AIP | Applied Physics Letters

Signal-to-noise ratio for magneto-optic readout from quadrilayer structures

G. A. N. Connell, D. Treves, R. Allen, and M. Mansuripur

Citation: Applied Physics Letters **42**, 742 (1983); doi: 10.1063/1.94046
View online: http://dx.doi.org/10.1063/1.94046
View Table of Contents: http://scitation.aip.org/content/aip/journal/apl/42/8?ver=pdfcov
Published by the AIP Publishing

Signal-to-noise ratio for magneto-optic readout from quadrilayer structures

G. A. N. Connell, D. Treves,[a] R. Allen, and M. Mansuripur
Xerox Palo Alto Research Center, Palo Alto, California 94304

(Received 20 December 1982; accepted for publication 27 January 1983)

We present an experimental investigation of our earlier theoretical predictions regarding the signal-to-noise ratio for magneto-optic readout from quadrilayer structures in a differential detection scheme. Using quadrilayer structures employing amorphous Tb-Fe alloys as the magnetic material, quartz as the dielectric material, and aluminum as the reflecting material, we show that the signal enhancement predicted for quadrilayers occurs even when the numerical aperture of the readout system is large, a crucial result for their effectiveness in magneto-optic storage applications. We also show that the signal-to-noise ratios measured are in quantitative agreement with theory.

PACS numbers: 85.70.Sq

In earlier works[1-3] we discussed theoretically the optimization of the signal-to-noise ratio for a magneto-optic readout from quadrilayer structures using a differential detection scheme. In this letter we make the first direct comparison of these theoretical predictions with experimental observations. We show empirically that the signal enhancement predicted for quadrilayer structures occurs even when the numerical aperture of the readout system is large. We also show that the signal-to-noise ratios measured on quadrilayers are in quantitative agreement with theory.

The magnetic material used in this study was amorphous Tb-Fe. Full details of its preparation and the magneto-optical properties of thick material have been published elsewhere.[4,5] It is crucial for this study, however, to establish the range of film thicknesses over which these optical parameters are applicable. Therefore, we first deposited $Tb_{0.23}Fe_{0.77}$ films with thicknesses ranging from 5 to 100 nm in the quadrilayer structure shown in Fig. 1. In this structure the magnetic film lies between two transparent dielectric films that together rest on an opaque reflector.[1,2] In our case, the whole device was deposited *in situ*, using quartz and aluminum, respectively, as the dielectric and reflecting materials, and Corning 7059 glass as a substrate. The device has therefore two essential attributes: first, it prevents any oxidation of the magnetic layer from occurring[4]; second, it produces a real enhancement in the polar Kerr intensity for a large range of magnetic film thicknesses. To understand this, consider that plane polarized light ($E \| x$) is incident normally on a very thin sample with perpendicular magnetization. The reflected light then has a regular component r_x and a magneto-optically induced component r_y. In the quadrilayer structure, however, the thicknesses of the quartz films are adjusted so that $|r_x|$ is small. This occurs when the ray reflected directly from the sample is out of phase with light which has suffered at least one reflection from the back reflector. To achieve this, the optical thicknesses of the quartz interlayers and overlayers must be approximately quarter-wave and zero (or half) wave, respectively. Under these conditions, the magneto-optically induced light which is emitted toward the reflector is returned in phase with the component emitted directly from the sample, and amplitude addition of the exiting rays occurs. This is the origin of the effectiveness of the quadrilayer structure in the magneto-optic readout, but the enhancement of the Kerr intensity coefficient ($|r_y|^2$) relative to its bulk value is also the best measure of the agreement between experiment and theory.[6]

The results for fixed quartz interlayer and overlayer thicknesses of 75 and 20 nm, respectively, are shown in Fig. 2. Namely, the reflectance and the absolute values of the polar Kerr rotation, ellipticity and intensity enhancement, calculated from the bulk dielectric tensor for a wavelength of 850 nm and temperature of 298 K, are shown versus the magnetic film thickness. We see that at thicknesses of $Tb_{0.23}Fe_{0.77}$ above 15 nm, there is excellent agreement, but at 5 nm, the measured enhancement is about 17% lower than that calculated. This cannot be accounted for by an error in the magnetic film thickness, since the necessary change would result in large discrepancies between the measured and calculated rotations and ellipticities. While the origins of these deviations have been described elsewhere,[7] a sufficient conclusion for our purposes here is that we expect a quantitative contact between theoretical and experimental signal-to-noise ratios for magnetic films with thicknesses above 20 nm.

The foregoing measurements were made at low numerical aperture. A significant question for the magneto-optical readout of digital information in quadrilayer structures, however, is whether the level of intensity enhancement (and

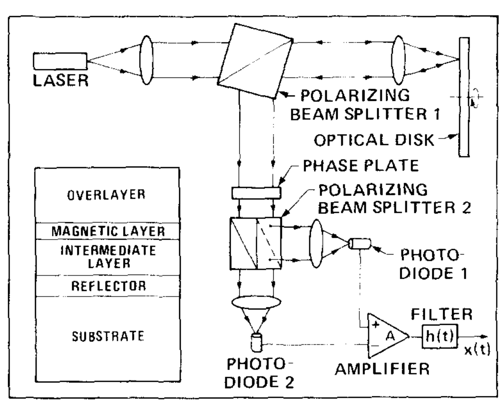

FIG. 1. Schematic representation of the layout of the differential detection system and, as an inset, a blowup of the magneto-optical medium.

[a] Harry De Jure Professor in Applied Physics, on leave from The Weizmann Institute of Science.

 0003-6951/83/080742-03$01.00

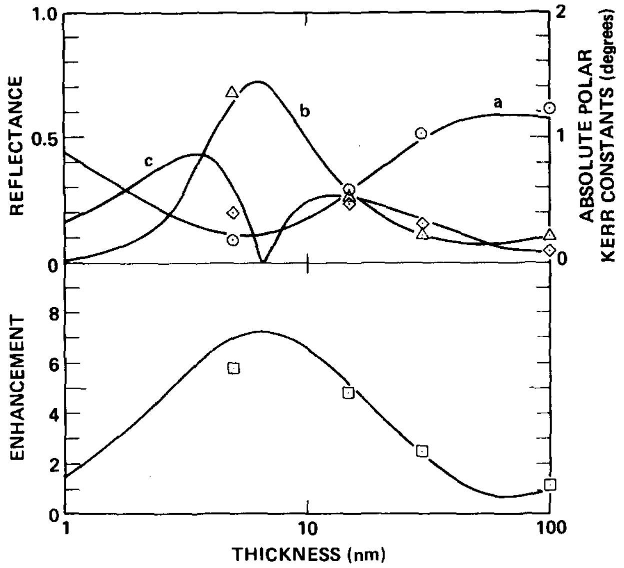

FIG. 2. Calculated (——) and measured thickness dependence of (a) the reflectance (○ ○), (b) the absolute value of polar Kerr rotation (△ △), (c) the absolute value of polar Kerr ellipticity (◇ ◇), and (d) the enhancement of polar Kerr intensity (□ □) in the quadrilayer configuration for a wavelength of 850 nm and temperature of 298 K.

agreement with theory) obtained continues for illumination at high numerical aperture. The answer to this question (and the later signal-to-noise ratio measurements) was derived using the illumination and detection system shown in Fig. 1. In this system, collimated linearly (horizontally) polarized light from a GaAs laser passes through a polarizing beam splitter (1) and is incident at 0.85 numerical aperture on a magneto-optic medium. (The focusing optics and servodesign are discussed in Ref. 8.) The reflected elliptically polarized light is then guided to the differential detection module by the same polarizing beam splitter (1). Notice that this beam splitter is rotated about the vertical axis by an angle θ such that a fraction $\sin\theta$ of the horizontal amplitude component (r_x) and a fraction $\cos\theta$ of the vertical (magneto-optically induced) amplitude component (r_y) of the elliptically polarized reflected light reach the detector module. This resulting polarization state is finally linearized by the suitably adjusted phase plate, split by the second polarizing beam splitter (2) and detected by separate avalanche photodiodes. Thus, when the two outputs are fed to the differential amplifier, the amplified signal power is directly proportional to the product of the polar Kerr intensity $(P_0|r_y|^2)$ and the reflected light intensity $(P_0|r_x|^2)$, where P_0 is the laser power incident on the medium. The total signal power is proportional to $P_0|r_x|^2$ directly, when $|r_y|^2 \ll |r_x|^2$.

The experimental tests of the effect of numerical aperture were made through comparison of measurements on simultaneously fabricated bilayer and quadrilayer samples. Each sample consisted of a 19-nm-thick Tb-Fe film sandwiched between a 135-nm-thick underlayer and a 160-nm-thick overlayer of quartz. Thus, while fabricated from three layers, that part formed directly on a glass substrate responds optically as a bilayer while that formed on an aluminum layer responds as a quadrilayer. The results of the comparison are shown in Table I for various Tb-Fe

TABLE I. Comparison of quadrilayer-to-bilayer enhancement at low and high numerical aperture.

Nominal sample composition	Enhancement ($\|r_y\|_Q^2/\|r_y\|_B^2$)		
	Calculated	NA = 0	NA = 0.85
$Tb_{0.20}Fe_{0.80}$	2.34 ± 0.1	2.33 ± 0.05	2.09 ± 0.1
$Tb_{0.23}Fe_{0.77}$	2.34	2.23	2.25
$Tb_{0.25}Fe_{0.75}$	2.34	2.33	2.26

compositions, and we can see immediately that there is no significant difference between the calculated and measured quadrilayer-to-bilayer enhancement. (In the case of the calculated results, the error is estimated using the experimental uncertainty in the film thicknesses.) The similarity of the measurements at low and high numerical aperture moreover, while crucial for the effectiveness of quadrilayer media in magneto-optical storage applications, is intriguing in itself and warrants further investigation in future.

The signal-to-noise ratio for the detection system in Fig. 1 is readily written down after inspection of our earlier work.[1,2] It is

$$\mathrm{SNR} = \frac{8\eta\alpha P_0|r_x|^2|r_y|^2\sin^2\theta\cos^2\theta}{B\,[eF_G(|r_x|^2\sin^2\theta + |r_y|^2\cos^2\theta) + 2i_n^2/(\eta\alpha P_0 G^2)]}, \tag{1}$$

where α is the transmission efficiency of the detection optics, B the system noise bandwidth set by the electronic filter $h(t)$, i_n the thermal noise current density, and η, G, and F_G the conversion factor, gain, and noise factor,[9] respectively, of the avalanche diodes. It is readily seen that in the absence of thermal noise $(i_n = 0)$ and noise in the avalanche detection process $(F_G = 1)$, the signal-to-noise ratio reduces to the shot-noise limit that is often used to describe this type of detection system (e.g., Ref. 8). (For later convenience, we have defined the signal-to-noise ratio in Eq. (1) as peak-to-

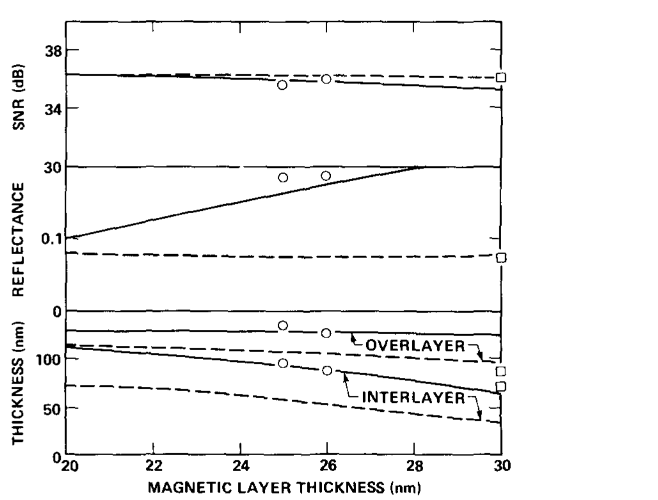

FIG. 3. Maximum signal-to-noise ratio, reflectance, and interlayer and overlayer thicknesses vs $Tb_{0.23}Fe_{0.77}$ thickness. The calculations are for dielectric refractive indices of 1.5 (——) and 2.0 (— —), respectively. The experimental results are for SiO_2-based (○ ○) and SiO-based (□ □) quadrilayers.

peak signal power to mean noise power, as distinct from our earlier work.) The maximum signal-to-noise ratio for any experimental system constants may therefore be achieved by appropriate quadrilayer design, and in Fig. 3 the dielectric layer thicknesses required for optimum response are shown versus $Tb_{0.23}Fe_{0.77}$ thickness. In these calculations, we have used our experimental values of α, B, i_n, and η, the optical constants of amorphous $Tb_{0.23}Fe_{0.77}$[4] and aluminum at 840 nm, and a dielectric refractive index of either 1.5 or 2.0. Note that in the range of $Tb_{0.23}Fe_{0.77}$ thicknesses covered, the maximum signal-to-noise ratio depends very little on the refractive index of the dielectric material, whereas both the reflectivity and dielectric layer thicknesses of structures with the same $Tb_{0.23}Fe_{0.77}$ thickness are sensitive to it. Thus, while the signal-to-noise ratio itself does not differentiate one design from another, other factors which influence the thermal response during writing and readout,[3] for example, provide important criteria for a selection process.

In Fig. 3 we also plot experimentally determined signal-to-noise ratios and reflectances of theoretically optimum SiO_2 based and empirically adjusted SiO-based[10] quadrilayer media. In these studies, the signal-to-noise ratio measurements were performed by bulk switching the TbFe films and measuring the peak-to-peak excursion of the signal power and mean noise power as the medium moved at 2.5 m/s. The results so obtained may therefore be directly compared with the earlier calculated curves. We then see that in both cases the measured reflectivities and signal-to-noise ratios are in excellent agreement with theory, even when the dielectric layer thicknesses deviate somewhat from their optimum values. (Indeed, other calculations indicate that even the large discrepancy in interlayer thickness in the SiO-based quadrilayer causes a reduction of only a few tenths of a decibel in the signal-to-noise ratio.) We conclude, therefore, that the quadrilayer design provides experimentally what it promised theoretically!

[1] M. Mansuripur, G. A. N. Connell, and J. W. Goodman, J. Appl. Phys. **53**, 4485 (1982).
[2] M. Mansuripur, G. A. N. Connell, and J. W. Goodman, SPIE **329**, 215 (1982).
[3] M. Mansuripur and G. A. N. Connell (unpublished).
[4] R. Allen and G. A. N. Connell, J. Appl. Phys. **53**, 7353 (1982).
[5] G. A. N. Connell, R. Allen, and M. Mansuripur, J. Appl. Phys. **53**, 7759 (1982).
[6] G. A. N. Connell, Appl. Phys. Lett. **40**, 212 (1982).
[7] G. A. N. Connell, R. Allen, and M. Mansuripur, Proceedings of the 10th International Colloquium Magnetic Films and Surfaces (Yokohama, Japan, 1982).
[8] D. Cheng, D. Treves, and T. Chen, SPIE **329**, 223 (1982).
[9] S. D. Personick, Bell Syst. Tech. J. **50**, 3075 (1971).
[10] T. Chen and D. Treves (unpublished).

Size effect on magnetic moment density of dispersed nickel

T. S. Cale,[a] J. T. Richardson, and J. Ginestra

Department of Chemical Engineering, University of Houston, Houston, Texas 77004

(Received 29 November 1982; accepted for publication 27 January 1983)

An extension of superparamagnetic superposition analysis is used to show a crystallite size effect on the magnetic moment density of nickel dispersed on silica. A clear effect on room-temperature moment density is seen for samples with crystallites much less than 3 nm in radius.

PACS numbers: 75.60.Jp, 75.90. + w

The effect of dispersion on the physical properties of metals is a subject of much current research. Verification of a crystallite size effect on the magnetic properties of nickel is important, as magnetic methods are often used to characterize supported nickel catalysts. It is not yet clear at what size the effects are important, but Selwood concludes there is no significant effect on the Curie temperature for nickel crystallites down to 3-nm diameter.[1,2]

Superparamagnetic superposition analysis was recently extended to determine the moment density of supported magnetic catalysts. This is the spontaneous magnetization (I_s) of ferromagnetism where an external field easily aligns domains. The term is confusing when dealing with single domain materials which are ferromagnetic in the bulk; however, I_s is the moment density of these materials, which are often superparamagnetic.[1] I_s is usually taken as that of the bulk ferromagnet of the same composition at the same temperature; however, a volume dependence is expected for small enough crystallites.

For superparamagnetic samples with a distribution of particle moments, magnetic moment M at applied field H and temperature T, relative to its saturation value $M_\infty(T)$ is[1,3]

$$\frac{M(H,T)}{M_\infty(T)} = \frac{M(H,T)}{I_s(T)V} = \int_0^\infty f(v)\left[\coth\left(\frac{I_s vH}{kT}\right) - \frac{kT}{I_s vH}\right]dv, \quad (1)$$

where v is crystallite volume, f is its density function ($\int_0^\infty f\,dv = 1$), k is Boltzmann's constant, and V is magnetic vol-

[a] Present address: Chemical Eng. Dept., Arizona State University, Tempe, AZ 85287.