystals[18]. It is possible to reduce the lack of thermal induced depolarization , which causes loss of power using YAG crystallization[19-20].

2. Theory of thermal induced depolarization

To calculate the resulting thermally induced depolarization of linearly polarized radiation after passing through a system of two thermally loaded optical elements 1 and 2 in the presence of circular birefringence in them separated by a quartz rotator 3(figure 1) let a linearly polarized field along the x axis $E_{in} = E_r.\begin{pmatrix} 1 \\ 0 \end{pmatrix}$.

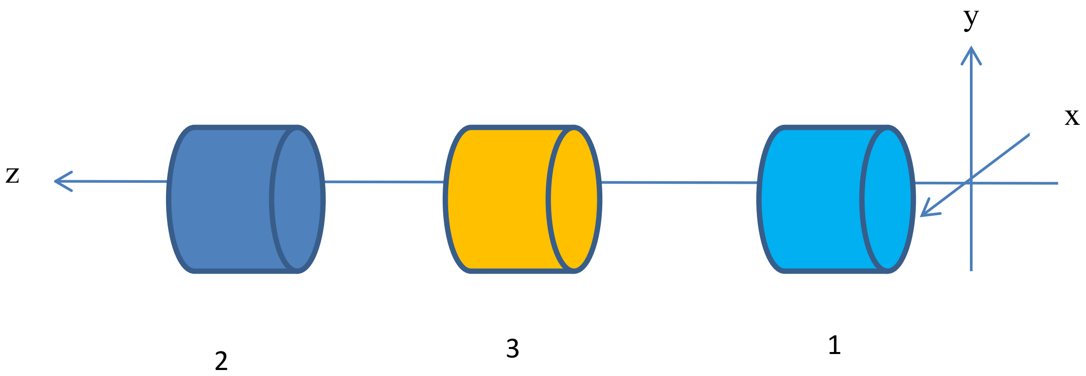

Figure1. A system of two optical elements separated by a quartz rotator. 1 and 2 - first and second optical elements, 3 - quartz rotator

We assumed that the thermally induced linear and circular. Birefringence in the first element is determined by δ_1, Ψ_1 and δc_1, in the second - δ_2, Ψ_2 and δc_2. The quartz rotator turns the plane of polarization of the transmitted radiation is given by the angle θ_r. The field at the output of the system will be determined by the expression[21].

$$E_{out} = R\left(-\left[\theta_r + \frac{\delta_{c1} + \delta_{c2}}{2}\right]\right) M(\delta_2, \psi_2, \delta_{c2}) R(\theta_r) M(\delta_1, \psi_1, \delta_{c1},) E_{in} \quad (1)$$

$$R(\theta) = \begin{pmatrix} \cos(\theta) & -\sin(\theta \\ \sin(\theta & \cos(\theta) \end{pmatrix}$$

The Jones matrix M for an optical element with simultaneous circular and linear birefringence in the absence of dissipation and amplification is determined by the expression [21, 22].

$$M = \exp(-i\psi) \begin{pmatrix} \cos\frac{\delta}{2} - i\frac{\delta_l}{2}\sin\frac{\delta}{2}\cos\frac{\Psi}{2} & \left(-\frac{\delta_c}{\delta} - i\frac{\delta_l}{\delta}\sin 2\Psi\right)\sin\frac{\delta}{2} \\ \left(\frac{\delta_c}{\delta} - i\frac{\delta_l}{\delta}\sin 2\Psi\right)\sin\frac{\delta}{2} & \cos\frac{\delta}{2} + i\frac{\delta_l}{2}\sin\frac{\delta}{2}\cos\frac{\Psi}{2} \end{pmatrix} \quad (2)$$

$$E_{out} = M.E_{in} \quad (3)$$

$$\delta^2 = \delta_l{}^2 + \delta_c{}^2 \quad (4)$$

$$\psi = k\int_0^L n_\Sigma \; dZ = \frac{\delta_{e1} + \delta_{e2}}{3} \quad (5)$$

$$\delta_l = \; k\int_0^L n_\Delta dZ = \delta_{e1} + \delta_{e2} \quad (6)$$

Here $\delta_{e1,2}$ - incursions of the phases of the eigen polarizations with linear birefringence in the absence of a circular one; δ_l is the phase difference of the eigen polarizations for linear birefringence; Ψ is the angle of inclination of the intrinsic polarization with respect to the Cartesian laboratory axis x; ψ is the average phase between two proper polarizations; $k = 2\pi / \lambda$ is the wave number; L - length of the element, in general, can depend on the transverse coordinates; δ_c is the phase difference of two circular polarizations in the absence of linear birefringence, with the rotation angle of the polarization plane for Faraday rotation being $\varphi_F = \delta_c / 2$, n_Σ and n_Δ are the mean and difference refractive index coefficients. Thus, knowing the values of δ_{e1}, δ_{e2}, δ_c and E_{in} using expressions (1) - (6), we can uniquely determine the Jones vector at the exit of the medium E_{out}. The Jones matrix of the medium in the absence of Faraday rotation is obtained from expression (2) with the substitution $\delta_c = 0$.

The local degree of depolarization γ in the absence of rotation of the plane of polarization of the transmitted radiation is the fraction of the intensity of the transmitted radiation with polarization orthogonal to the initial one in E_{in}, and is determined from the Jones vectors at the input and at the output in accordance with expression

$$\gamma = 1 - \frac{\left|E_{out}.E_{in}{}^*\right|^2}{\left|E_{out}\right|^2 .\left|E_{in}\right|^2}$$

The equation of thermal induced depolarization is given by fowling expression:

$$\begin{aligned}\gamma = \; & \frac{\sin\left(\frac{\delta_{c2}}{2}\right)}{\delta_{c2}} D\left[\left(1-\xi_2\right)\sin\left(4\theta_2\right)\cos\left(2\theta_r+\delta_{c1}+\frac{\delta_{c2}}{2}\right) - \left[1+\xi_2+\left(1-\xi_2\right)\cos\left(4\theta_2\right)\right]\sin\left(2\theta_r+\delta_{c1}+\frac{\delta_{c2}}{2}\right)\right] \\ & + \left[\left(1-\xi_1\right)\sin\left(4\theta_1\right)\cos\left(\frac{\delta_{c1}}{2}\right) - \left[1+\xi_1+\left(1-\xi_1\right)\cos\left(4\theta_1\right)\right]\sin\left(\frac{\delta_{c1}}{2}\right)\right]\frac{\sin\left(\frac{\delta_{c1}}{2}\right)}{\delta_{c1}} \\ + \; & \frac{\sin\left(\frac{\delta_{c2}}{2}\right)}{\delta_{c2}} D\left[1+\xi_2+\left(1-\xi_2\right)\cos\left(4\theta_2\right)\cos\left(2\theta_r+\delta_{c1}+\frac{\delta_{c2}}{2}\right) - \left[\left(1-\xi_2\right)\sin\left(4\theta_2\right)\right]\sin\left(2\theta_r+\delta_{c1}+\frac{\delta_{c2}}{2}\right)\right] \\ & + \left[1+\left[\xi_1-\left(1-\xi_1\right)\right]\cos\left(4\theta_1\right)\cos\left(\frac{\delta_{c1}}{2}\right) - \left[\left(1-\xi_1\right)\sin\left(4\theta_1\right)\right]\sin\left(\frac{\delta_{c1}}{2}\right)\right]\frac{\sin\left(\frac{\delta_{c1}}{2}\right)}{\delta_{c1}}\end{aligned}$$

In the above equation the parameter $\zeta_{1,2}$ represented optical anisotropy of the materials, D- ratio of normalized powers in the first and second elements, $\delta_{c1,2}$ are values of circular birefringence, $\theta_{1,2}$ the angle between the crystallographic axis and the x axis of the laboratory coordinate system and θ_r is angle of quartz rotator.

3. results and discussion

Figure 2 illustrates the depending of thermal-induced depolarization on the optical anisotropy of the materials of the first and second optical elements with different values of ratio of normalized powers in the first and second elements D .

Figure 2a shows that thermal-induced depolarization γ decreases as the value of the second optical anisotropy ζ_2 increases .We noticed that when value of ζ_2 equal 1 the value of γ was 3.25 and this value decreased to 1.25 when anisotropy of second optical element equal to 14(D changed from 0 to10),while the opposite occurs in figure2b such that at the first optical element the thermal induced depolarization increased with increasing anisotropy property ζ_1 and the highest value for γ was 4.25 and decreased to 2.51 when value of anisotropy ζ_1 was1 .

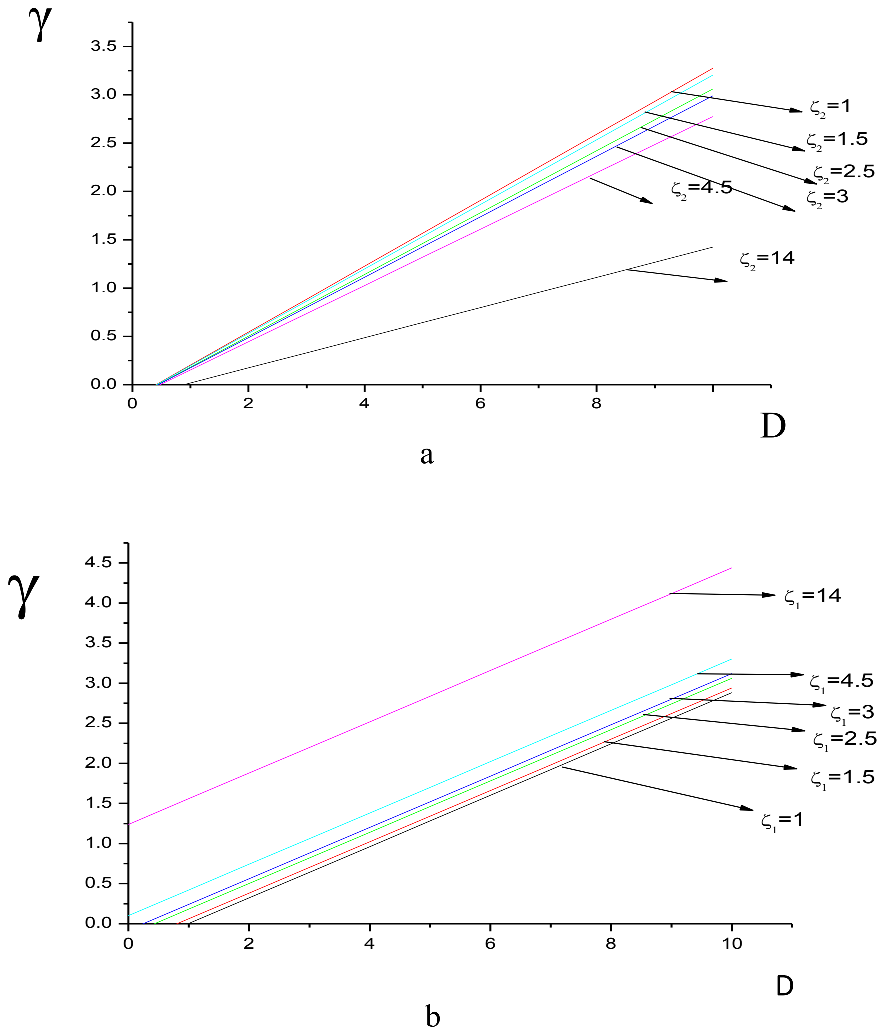

Figure2. Dependence of thermally induced depolarization on the ratio normalized power of heat in the second and first elements with different value of optical anisotropy ζ_2(a), ζ_1 (b)

The effect of rotate angle of quartz by using different values of the ratio normalized power of heat was shown by figure 3.Figure 3a showed that when we rotate quartz crystal in first, the thermal induced depolarization begin decreased to minimum value 0.2 and then when we rotated the quartz again by large angle the value of depolarization γ started increase again to certain value (γ=1.58) and then also decreased. In this case the value of the ratio normalized power of heat was 1,the biggest reading of γ was 1.78.

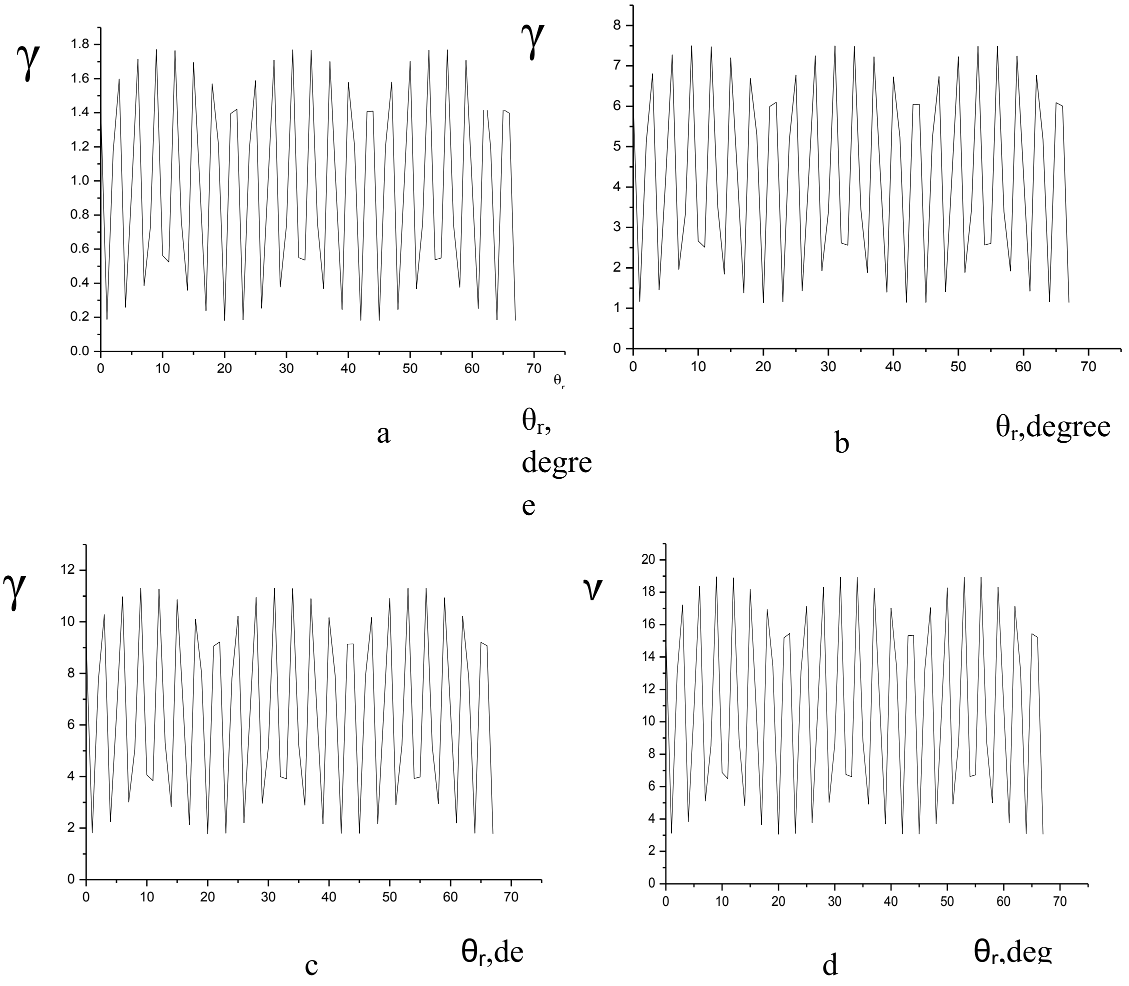

Figure3. Thermal induced depolarization against angle of quartz rotator by using different values of the ratio normalized power of heat D=1(a),D=4(b),D=6(c),D=10(d)

We noticed from figure 3a that if we continued rotate quartz up and down the largest and smallest account of thermal depolarization will be 1.78 and 0.2 respectively. These values of thermal induced depolarization was changed by using different value of D and that can be seen from figure 3b,3c,3d. From figure 3b it was easily seen that the largest and smallest reading of thermal induced depolarization were 7.5,1.3 while in figure 3c were 10.7,1.9. Figure 3d showed that these values becomes 12.5,2.7 so for the same values of the angle of quartz rotator the changed of the ratio normalized power of heat D will be very effected on the thermal induced depolarization γ.

The effect of circular birefringence in the first and second optical element on the thermal induced depolarization was shown by figures 4 and figure 5.Figure 4 showed how changed thermal depolarization γ with circular birefringence in the first optical element δ_{c1} such that for D=1 (figure4a)the peak was 3 and goes under zero and then rise to 0.5 and goes up and down until it has constant value(0.05) when the circular birefringence δ_{c1} increased above 70. When the ratio normalized power of heat (D) equal to 10(figure4b) the maximum value of γ was increased to 27.5 and then was be constant(zero) at δ_{c1} above 70.In figure 4c the best values for minimum reading of thermal depolarization were δ_{c1}=10,D=4. For second optical element figure 5 showed effect of circular birefringence δ_{c2} on thermal induced depolarization such that the largest value of γ was

27.5 and this reading similar to that was in the first element and also minimum value was the same for both element for the same ratio normalized power of heat(D) but in the second optical element the reading of maximum and minimum value for thermal depolarization was repeated and don’t goes to constant value as we showed in first optical element .

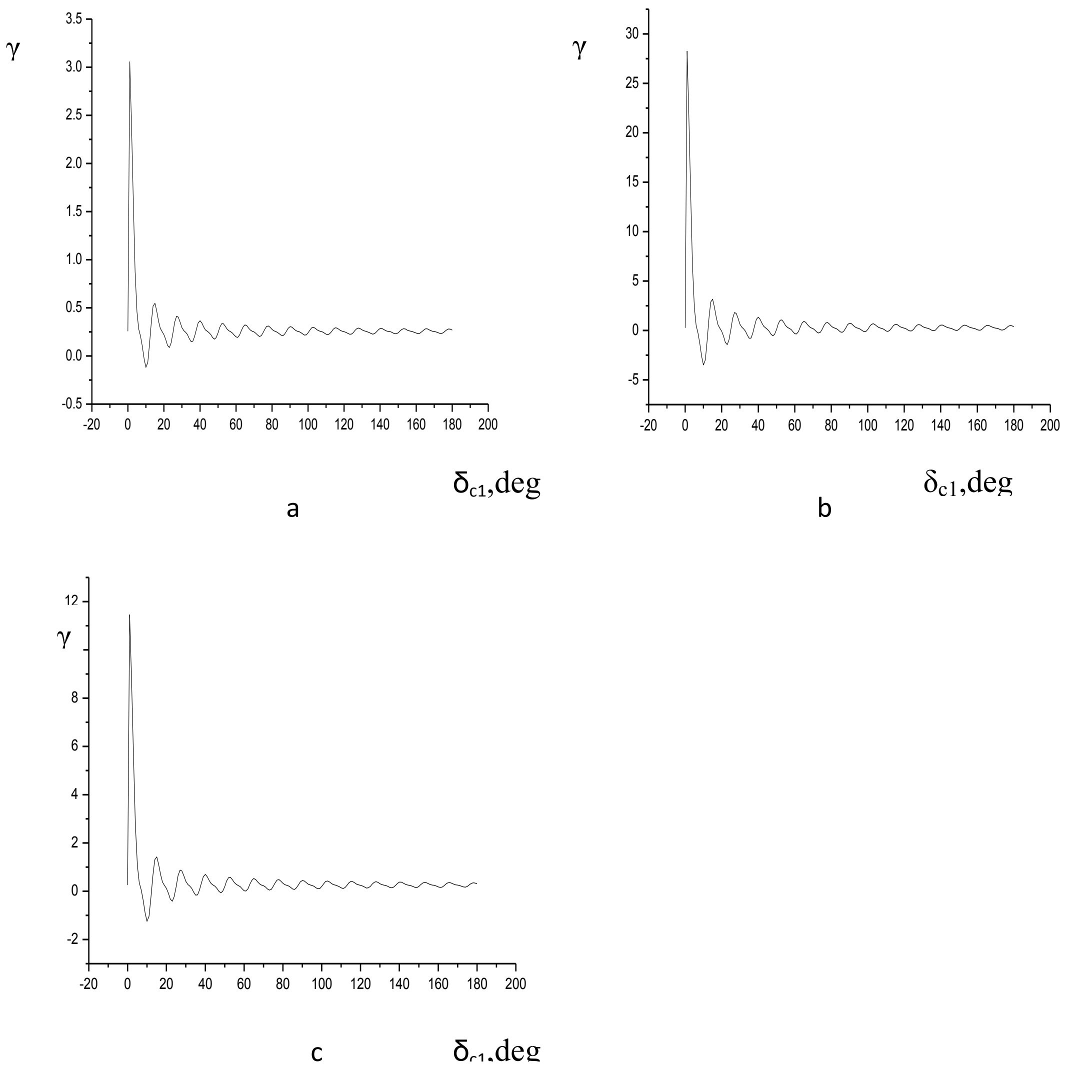

Figure4. Effect of circular birefringence for first optical element on thermal induced depolarization with different values of the ratio normalized power of heat D=1(a),D=10(b),D=4(c)

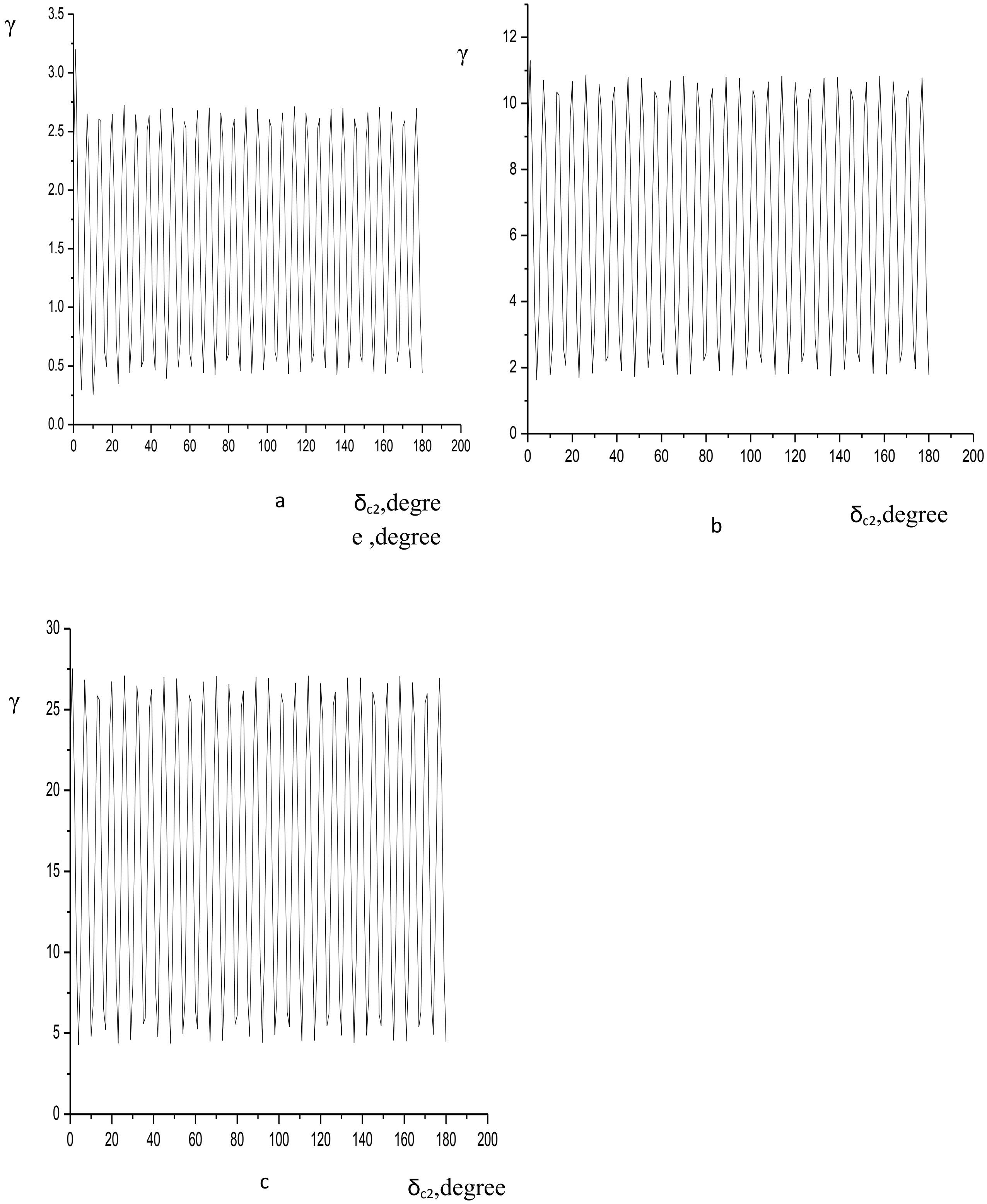

Figure5. Effect of circular birefringence for second optical element on thermal induced depolarization with different values of the ratio normalized power of heat D=1(a),D=4(b),D=10(d)

4. conclusion

The results have shown that thermal induced depolarization increased by increasing optical anisotropy for the first optical element and decreased by increasing the same property for second element in the system , thermal depolarization can be reduced even if ratio normalized power of heat was high by increasing anisotropy for the second optical element so we could avoid loss in power of radiation. The normalized power of heat affect strongly on the thermal induced depolarization when we have the same value of angle of quartz rotator such that when it was high thermal induced depolarization was high and then big loss in power. Circular birefringence property has a different effect for the first and second element, for the first element we were able to get a fixed and stable value of thermal induced depolarization and then reduced it to minimum value .

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