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Measurements of the angular performance of magneto-optic phase enhanced quadrilayers based on TbFeCo

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Abstract. Seven TbFeCo based magneto-optic phase enhanced quadrilayers have been designed and fabricated to improve the detection of the polar Kerr effect in order to maximize the SNR associated with the read process in a magneto-optic memory. Each system consisted of ZnS/TbFeCo/ZnS/Al/glass and was fabricated using RF and DC sputtering techniques as well as conventional thermal evaporation. The experimental performance of these structures as a function of angle of incidence is reported and compared with theoretical predictions. Results obtained with incident radiation polarized in both P and S states indicate the success of the design philosophy and the fabrication procedure.

1. Introduction

The details of the design procedure for magneto-optic phase enhanced quadrilayer structures has already been presented [1] together with an account of the performance of such devices at normal incidence as a function of wavelength λ from 300 to 900 nm [2]. The design philosophy is straightforward and may be summarized as follows. First, the system noise sources determine what reflectance R the structure should have. Typically this will be in the range 0–33%. Second, the parasitic Kerr ellipticity must be reduced to zero in order to simplify read-out head design and maximize the Kerr effect signal. Third, a mirror system, beneath the magnetic layer, must be designed to optimize the potential Kerr coefficient [3]. This results in the absolute maximum Kerr rotation possible for a particular disc reflectance. The design procedure produces devices capable of achieving the maximum SNR with respect to the magneto-optical read process.

The spectral dependence of the performance of such devices is of some interest [2] as are their optical and magneto-optical properties at normal incidence. Equally important, however, are the variations of the principal optical and magneto-optical functions with angle of incidence since it is usual for the read process to involve the use of a highly convergent light beam [4].

In this paper we report on the measured optical and magneto-optical properties of several quadrilayer devices and compare the actual performance with theoretical predictions based on the optical and magneto-optical constants of the component materials [2, 5, 6] used in conjunction with the 4×4 matrix approach to magneto-optic multilayer calculations, which have been well known for over 25 years [7].

2. Experimental details

The quadrilayer structure, shown in figure 1, was designed to operate at a wavelength of 633 nm. At this wavelength, the normal incidence reflectance was arbitrarily chosen to be

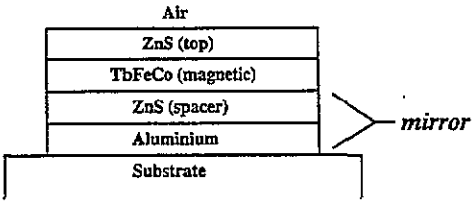

Figure 1. The quadrilayer structure.

17% whilst the Kerr rotation was to be the maximum possible with an accompanying zero Kerr ellipticity. This requires the important magneto-optic phase parameter cos δ_k to be equal to ± 1 [1].

The material constants were either taken from the literature [6], or were measured by magneto-optic ellipsometry in samples prepared in our own laboratories [5]. Table 1 gives the optical and magneto-optical constants of the individual materials together with the design thicknesses of the layers in the system.

Table 1. Optical and magneto-optical constants and layer thicknesses for a phase optimized quadrilayer system designed for a radiation wavelength of 633 nm.

Layer	n'	n''	Q'	Q''	Thickness (nm)
ZnS (top)	2.35	0	0	0	25.5
$Tb_{27}Fe_{62}Co_{11}$	2.68	3.37	0.0156	-0.37×10^{-3}	12.2
ZnS (spacer)	2.35	0	0	0	66.9
Al	1.38	7.65	0	0	>100

All samples were prepared using DC and RF sputtering of the TbFeCo alloy and the ZnS layers respectively at pressures of 10^{-1} Pa of Ar. The Al layer was deposited by thermal evaporation at a reduced pressure of 10^{-4} Pa. During the depositions of the layers the film thicknesses were monitored using a quartz crystal monitor. In addition the optical response of the growing system was also monitored continuously in reflectance. This provides a valuable indicator of the progress of developing multilayer systems and can be compared directly with theoretical predictions [2].

The Kerr rotations and ellipticities were measured in the angular range 10–75° for each of seven samples using a rotating analyser Kerr polarimeter with a precision better than 0.004°.

3. Angular performance

3.1. Incident radiation: S state

Figures 2 and 3 show the measured and theoretical variations of the complex Kerr rotation and the magneto-optic phase parameter cos δ_k as a function of angle of incidence from 10 to 70° with incident radiation polarized in the S plane. On these curves we show error bars that indicate the standard deviation in the measurements made on seven coatings. The precision of the Kerr polarimeter, as already indicated, is much smaller than the errors shown in these figures. Consequently, the error bars are an indication of the variations in sample quality caused by uncontrolled factors during fabrication. These may manifest themselves as film thickness error or compositional variations due to ageing of the TbFeCo sputter target.

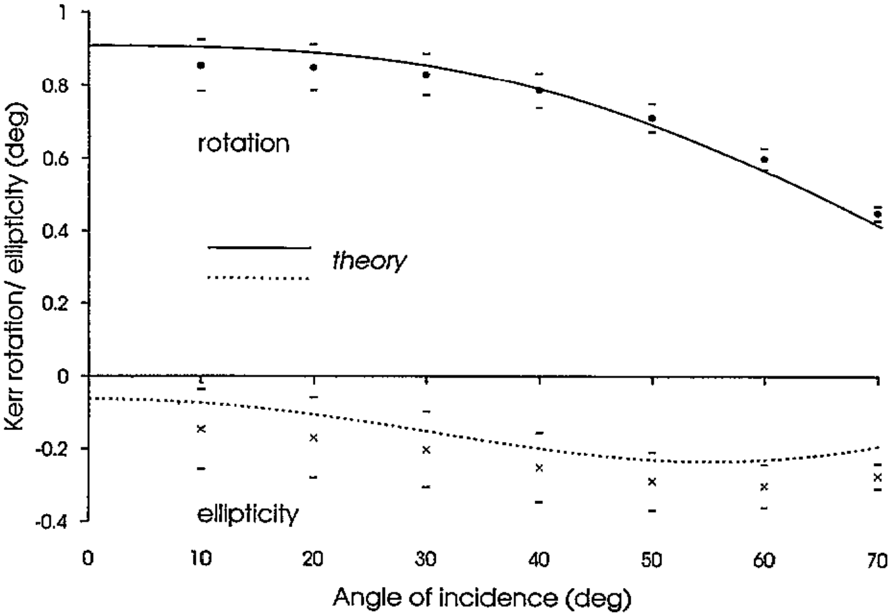

Figure 2. Angular variation of the complex Kerr rotation.

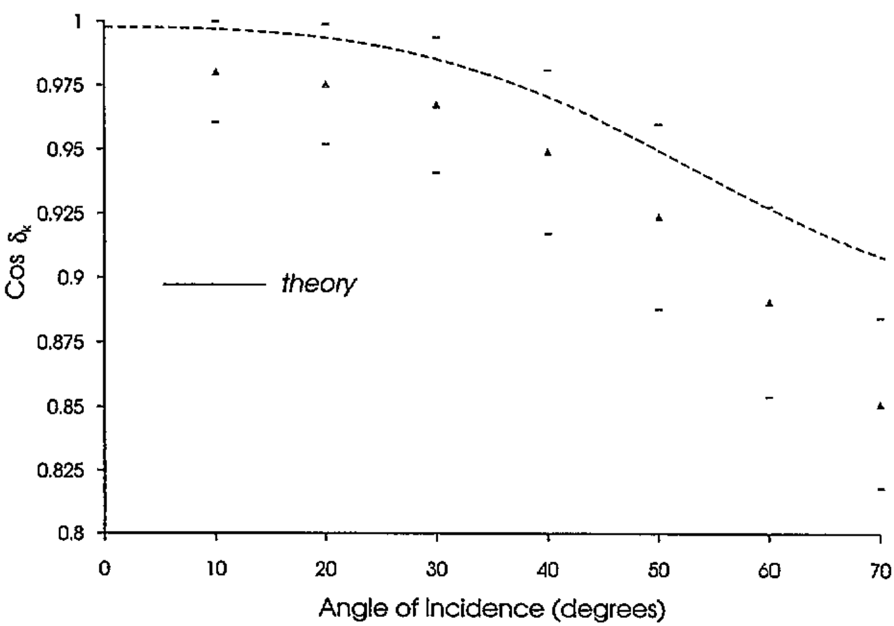

Figure 3. Angular variation of the magneto-optic phase parameter for radiation of wavelength 633 nm incident in the S state.

One can see immediately that the level of agreement between theory and practical performance is very good indeed for all samples. It should be noted that the Kerr ellipticity tends towards zero at normal incidence, in agreement with the design specification. As the angle of incidence increases the Kerr rotation begins to decrease as the amplitude reflectance for S polarized radiation increases and at the same time the magnitude of the Kerr ellipticity also increases slightly. The degradation of performance in terms of the onset of non-zero ellipticities is however not too serious, as can be seen from figure 3.

It is quite clear that for the angular range 0–60° the cos δ_k parameter is above 0.9 and that for most practical situations it is unlikely to fall below about 0.95.

3.2. Incident radiation: P state

In figure 4 we show the measured and theoretical performance of a quadrilayer for radiation incident in the P state up to an angle of incidence of 60°. As can be seen the agreement is very good for both Kerr rotation and ellipticity. It is worth noting that for this polarization state cos δ_k is greater than 0.96 over the whole of this range.

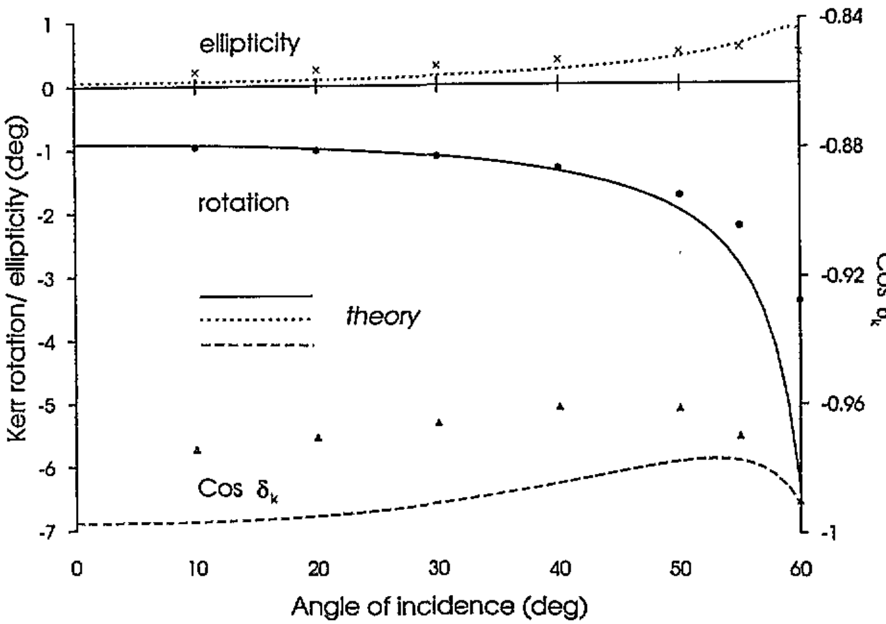

Figure 4. Angular variations of the complex Kerr rotation and magneto-optic phase parameter for radiation of wavelength 633 nm incident in the P state.

As the angle of incidence increases beyond 60° the changes in the magneto-optic functions are dramatic. This can be seen in figures 5 and 6 for the angular range 50–75°. The onset of rapid variations in all three functions is associated with the existence of a pseudo-Brewster angle normally associated with the P polarization state. At this angle, the P state reflectivity passes through a minimum with a corresponding phase reversal of the amplitude reflection coefficient. This gives rise to two peaks in the Kerr rotation: one positive and one negative. Between these two peaks the phase difference (δ_k) between the magneto-optic Kerr component and the isotropic Fresnel amplitude component is exactly 90°. This gives rise to zero Kerr rotation and a peak in the magnitude of the Kerr ellipticity. This is clearly seen in the theoretical areas of figure 5. One can also see that the magneto-optic phase parameter cos δ_k also undergoes a corresponding rapid change in sign; though away from the region of the Brewster angle the magnitude is still very close to unity. Despite the fact that the actual magnitudes and positions of the predicted peaks are not followed exactly in the practical measurements the general agreement is qualitatively correct as can be seen in figure 6. Here one sees the existence of the peaks in the Kerr rotation and ellipticity and the sign changes that occur in the Kerr rotation and of course cos δ_k. The peak in the magnitude of the Kerr ellipticity coincides with the zero in Kerr rotation as is expected, though the pseudo-Brewster angle occurs at about 68±0.2° compared to the theoretical value of 63.5°.

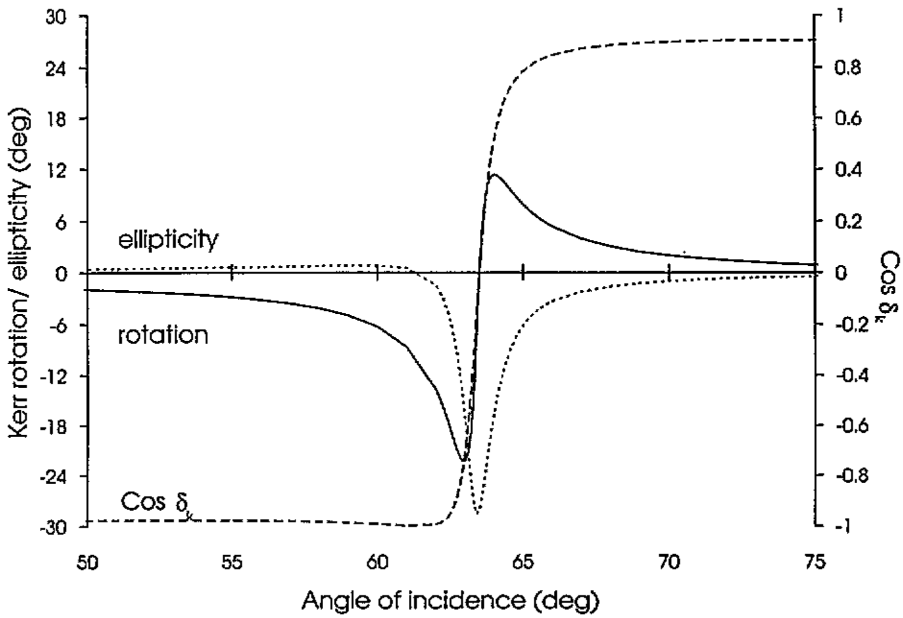

Figure 5. The theoretical variation of the complex Kerr rotation and magneto-optic phase parameter in the vicinity of the pseudo-Brewster angle for radiation incident in the P state.

It may be observed from a comparison of theoretical and experimental curves (figures 5 and 6) that the functional variations around the pseudo-Brewster angle are only in qualitative agreement. This is probably related to the sensitivity of these functions to errors in the layer thickness and/or variations in the optical and magneto-optical constants of the materials. Consequently the true test of the quality of such a device should perhaps be made in this region. However, from a practical performance point of view this angular region is of little interest. This is for two reasons. First, the angles of incidence are excessively large even for convergent beams. Second, beyond the Brewster angle the sign change in Kerr rotation would cause a deterioration in the read-out signal. Consequently, focused beams should be stopped down in order to limit convergence to an angle less than the pseudo-Brewster angle of the quadrilayer structure.

4. Conclusions

We have successfully designed quadrilayer structures based on the system ZnS/TbFeCo/ZnS/Al, which, in principle, will maximize the SNR associated with the read-out of stored information in a magneto-optic recording system using a differential detection technique to sense the polar Kerr effect produced by written domains.

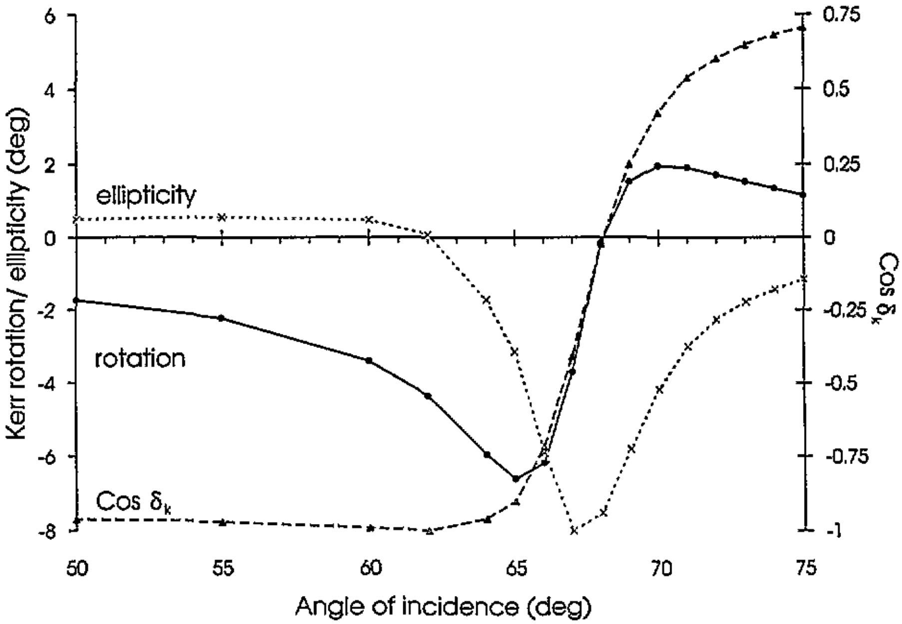

Figure 6. Measured angular variations of the complex Kerr rotation and magneto-optic phase parameter in the vicinity of the pseudo-Brewster angle for radiation incident in the P state.

A number of devices based on this system have been fabricated with good reproducibility using RF/DC sputtering and conventional evaporation techniques with layer thickness being monitored by a quartz crystal balance and the normal incidence optical reflectance method.

The performance of the devices, in terms of their magneto-optical complex polar Kerr rotation and the corresponding phase parameter cos δ_k, has been measured using a rotating analyser Kerr polarimeter as a function of angle of incidence within the range 10–75°.

The agreement with theoretical predictions based on known optical and magneto-optical constants is excellent for angles up to 60°, which is well above any angle of practical importance. Above this angle and in the vicinity of the pseudo-Brewster angle the performance may become sensitive to the errors in layer thickness and variations in material constants for incident radiation linearly polarized in the principal P state.

Finally, it is worth pointing out that in conventional magneto-optic discs, stored information is addressed through the substrate rather than at the air–coating interface as in this simple example. However, the quadrilayer design procedure referred to in this paper may be easily adapted to take into account an incident medium of high (~1.5) refractive index.

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