

XVI. COMPUTER COMPONENTS AND SYSTEMS*

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A. FUNDAMENTAL PHYSICS OF THE THIN-FILM STATE

1. MAGNETO-OPTIC EFFECTS IN FERROMAGNETIC THIN FILMS

In Quarterly Progress Report No. 62 the transmission coefficients for the longitudinal Faraday effect were derived for a thin ferromagnetic film.¹ However, the expressions given by Eqs. 6, 7, 8, and 9 of that report were only approximate answers that were based upon the first few internal reflections. In this report the exact form of the transmission coefficients as given by the first order of the magnetic perturbation will be shown. Also, the longitudinal Kerr effect reflection coefficients for a thin film will be given. The longitudinal Kerr effect reflection coefficients given by Voigt, and by the author,² have been for an infinitely thick ferromagnetic surface.

The author must report that Eqs. 8 and 9 in his previous report contained some errors that will be corrected now.

The transmission and reflection coefficients in the present discussion will be for the tangential components of the electric fields along the interfaces. This is in contrast with the earlier work in which the total electric fields in the medium were included in the ratios defining these quantities. For the reader's convenience, Fig. XVII-1 of the previous report, which illustrates the coordinate system that will be used, is repeated here as Fig. XVI-1; the subscripts x and z will refer to the transmission and the

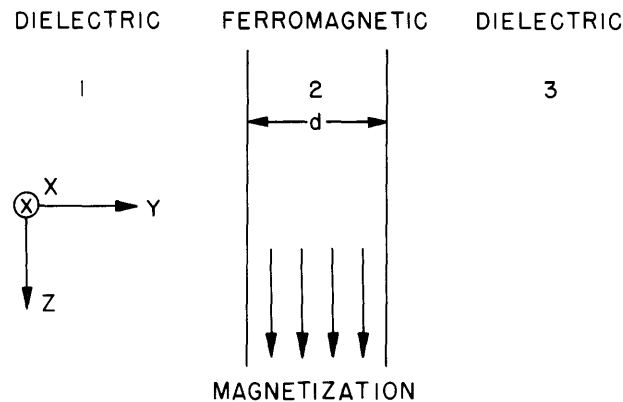


Fig. XVI-1. A ferromagnetic thin film between two dielectrics.

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reflection of the tangential electric field plane-polarized in these directions. Otherwise, the notation will be the same as that employed previously.

The form of the transmission coefficients for the longitudinal Faraday effect is given by

$$T_{z_3} = t_{zz}I_{z_1} + t_{zx}I_{x_1} \quad (1)$$

$$T_{x_3} = t_{xz}I_{z_1} + t_{xx}I_{x_1}, \quad (2)$$

where

$$t_{zx} = -\left(\frac{i \sin \phi_2 Q}{\cos^2 \phi_2}\right) \left(\frac{t_{12_z} t_{23_x} e^{j\rho/2}}{1 - r_{23_z} r_{21_z} e^{j\rho}}\right) \left\{ \frac{r_{21_x} - r_{23_z}}{2 \cos \phi_2} + j \frac{2\pi d}{\lambda_2} + \frac{e^{j\rho/2}}{1 - r_{21_x} r_{23_x} e^{j\rho}} \right. \\ \left. \left[\frac{t_{12_x} (Z_{x_1} + Z_{x_3})}{2 \cos \phi_2 (Z_{x_2} + Z_{x_3})} (r_{23_z} + r_{12_x}) + j \frac{2\pi d}{\lambda_2} r_{12_x} (r_{23_z} + r_{32_x}) \right] \right\}. \quad (3)$$

The form of the reflection coefficients for the longitudinal Kerr effect in a thin ferromagnetic film is given by

$$R_{z_1} = r_{zz}I_{z_1} + r_{zx}I_{x_1} \quad (4)$$

$$R_{x_1} = r_{xz}I_{z_1} + r_{xx}I_{x_1}, \quad (5)$$

where

$$r_{zx} = \left(\frac{i \sin \phi_2}{\cos^2 \phi_2}\right) t_{21_x} t_{12_z} \left\{ -\frac{1}{4 \cos \phi_2} + \frac{r_{23_z} e^{j\rho}}{1 - r_{23_z} r_{21_z} e^{j\rho}} \left[\frac{(r_{23_x} - r_{21_z})}{2 \cos \phi_2} + j \frac{2\pi d}{\lambda_2} \right] \right. \\ \left. + \frac{e^{j\rho}}{(1 - r_{23_x} r_{21_x} e^{j\rho})} \left[\frac{(Z_{x_1} + Z_{x_3})}{(Z_{x_1} + Z_{x_2})} \frac{t_{32_x}}{2 \cos \phi_2} + j \frac{2\pi d}{\lambda_2} r_{32_x} \right] \right. \\ \left. + \frac{r_{23_z} e^{j2\rho}}{(1 - r_{23_z} r_{21_z} e^{j\rho}) (1 - r_{23_x} r_{21_x} e^{j\rho})} \left[\frac{(Z_{x_1} + Z_{x_3})}{(Z_{x_1} + Z_{x_2})} \frac{(r_{21_z} + r_{32_x}) t_{32_x}}{2 \cos \phi_2} \right. \right. \\ \left. \left. + \frac{2\pi d}{\lambda_2} (r_{21_z} + r_{12_x}) r_{32_x} \right] \right\}. \quad (6)$$

The expressions for t_{xz} and r_{xz} are formed from those of t_{zx} and r_{zx} by interchanging z and x in the subscripts and by substituting $i \sin \phi_2 Q$ for $\frac{i \sin \phi_2 Q}{\cos^2 \phi_2}$.

The correct approximate expression for the Faraday transmission coefficient is given by the first two terms enclosed in braces in Eq. 3. This part of Eq. 3 then supersedes Eqs. 8 and 9 of the previous report. To convert from the tangential components to the complete electric-field components, the transmission coefficient t_{zx} is multiplied by $\cos \phi_1$ and t_{xz} is multiplied by $1/\cos \phi_3$ to give t_{ps} and t_{sp} , respectively.

C. C. Robinson

References

1. C. C. Robinson, Magneto-optic effects in ferromagnetic thin films, Quarterly Progress Report No. 62, Research Laboratory of Electronics, M. I. T., July 15, 1961, pp. 291-293.
2. C. C. Robinson, Measurement of the Kerr effect in nickel-iron films, High Speed Computer System Research, Quarterly Progress Report No. 11, Computer Components and Systems Group, M. I. T., 31 July 1960, p. 11.

2. THE TRANSVERSE KERR MAGNETO-OPTIC EFFECT IN THIN MAGNETIC FILMS

This project is a study of the transverse Kerr magneto-optic effect in thin ferromagnetic films covered by one or more layers of transparent dielectrics. The presence of the dielectrics will effectively increase the magnitude of the effect.

In the process of finding some substances that could be usefully and easily employed for the purposes of this work, the following dielectrics were evaporated: (a) Cadmium Sulfide ($n=2.6$); (b) Zinc Sulfide ($n=2.3$); (c) Magnesium Fluoride ($n=1.38$); and (b) Aluminum Oxide ($n=1.76$). These substances were evaporated individually on glass substrates, and individually on a thick film of iron. Also, combinations of films of dielectrics were obtained of two or three films, one over the other. All of the films obtained, or combinations of them, showed good resistance to abrasion and would easily adhere to each other.

The thickness of the dielectric films was monitored during evaporation by optical means. The monitoring was mostly successful in the case of the cadmium sulfide films, for which distinct maximum and minimum in reflectivity could be observed as the evaporation took place. Greatly unsuccessful was the monitoring of the magnesium fluoride; no appreciable change in reflectivity was observed.

Theoretical calculations of the values of the reflectivity for each evaporation were carried out by means of the Smith chart, by using the analogy between polarized light crossing a system of films and a transmission line problem. Agreement was found to

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be within 15-20 per cent.

A simplified and approximate expression for the characteristic impedance of a magnetized thin metallic film was obtained more directly in terms of the constants of the film.

The next step in this research will be that of properly combining a number of dielectric films on iron substrate so that the ensemble will have a minimum reflectivity (of narrow bandwidth) at a given wavelength of light.

R. Callarotti

3. MEASUREMENT OF THE KERR EFFECT IN THIN NICKEL-IRON FILMS

The longitudinal Kerr magneto-optic effect in thin nickel-iron films will be measured for wavelengths of light from 0.6 micron to 2 microns. An infrared photoelectric ellipsometer is being built to measure the effect. The ellipsometer consists of a xenon light source, a monochromator, a polarizer, a Faraday cell, an analyzer, a lead-sulfide detector, an amplifier, and a synchronous detector.

The xenon arc lamp light source has been converted to direct current operation by the addition of a full-wave semiconductor bridge rectifier, a choke, and a capacitor filter to the original ac power supply. This change was made because severe 60-cycle modulation of the lamp intensity occurred when the lamp was operated on alternating current.

The high-gain selective twin-Tee filter is no longer necessary because the objectionable 60-cycle component, which the filter was designed to reject, is no longer present in the output of the arc lamp. The sulfide cell will be used in series with a high-voltage battery, and will appear as a current source to the amplifier. This will permit the use of a low-input impedance amplifier that will reduce stray signal pickup at the input of the amplifier. Preliminary measurements have shown that the system's sensitivity to change in polarization angle of the light beam has been increased.

S. B. Russell

B. CRYSTAL ALGEBRA

In Quarterly Progress Report No. 62 (page 297) we reported the beginning of a study of some derivatives of the sphalerite (ZnS) structure. Models of stannite ($\text{Cu}_2\text{FeSnS}_4$) and chalcopyrite (CuFeS_2) were built with the aid of moduledra crystal building blocks. Surprisingly, it appeared that, while both structures are indeed derivatives of sphalerite, stannite is not a derivative of chalcopyrite. Both L. V. Azaroff¹ and A. F. Wells² discuss these structures. Wells states: "If now the Zn atoms (in sphalerite) are replaced by alternate Cu and Fe atoms the structure is that of chalcopyrite We may proceed a stage further by replacing one-half of the Fe atoms in CuFeS_2 by Sn, and so arrive at the structure of stannite, $\text{Cu}_2\text{FeSnS}_4$." This last statement is in error, for the positions of Cu in $\text{Cu}_2\text{FeSnS}_4$ do not correspond to the positions of Cu in CuFeS_2 .

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The $\text{Cu}_2\text{FeSnS}_4$ turns out to be the simpler of the two structures; the substitution of Cu, Fe, and Sn follows the simple pattern first found for spinel and for magnetic-dipole arrays.³ Accordingly, its distribution pattern is as shown in Table XVI-1.

Table XVI-1. Distribution pattern of stannite.

		$v_{\text{mod } 2}$	$w_{\text{mod } 2} \rightarrow$	
	$\frac{3}{2}$	0	0	0
$\uparrow h_{\text{mod } 1}$	$\frac{1}{2}$	Cu	Cu	Fe
				Sn

The distribution pattern for CuFeS_2 is more complex; it is surmised that this complexity is related to the impossibility of subdividing the hexagonal net into two equivalent subnets.⁴ The subdivision of the hexagonal net for chalcopyrite is according to the value of the function $\left[\frac{1}{3}(v-w)\right]_{\text{mod } 4}$, which can have values 0, 1, 2 or 3 (v and w are hexagonal coordinates). In terms of this function the distribution pattern for chalcopyrite is as given in Table XVI-2.

Table XVI-2. Distribution pattern of chalcopyrite.

		$\left[\frac{1}{3}(v-w)\right]_{\text{mod } 4}$			
		0	1	2	3
	$\frac{7}{2}$	0	0	0	0
$\uparrow h_{\text{mod } 4}$	$\frac{5}{2}$	Fe	Fe	Cu	Cu
	$\frac{3}{2}$	0	0	0	0
	$\frac{1}{2}$	Cu	Cu	Fe	Fe

A paper, entitled "Moduledra, a Teaching and Research aid in Solid-State Physics," has been written and will be submitted to the American Journal of Physics.

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2. A. F. Wells, Structural Inorganic Chemistry (Oxford University Press, London, 1958), p. 403.
3. A. L. Loeb, Acta Cryst. 11, 469 (July 1958).
4. A. L. Loeb, Topology of Structures: Subdivision Hexagonal Nets, High Speed Computer System Research, Quarterly Progress Report No. 12, Computer Components and Systems Group, M. I. T., 31 October 1960, pp. 22-24.