doi:10.3788/gzxb20154405.0523003

石榴石型偏振调节器温度效应研究

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摘　要:采用磁控溅射法制备了石榴石型偏振调节器并研究了温度对其的影响. 利用斯托克斯偏振仪和CCD,研究激光透过石榴石及石榴石型偏振调节器的偏振极化性质和光斑变化. 实验结果表明:在 25～75℃温度范围内,激光穿过不同材料时,斯托克斯参量变化趋势不同;但是因方位角不改变,激光的偏振度、线偏振度、圆偏振度基本不变.

关键词:石榴石; 条状; 薄膜; 温度; 偏振调节器

中图分类号:O436.3　　**文献标识码**:A　　**文章编号**:1004-4213(2015)05-0523003-6

Temperature Dependence of Garnet-type Polarization-modulation

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Abstract: The influence of temperature on the garnet-type polarization modulation was investigated. The garnet-type polarization modulation was prepared by magnetron sputtering method, the polarization properties and optical spots of laserbeam through garent and garnet-type polarization modulation were examined by Stokes polarimeter and CCD. The experimental results show that the Stokes parameters of the laser beam passing through different materials present different trends, while the degree of polarization, degree of linear polarization and degree of circular polarization are nearly unchanged as the ellipticity angle does not change, when changing the temperature from 25 to 75°C.

Key words: Garnet; Grooves; Films; Temperature; Polarization modulation

OCIS Codes: 230.5440; 290.5855; 310.6860; 210.3820

0 Introduction

In recent years, optical technologies using liquid crystals, electro-optic devices, polarimetric sensors, amplifier focusing the research interest on the evolution of the state polarization of light through anisotropic media are widely studied[1-5]. The polarization properties of laser beam can be modulated by different techniques such as smectic liquid crystals phases[6], periodically modulated metal film[7], the scattering medium[8-10], a simple lens[11-12], and Faraday rotator producing circularly polarized eigenstates for the laser[13]. Polarization self modulated laser contaning Faraday rotator is investigated[14]. Garnet films with high coercivity is researched for data storage[15], the magneto-optical readout system based on a signal transfer from videotape to magnetic garent has been proposed[16]. Bi-substituted garnet film is used to prepare low noise LD module[17]. Garnet as Faraday effect current sensor are researched as high sensitivity[17-19]. Wu Bao-jian researches the polarization characteristics of mganeto optic fibers[20]. The rotation of garnet films and garnet with groove films can be used as polarization modulation at room

Foundation item: The National Natural Science Foundation of China (No. 61205076), the University Young Teacher Training scheme of Shanghai, Hujiang Foundation of China(No. C14002), Shanghai Natural Science Foundation of China(No. 12ZR1420800)

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Received: Jan. 7, 2013; **Accepted**: Mar. 4, 2013

temperature due to the change of ellipticity angle of the transmitted and received polarization, the rotation of garnet with groove films can modulate the degree of polarization of laser beam from 0.16 to 0.945[21]. However, the polarization characteristics of light transmitting through garnet as a function of temperature is unclear, of particular interest is polarimetry at high temperature.

In this work, we demonstrate a polarization measurement system to better understand the polarization properties of garnet and garnet with groove films. we create theoretical basis and show that polarimetry in this context entails the complete measurement of Stokes parameters. Then, we describe the experiments used to study the change of Stokes parameters of light and optical spots emerging from garnet and groove films when increasing the temperature from 25 to 75℃.

1 Theory

The Stokes parameters can characterize all polarization states of laser beam. For purely monochromatic coherent radiation, Stokes parameters can show that

$$S_0^2=S_1^2+S_2^2+S_3^2 \tag{1}$$

The DOP, DOLP and DOCP of garnet Stokes vector can be defined by the following equations [21]

$$\mathrm{DOP}=\frac{\sqrt{S_1^2+S_2^2+S_3^2}}{S_0} \tag{2}$$

$$\mathrm{DOLP}=\frac{\sqrt{S_1^2+S_2^2}}{S_0} \tag{3}$$

$$\mathrm{DOCP}=\frac{|S_3|}{S_0} \tag{4}$$

However, for the whole (non-coherent) beam radiation, the Stokes parameters are defined as average quantities, Eq. (1) becomes an inequality

$$S_0^2\geqslant S_1^2+S_2^2+S_3^2 \tag{5}$$

S_2, S_3, DOP of non-coherent beam radiation at different temperatures can also be measured from Stokes polarimeter. And the $\mathrm{DOLP_{non}}$ can be calculated from

$$\mathrm{DLOP_{non}}=\frac{\mathrm{DOP_{non}}\sqrt{S_{1\mathrm{non}}^2+S_{2\mathrm{non}}^2}}{\sqrt{S_{1\mathrm{non}}^2+S_{2\mathrm{non}}^2+S_{3\mathrm{non}}^2}} \tag{6}$$

$$\mathrm{DLCP_{non}}=\frac{|S_{3\mathrm{non}}|\,\mathrm{DOP_{non}}}{\sqrt{S_{1\mathrm{non}}^2+S_{2\mathrm{non}}^2+S_{3\mathrm{non}}^2}} \tag{7}$$

where S_0 is the total intensity of the light, S_1 is the intensity of 0 degree linear polarization minus the intensity of 90 degree linear polarization, S_2 is the intensity of 45-degree linear polarization minus the intensity of −45 degree linear polarization, S_3 is the intensity of right-hand circular polarization minus the intensity of left-hand circular polarization. DOP is an important property of light sources. It is used to describe how much in the total light power is polarized. DOLP indicates the crystalline alignment of material parallel to the linear polarization states. The DOCP is a measurement of how effectively the material flips the circularly scattered light within the local volume. When the DOP of the exiting beam is less than the DOP of the incident beam, the polarization modulation occurs. The Mueller matrix can be used to represent linear laser beam-sample interaction. The polarization properties of laser beam can be described by a Mueller matrix ($\boldsymbol{M}$) that relates the incident Stokes vector $\boldsymbol{S}_{\mathrm{Incident}}$ with the exciting Stokes vector $\boldsymbol{S}_{\mathrm{Exiting}}$, when the laser beam interacts with garnet and groove films[22-23]. The $\boldsymbol{S}_{\mathrm{Exiting}}$ can be given by

$$\boldsymbol{S}_{\mathrm{Exiting}}=\boldsymbol{M}\times\boldsymbol{S}_{\mathrm{Incident}}=\begin{bmatrix}M_{00} & M_{01} & M_{02} & M_{03}\\ M_{10} & M_{11} & M_{12} & M_{13}\\ M_{20} & M_{21} & M_{22} & M_{23}\\ M_{30} & M_{31} & M_{32} & M_{33}\end{bmatrix}\times\begin{bmatrix}S_0\\ S_1\\ S_2\\ S_3\end{bmatrix} \tag{8}$$

when the laser beam interacts with groove films the back-scatter phase Mueller matrix may be generally written

$$\boldsymbol{M}(\pi)=\beta\begin{bmatrix}1 & 0 & 0 & 0\\ 0 & 1-d & 0 & 0\\ 0 & 0 & d-1 & 0\\ 0 & 0 & 0 & 2d-1\end{bmatrix} \tag{9}$$

where β is the volume back-scatter coefficient and d is referred to the depolarization of the scattering medium with allowable value between 0 and 1. For an arbitrary polarization, d may be calculated by

$$d=\frac{4N_{\mathrm{Pe}}}{(N_{\mathrm{Pe}}+N_{\mathrm{Pa}})(3-\cos 4\chi_{\mathrm{L}})} \tag{10}$$

where N_{Pe} and N_{Pa} are signals measured on the polarization channel perpendicular and parallel to the transmit polarization, χ_{L} is the ellipticity angle of the transmitted and received polarization.

2 Experiments

In order to evaluate the temperature dependence of polarization properties of garnet and garnet with groove films, Ta(50 nm)/$Nd_2Fe_{14}B$(100 nm)/Ta(50 nm), Ta(50 nm)/$Nd_2Fe_{14}B$(500 nm)/Ta(50 nm) groove films are prepared on garnet films through a stainless mask in a magnetron sputtering system with base pressure$<1\times10^{-5}$ Pa. During deposition, the garnet was heated to 400℃, after deposition, the sample was annealed at temperature 550℃ for 30 minutes in a vacuum of 1×10^{-4} Pa to crystallize $Nd_2Fe_{14}B$ phase. The height and phase were conducted by a Magnetic Force Microscope

(MFM) Dimension 3100. A schematic drawing of the experimental set-up for measuring the polarization properties of laser beam at different temperatures is shown in Fig 1. A continuous laser is used as the light source, which has a center wavelength of 1550nm. Thorlabs PAX5710IR3 polarimeter based on rotating waveplate technique is used as a detector.

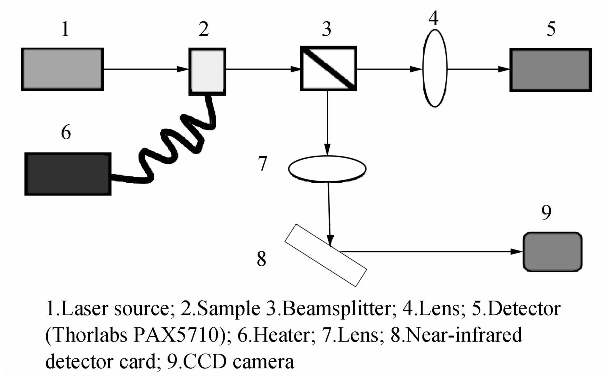
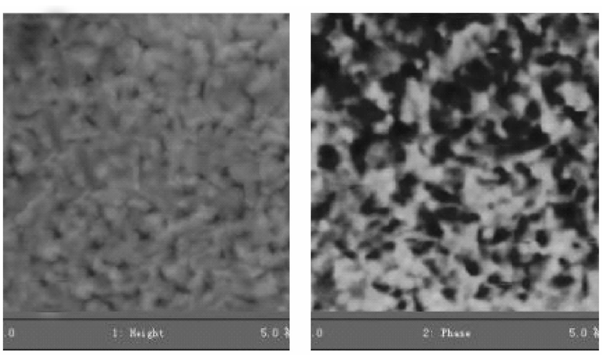


Fig. 1 Schematic drawing of experimental set-up

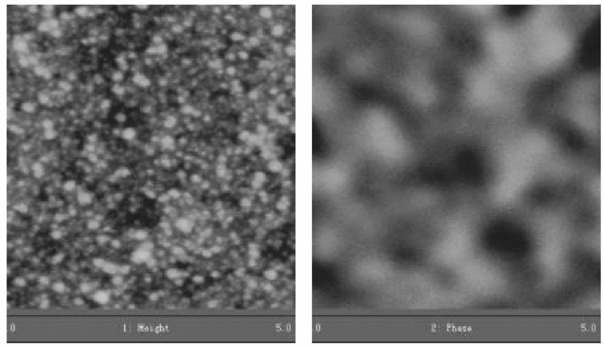
The laser beam (1) transmits through the sample. After emerging from the sample (2), 1 500 nm laser beam is divided into two parts by using a non-polarizing 50 : 50 Thorlabs CM1-BS015 beamsplitter (3): one arrives at the Thorlabs PAX5710IR3 detector (5) after passing through lens (4), another appears on a near-infrared detector card (8) via lens (7). And a CCD (9) is used to capture and observe optical spot energy distribution on the near-infrared detector card (8). The Stokes parameters can be got from the polarimeter. The DOP accuracy and resolution of Thorlabs PAX 5710IR3 are ±0. 5% and 0. 0001, respectively. The sample are three types, one garnet, another garnet/Ta (50 nm)/$Nd_2Fe_{14}B$- (100 nm)/Ta(50 nm)(100 nm), the third is garnet/Ta(50 nm)/$Nd_2Fe_{14}B$(500 nm)/Ta (50 nm)(500 nm)).

3 Results and discussion

The height and phase images of 100 nm, 500 nm groove films are shown in Fig. 2. The height image of 100 nm groove film is shown in left of Fig. 2(a). The film is very smooth and clean . The phase image of



(a) MFM of garnet/Ta(50nm)/$Nd_2Fe_{14}B$(100nm)/Ta(50nm)



(b) MFM of garnet/Ta(50nm)/$Nd_2Fe_{14}B$(500nm)/Ta(50nm)

Fig. 2 MFM of garnet with groove films

100 nm groove films is shown in right of Fig. 2(a). The magnetic domains show pronounced random strips structures, as the domain self energy and interaction energy are much greater than the thermal fluctuation energy. The height and phase images of 500 nm groove films are shown in left and right of Fig. 2(b), respectively. Fig. 2(b) shows the fine details for both the topographic and magnetic images.

The relationship between Stokes parameter S_1 and temperature for different samples (garnet, 100 nm and 500 nm $Nd_2Fe_{14}B$ groove films) are shown in Fig. 3 (a). When the temperature is changed from 25 to 50℃, Stokes parameter S_1 is nearly unchanged. When the temperature exceeds 50℃, however, the Stokes parameter S_1 of different samples shows different trends: S_1 increases from 0. 25 to 0. 4 in case of the garnet sample and from −0. 15 to −0. 04 for 100nm $Nd_2Fe_{14}B$ groove film, while S_1 reduces −0. 3 to −0. 4 for 500 nm $Nd_2Fe_{14}B$ groove film. It can be seen that temperature effect on S_1 is not the same for groove garnet films with different thickness.

Fig. 3(b) shows the change of Stokes parameter S_2 for different samples when changing temperature from 25 to 75℃. As mentioned above, S_2 represents the intensity difference between +45° and −45° polarized components. When rising the temperature from 25 to 50℃, S_2 is slightly changed for the garnet and 100 nm $Nd_2Fe_{14}B$ groove film: changing from 0. 93 to 0. 94 in case of garnet sample and that is from 0. 96 to 0. 95 for 100 nm $Nd_2Fe_{14}B$ groove film; while S_2 changes from 0. 90 to 0. 87 with the sample of 500 nm $Nd_2Fe_{14}B$ groove film. Stokes parameter S_2 for different samples has decreasing trend when changing the temperature from 50 to 75℃.

The relationship between Stokes parameter S_3 and temperature for different samples is shown in Fig. 3 (c). With the garnet sample, S_3 decreases from 0. 27 to 0. 23 when increasing the temperature from 25 to 50℃, and still has downward tendency when the temperature exceeds 50℃. However, S_3 increases from 0.22 to 0.25 when changing the temperature from 25 to 50℃, and still shows upward tendency when increasing the temperature over 50℃ in case of 100 nm $Nd_2Fe_{14}B$ groove film. For 500 nm $Nd_2Fe_{14}B$ groove film, S_3 increases from 0.33 to 0.40 with the temperatures below 50℃ while it gradually decreases but still greater than that at the room temperature when the temperature is over 50℃.

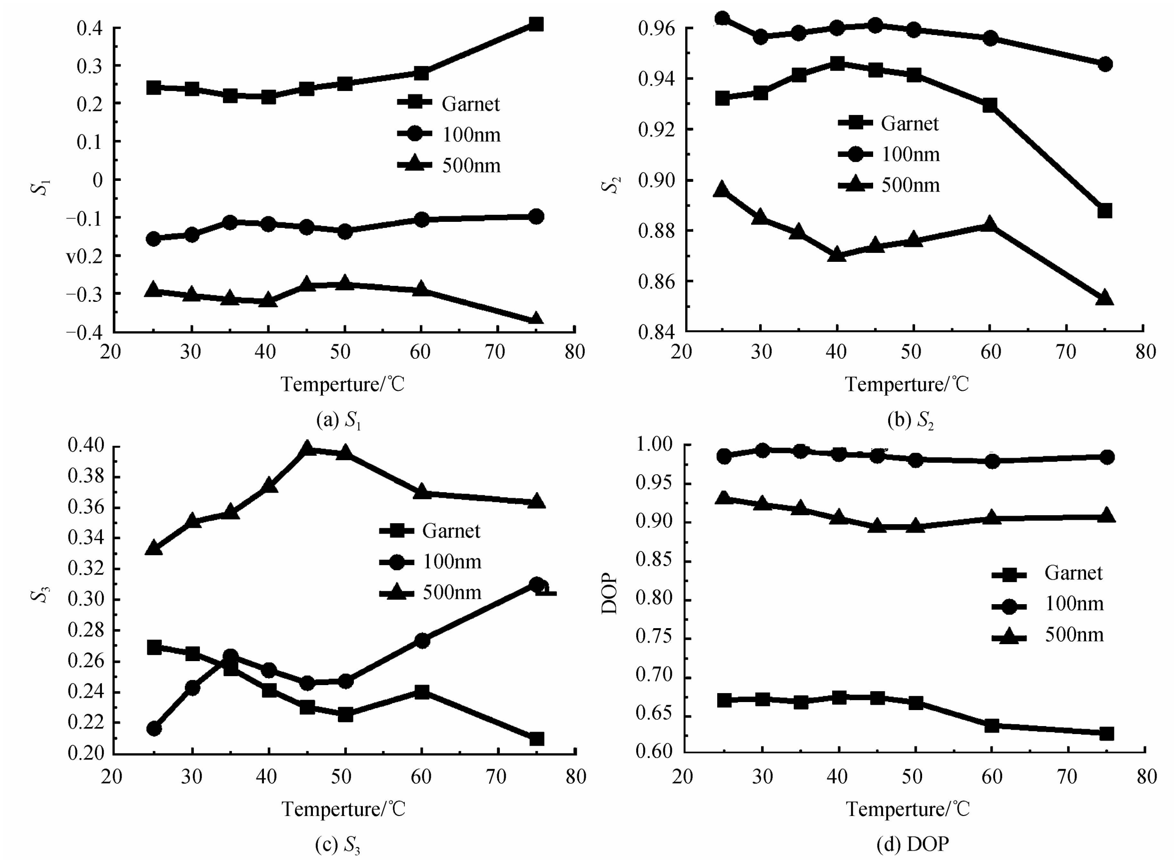
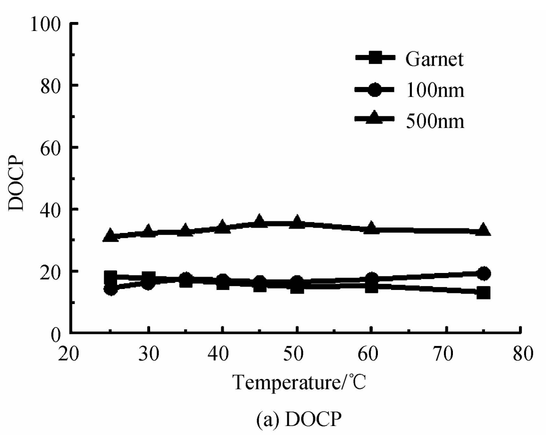


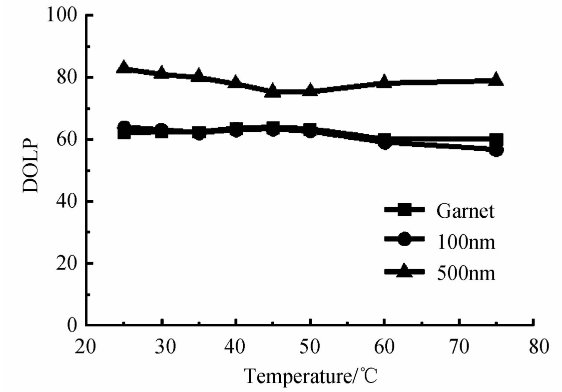
Fig. 3 Stokes parameters of laser beam going through samples at different temperatures

Fig. 3(d) illustrates the change of DOP of different samples with the temperature. DOP for different samples is almost unchanged when increasing the temperature from 25 to 50℃. DOP of the laser beam has downward tendency in case of garnet sample when increasing the temperature over 50℃, while those of other samples are nearly unchanged. It shows that the Stokes parameters of S_1, S_2, S_3 can be affected when the temperature is changed, but the degree of polarization of different samples nearly can not be changed.

The DOLP and DOCP of laser beam going through garnet can be calculated from Eq. (3), Eq. (4), while the DOLP and DOCP of garnet with different groove films can be calculated from Eq. (6), Eq. (7). Fig. 4 shows the relationship between DOLP, DOCP and temperature of garnet and garnet with groove films. The DOLP and DOCP value of garnet and garnet with different groove films basically do not change, when the temperature changes from 25 to 75℃. From Eq. (8), Eq. (9), Eq. (10), we can see that the DOLP and DOCP only have a relationship with the ellipticity angle. The Stokes parameters are determined by azimuth and ellipticity[24]. The Stokes parameters basically do not change, when the changes of azimuth and ellipticity are small values, even the temperature is changed from 25 to 75℃. And the azimuth and ellipticity are determined by their initial states.

The transmittance of garnet does not change, and the transmittance of garnet with groove films changes when the garnet rotates from 0 to 70°[21]. How about the transmittance of garnet and garnet with groove films, is unclear, so a CCD is used to study the optical





(b) DOLP

Fig. 4 DOLP and DOCP of laser beam going through samples at different temperatures

spot energy distribution when the laser beam goes through different samples at different temperatures as shown in Fig. 5. The laser light spot energy distribution can be seen in Fig. 5(a) when the sample is garnet, 25℃ (left), 50℃ (middle), 75℃ (right). The optical spot is almost unchanged when the temperature is increased from 25 to 75℃. Fig. 5(b) shows that the intensity of laser spot, for 100 nm $Nd_2Fe_{14}B$ groove film, 25℃ (left), 50℃ (middle), 75℃ (right), the central region of the light spot is reduced when the temperature is increased from 25 to 75℃. And the optical spots of 500 nm $Nd_2Fe_{14}B$ groove film are nearly invisible when increasing the temperature from 25 to

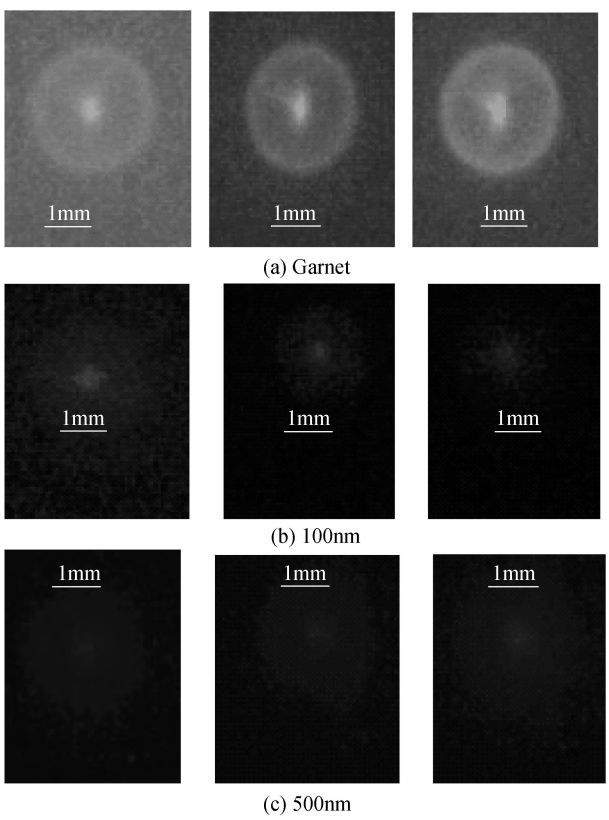


Fig. 5 The optical energy distribution of laser beam going through different samples with the temperature

75℃ as shown in Fig. 5(c), 25℃ (left), 50℃ (middle), 75℃ (right). This shows that when increasing the film thickness the laser spot energy is weakened since the scattering effect of the laser beam is enhanced[25].

4 Conclusion

In conclusion, the Stokes parameters of garnet and garnet with groove films S_1, S_2, S_3, DOP, DOLP, and DOCP can be obtained by using Stokes polarimeter when the temperature is changed from 25 to 75℃. The Stokes parameters of S_1, S_2 and S_3 of different samples can be changed when changing the temperature, while the DOLP and DOCP of different samples are nearly unchanged as the ellipticity angle does not change. The optical spot energy distribution is weakened due to enhanced scattering effect when increasing the thickness of groove film.

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