

and

$$1/\chi = e^2 m S_0 (m)(n-m)/18L^4. \quad (4)$$

The symbols have the usual significance, and of the right-hand side quantities, only  $L$ , the lattice distance, is dependent on pressure. On combining Eqs. (3) and (4) we get

$$\nu^2 = C_2 / (\rho^{1/3} \chi), \quad (5)$$

where  $C_2$  is a constant. Equation (5) is equivalent to the Madelung relation.<sup>4</sup> Equations (2) and (5), when combined, yield

$$K - K_0 = C \chi \rho^{4/3}, \quad (6)$$

where  $C$  is a constant, independent of pressure. Differentiating and rearranging,

$$\frac{1}{K} \left( \frac{\partial K}{\partial p} \right)_t = \frac{K - K_0}{K} \left[ \frac{1}{\chi} \left( \frac{\partial \chi}{\partial p} \right)_t + \frac{4}{3} \chi \right] + 2K_0 \chi \frac{\partial n}{\partial \ln \rho}, \quad (7)$$

since  $\partial K_0 / \partial p = (\partial n^2 / \partial \ln \rho) (\partial \ln \rho / \partial p) = 2K_0 \chi (\partial n / \partial \ln \rho)$ , where  $n$  is the refractive index.

Values of  $-(\partial \ln K / \partial p)_t$  are calculated for different substances from the data quoted by Mayburg<sup>1</sup> and are given in Table I.

TABLE I. Data used in calculations. (All pressure changes are in bars. For MgO,  $\partial K_0 / \partial p = \chi(K_0 - 1)$  is obtained from  $(K_0 - 1) / \rho = \text{constant}$ .  $(-\Delta V / V \rho) = a\rho - b\rho^2$ .)

| Crystal | $K$  | $K_0$ | $a \times 10^7$ | $b \times 10^{12}$ | $\frac{\partial n}{\partial \ln \rho}$ | $-\frac{\partial \ln K}{\partial p}$ | $-\frac{\partial \ln K}{\partial p}$ | $\frac{\partial \gamma}{\partial \ln \rho}$ |
|---------|------|-------|-----------------|--------------------|--|--------------------------------------|--------------------------------------|---|
|         |      |       |                 |                    |  | $\times 10^6$                        | observed <sup>1</sup>                |   |
| LiF     | 9.27 | 1.92  | 1.52            | 5.5                | 0.10                                   | 0.41                                 | 0.448 ± 0.028                        | +2.8  |
| NaCl    | 5.62 | 2.25  | 43.1            | 49.6               | 0.24                                   | 0.98                                 | 0.98 ± 0.06                          | +2.6  |
| KCl     | 4.68 | 2.13  | 56.8            | 72.4               | 0.23                                   | 0.90                                 | 1.05 ± 0.08                          | -0.33                                       |
| KBr     | 4.78 | 2.33  | 67.0            | 105.3              | 0.35                                   | 1.00                                 | 1.17 ± 0.09                          | -0.16                                       |
| MgO     | 9.8  | 2.95  | 5.95            | 1.0                | —                                      | 0.17                                 | 0.320 ± 0.019                        | —   |

Values of  $\partial \gamma / \partial \ln \rho$  calculated by the author from Eq. (1) and data used by Mayburg are given in column 9 of the table.

The quantity  $\gamma$ , which is introduced in Mott and Littleton's theory to account for the effects of the overlap of ions, should decrease with increasing pressure and consequent increasing overlap. In contradiction to this expectation,  $\gamma$  must be taken to increase to a large extent in the cases of LiF and NaCl in order to justify the observed change of dielectric constant with pressure. Even in the cases of KCl and KBr, the sign of the variation  $\partial \gamma / \partial \ln \rho$ , which is small, will not be definite when the probable errors of the various experimental values are taken into consideration, as suggested by Mayburg. Thus, Mott and Littleton's theory leads to an anomalous position.

The explanation of the variation of dielectric constant on the basis of Eq. (6), which is a combination of the well-known Born and Madelung relations, is open to some criticism, as these relations are based upon ideal assumptions and hold good only approximately. Yet, it is interesting to note that the values of  $\partial \ln K / \partial p$  calculated on the basis of that equation and the values observed by Mayburg are in good agreement in all cases except for MgO, which also shows abnormal behavior in other respects.

<sup>1</sup> S. Mayburg, Phys. Rev. **79**, 375 (1950).

<sup>2</sup> Born and Mayer, Handbuch der Phys. **24/2**, 647 (1933).

<sup>3</sup> Born and Brody, Z. Physik **11**, 327 (1922).

<sup>4</sup> Born and Mayer, Handbuch der Phys. **24/2**, 656 (1933).

### Observation of Magnetic Domains by the Kerr Effect

H. J. WILLIAMS, F. G. FOSTER, AND E. A. WOOD  
Bell Telephone Laboratories, Murray Hill, New Jersey  
(Received January 18, 1951)

**M**AGNETIC domains have been observed by means of the Kerr magneto-optic effect on surfaces perpendicular and inclined to the  $c$  axis of hexagonal cobalt. The direction of easy magnetization in cobalt is along the  $c$  axis, so the domains are

magnetized in either a positive or negative sense along this axis. When a surface cuts the  $c$  axis, each domain that extends to the surface forms either a north or south magnetic pole. Plane polarized light incident normal to the (0001) surface undergoes a rotation of approximately a quarter of a degree upon reflection, the rotation being positive or negative depending on the polarity of the reflecting region. With the use of a polarized light compensator<sup>1</sup> it is possible to make a set of domains of either polarity appear dark while the other set is light, thus permitting the observation of the domains.

The optical equipment used was a Bausch and Lomb Research Metallographic Microscope, inverted type, equipped with a polarized light compensator. The incident light is polarized by a Foster<sup>2</sup> type polarizing vertical illuminator prism which acts as polarizer for the incident beam and as permanently crossed analyzer for the reflected beam. After emerging from the prism, the polarized beam passes through a rotation compensator and an ellipticity compensator, both before and after reflection from the cobalt specimen, so that half of the compensation is accomplished on each traversal.

The compensator can be set so as to produce a rotation of the plane of polarization equal and opposite to that produced by reflection from the domains of a given polarity. The sense of the rotation of the light due to reflection depends on the polarity

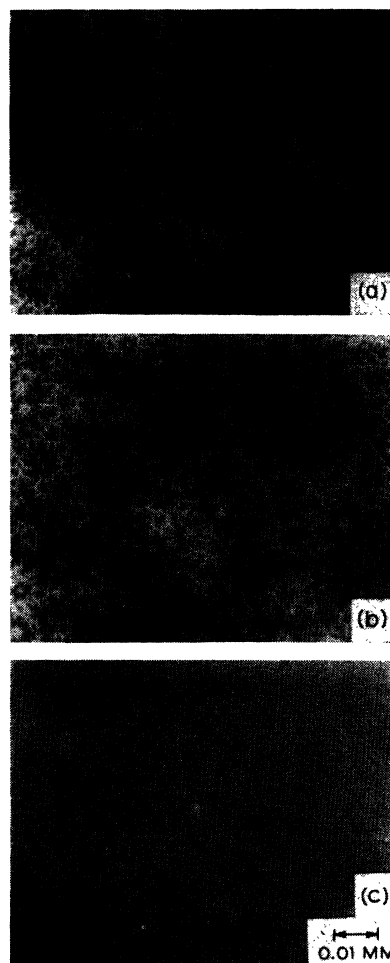


FIG. 1. Polarized light patterns showing dependence of rotation upon polarity of domains in cobalt single crystal. (Surface approximately normal to  $c$  axis.) (a) Rotation of  $+1/4^\circ$  optically compensated. (b) Rotation of  $-1/4^\circ$  optically compensated. (c) No rotational compensation.

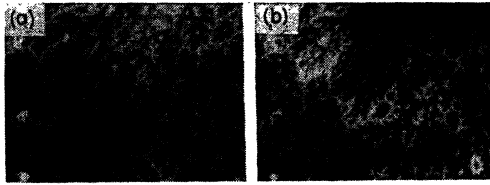


FIG. 2. Polarized light patterns showing change of domains in cobalt single crystal in response to a magnetic field. (a) Lower field. (b) Higher field.

of the magnetization at the reflecting surface. Thus, the rotation introduced by all the domains of like polarity can be compensated by a clockwise rotation of the compensator, for example, while those of the reverse polarity require a counter-clockwise rotation. Compare (a) and (b) in Fig. 1 of an electro-polished surface of a single cobalt crystal, approximately normal to the  $c$  axis. If the compensator is set to introduce no rotation, no distinction between the two sets of domains is observed [Fig. 1(c)], since the light intensity from each is dependent only on the amount of rotation of the plane of polarization and not on the sense of the rotation.

No magnetic field was applied when the pictures in Fig. 1(a),

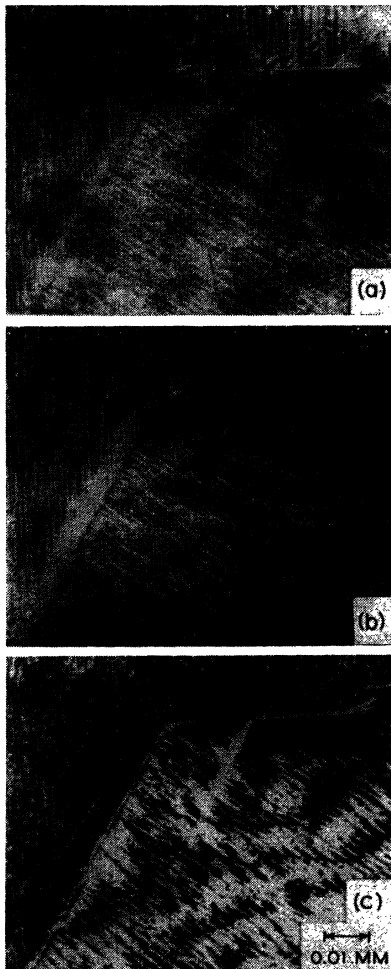


FIG. 3. Domains in polycrystalline cobalt. (a) and (b) Polarized light patterns showing change of domains in response to a magnetic field. (a) Lower field. (b) Higher field. (c) Pattern obtained with colloidal magnetite on the same region (dark field illumination).

(b), and (c) were taken. However, when a magnetic field is applied, the patterns change with the field, as in Fig. 2(a) and (b), which were obtained for different values of a field applied normal to the surface. In Fig. 3, (a) and (b) show the effect of varying the applied field on a polycrystalline cobalt specimen which exhibits a different type of pattern. Figure 3(c) is a powder pattern<sup>3</sup> obtained with colloidal magnetite on the same surface at a later time. Slight changes in the domain structure may have occurred prior to this photograph.

A pattern like that shown in Fig. 1(a), though hardly visible, has also been observed by the authors with a Zeiss neophot type of metallographic microscope equipped with separate polarizer and analyzer. Photographs of the pattern were obtained with this equipment in collaboration with E. E. Thomas.

It should be mentioned that although it is comparatively easy to obtain photographs of polarized light patterns which have good contrast and show the details clearly, visual observation is difficult because of the very low intensity of the light and lack of contrast.

We are indebted to W. Shockley and C. Kittel for suggestions and discussions, and to J. Benford and Colin Alexander of the Bausch and Lomb Optical Company for making available to us their optical compensator so that we might explore its potentialities for work of this type.

<sup>1</sup> Turner, Benford, and McLean, *Econ. Geol.* **XL**, No. 1 (1945).  
<sup>2</sup> L. V. Foster, *J. Opt. Soc. Am.* **28**, 124 (1938).  
<sup>3</sup> Williams, Bozorth, and Shockley, *Phys. Rev.* **75**, 155 (1949).

### $p-n$ Junction Rectifier and Photo-Cell

W. J. PIETENPOL

*Bell Telephone Laboratories, Murray Hill, New Jersey*  
 (Received December 21, 1950)

THIS note<sup>1</sup> discusses briefly the electrical characteristics of two semiconductor devices made from  $p-n$  junctions in single-crystal germanium by a process described by Teal, Sparks, and Buehler.<sup>2</sup> The two devices are quite similar in construction but differ widely in application.

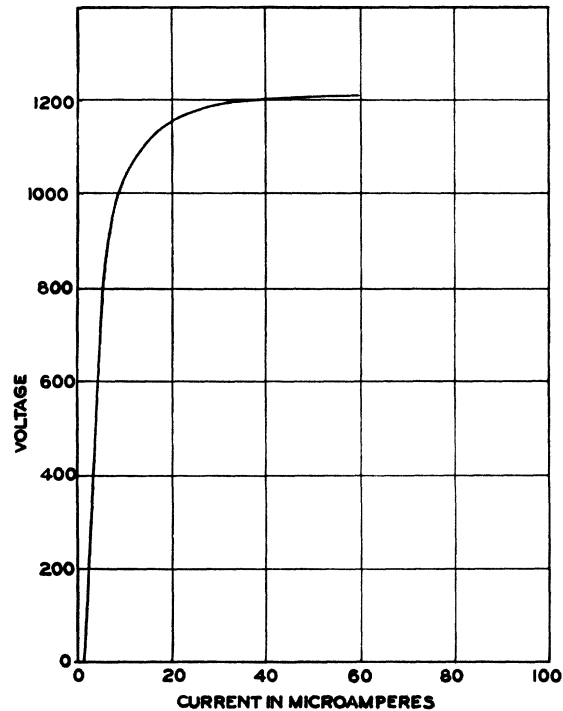


FIG. 1.  $p-n$  junction rectifier reverse characteristic.

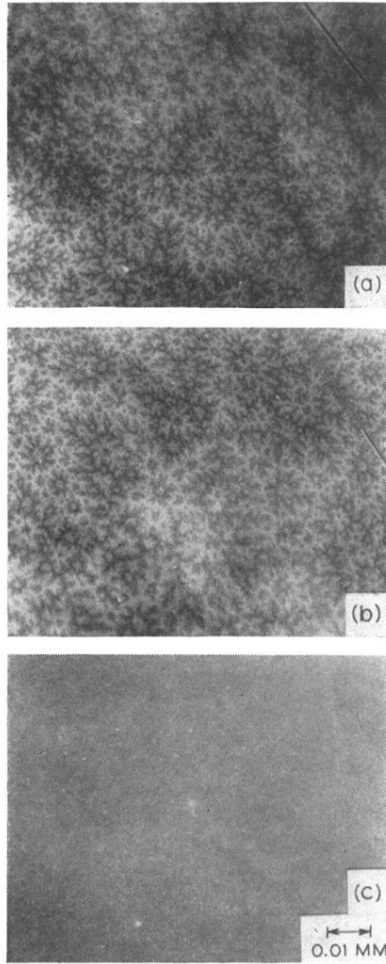


FIG. 1. Polarized light patterns showing dependence of rotation upon polarity of domains in cobalt single crystal. (Surface approximately normal to  $c$  axis.) (a) Rotation of  $+4^\circ$  optically compensated. (b) Rotation of  $-4^\circ$  optically compensated. (c) No rotational compensation.

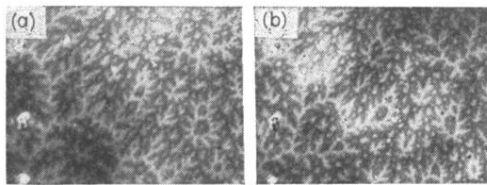


FIG. 2. Polarized light patterns showing change of domains in cobalt single crystal in response to a magnetic field. (a) Lower field. (b) Higher field.

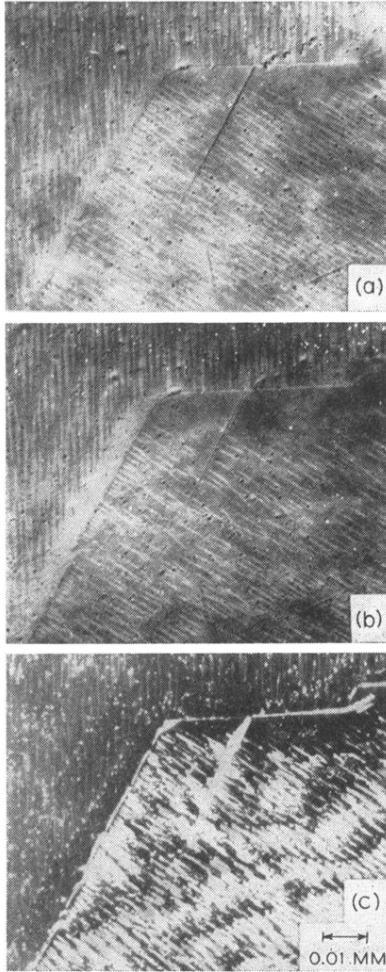


FIG. 3. Domains in polycrystalline cobalt. (a) and (b) Polarized light patterns showing change of domains in response to a magnetic field. (a) Lower field. (b) Higher field. (c) Pattern obtained with colloidal magnetite on the same region (dark field illumination).