ity would be to use Co^{2+} substitutions in octahedral sites (usually with Si^{4+} in tetrahedral sites for charge compensation) to alter the cubic anisotropy constant (12) and provide either $K_1 = 0$ for {111} plane applications or $K_1 > 0$ for the {001} planes.

For spinels, the λ_{100} constant is normally large and negative ($\sim -20 \times 10^{-6}$), while λ_{111} is small and positive ($\sim +0.5 \times 10^{-6}$). Trivalent manganese may be used to change the signs of both constants (13,14) and was effective in producing uniaxial anisotropy by compressive stress for a $Mn_{.7}Fe_{2.3}O_4$ epitaxial film deposited on an MgO substrate with a (110) orientation (4). Divalent cobalt is known to be extremely effective in altering K_1 in spinels (13) and could be a useful additive in designing compositions with zero or positive K_1 values for possible compressive stress applications.

Acknowledgements

The author is grateful to D. H. Temme for his interest and to Dr. J. B. Goodenough for pointing out the importance of shape anisotropy in this theory.

References

1. E. Stern and D. Temme, IEEE Trans. Microwave Theory and Techniques MTT-13, 873 (1965).
2. T. C. Tisone, W. B. Grupen, and G. Y. Chin, IEEE Trans. Mag. MAG-6, 712 (1970).
3. G. F. Dionne, IEEE Trans. Mag. MAG-5, 596 (1969).
4. J. E. Mee, G. R. Pulliam, J. L. Archer, and P. J. Besser, IEEE Trans. Mag. MAG-5, 717 (1969).
5. D. M. Heinz, P. J. Besser, J. M. Owens, J. E. Mee, and G. R. Pulliam, J. Appl. Phys. 42, 1243 (1971).
6. R. Becker and W. Doring, Ferromagnetismus, p. 146, Julius Springer, Berlin (1939).
7. J. F. Nye, Physical Properties of Crystals, p. 90, Oxford University Press, London (1960).
8. W. F. Brown, Jr., Micromagnetics, p. 87, Interscience Publishers, (1963).
9. E. M. Gyorgy, J. T. Krause, R. C. LeCraw, L. R. Testardi, and L. G. Van Uitert, J. Appl. Phys. 38, 1226 (1967).
10. G. F. Dionne and P. J. Paul, Mat. Res. Bull. 4, 171 (1969).
11. S. Iida, J. Phys. Soc. Japan 22, 1201 (1967).
12. J. Nicolas, A. Lagrange, and R. Sproussi, IEEE Trans. Mag. MAG-6, 608 (1970).
13. G. F. Dionne, J. Appl. Phys. 40, 4486 (1969).
14. G. F. Dionne, J. Appl. Phys. 41, 831 (1970).

Appendix

For three mutually orthogonal sets of direction cosines, γ_i, γ_i', and β_i,

$$\Sigma_i \gamma_i \gamma_i' = \Sigma_i \gamma_i \gamma_i = \Sigma_i \gamma_i' \beta_i = 0 \ . \tag{A1}$$

From basic analytical geometry theory, these cosines are related by

$$\begin{aligned} \gamma_1 &= \beta_2\gamma_3' - \beta_3\gamma_2' & \gamma_1' &= \beta_2\gamma_3 - \beta_3\gamma_2 \\ \gamma_2 &= \beta_3\gamma_1' - \beta_1\gamma_3' & \gamma_2' &= \beta_3\gamma_1 - \beta_1\gamma_3 \\ \gamma_3 &= \beta_1\gamma_2' - \beta_2\gamma_1' & \gamma_3' &= \beta_1\gamma_2 - \beta_2\gamma_1 \ . \end{aligned} \tag{A2}$$

By appropriate substitution from among the relations of Eq. (A2), it may be readily shown that

$$\gamma_1^2 = \beta_2^2(\beta_1\gamma_2 - \beta_2\gamma_1)^2 - \beta_3^2(\beta_3\gamma_1 - \beta_1\gamma_3)^2 \tag{A3}$$

and

$$\gamma_1'^2 = (\beta_2\gamma_3 - \beta_3\gamma_2)^2 \ . \tag{A4}$$

By adding Eqs. (A3) and (A4) and simplifying by means of Eq. (A1) in addition to the normality conditions of the cosines, it may be easily shown that the generalized result is given by

$$\gamma_1^2 + \gamma_i'^2 = 1 - \beta_i^2 \ . \tag{A5}$$

By similar applications of the relations in Eq. (A2),

$$\gamma_1\gamma_2 = \gamma_2^2\beta_1\beta_2 + \gamma_2\gamma_3\beta_1\beta_3 - \gamma_1\gamma_2(\beta_2^2 + \beta_3^2) \tag{A6}$$

and

$$\gamma_1'\gamma_2' = \gamma_1\gamma_3\beta_2\beta_3 - \gamma_3^2\beta_1\beta_2 - \gamma_1\gamma_2\beta_3^2 + \gamma_2\gamma_3\beta_1\beta_3 . \tag{A7}$$

After reductions and simplifications of the type employed in the derivation of Eq. (A5), the sum of Eqs. (A6) and (A7) becomes, after generalization,

$$\gamma_i\gamma_j + \gamma_i'\gamma_j' = -\beta_i\beta_j \ . \tag{A8}$$