structure) in deformed chalcopyrite compounds. While no abundant mechanical twins as predicted have been observed in shock-deformed natural chalcopyrite, large numbers of dislocations have been observed as noted in Fig. 4c. It is not unlikely, therefore, that certain grinding techniques could also induce large numbers of dislocations which would have an effect on the kinetics of chalcopyrite concentrate leaching. This feature is in fact being tested and the results will be reported elsewhere.

Natural chalcopyrite shock-loaded to a pressure of 19 GPa (190 kbars) was observed to form roughly 10^3 times more dislocations than present in the unshocked material. There was, contrary to previous predictions [1], no evidence of shock-induced faulting or mechanical twins leading to the conclusion that faults observed in the unshocked chalcopyrite arise by growth phenomena. There was no evidence of a shock-induced phase transformation.

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References

1. L. E. MURR and SUZANNE L. LERNER, *J. Mater. Sci.* 12 (1977) 1349.
2. L. E. MURR and F. I. GRACE, *Exptl. Mech.* 9 (1969) 145.
3. L. E. MURR and K. P. STAUDHAMMER, *Mater. Sci. Eng.* 20 (1975) 35.
4. "Electron Microscopy in Mineralogy", edited by H.-R. Wenk, P. E. Champness, J. M. Christy, J. M. Cowley, A. H. Heuer, G. Thomas and N. J. Tighe (Springer Verlag, New York, 1976).
5. "Metallurgical Effects at High Strain Rates", edited by R. W. Rohde, B. M. Butcher, J. R. Holland and C. H. Karnes (Plenum Press, New York, 1973).
6. R. G. McQUEEN, E. G. ZUKAS and S. P. MARSH, "High-Velocity Impact Phenomena", edited by R. Kinslow (Academic press, New York, 1970) pp. 293, 515.
7. G. E. DIETER, "Response of Metals to High Velocity Deformation", edited by P. G. Shewmon and V. F. Zackay (Interscience, New York, 1961) p. 409.
8. G. E. DUVALL and G. R. FOWLES, "High Pressure Physics and Chemistry", Vol. 2, edited by R. S. Bradley (McGraw–Hill, New York, 1963) p. 209.
9. R. K. HAM, *Phil. Mag.* 6 (1961) 1183.
10. L. E. MURR, "Electron Optical Applications in Materials Science" (McGraw–Hill, New York, 1970).

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The growth of $Dy_3Al_5O_{12}$

Cockayne *et al.* [1] have grown DyAG ($Dy_3Al_5O_{12}$) single crystals by the Czochralski method. They reported that DyAG was the only rare earth aluminium garnet which grew with a flat interface even at rotation rates as low as 5 r.p.m. These workers also showed that a substantial portion of the radiation emitted by a DyAG melt was absorbed by the crystal and that, in consequence, low radial gradients were produced near the growing interface. Under such conditions, controlled growth of large diameter crystals is difficult.

In the present work, single crystals of DyAG have also been grown from stoichiometric melts by the Czochralski technique. The apparatus used for this experiment was made by Kokusai Electric Co. for oxide crystals. It has been modified for automatic diameter control (ADC). The ADC method adapted was a popular crystal weighing system and either analogue or digital control could be selected. The load cell which was used to weigh the crystal was made by Ohkura Electric Co. and had a high sensitivity (0.01 g). A simplified block diagram of this system is shown in Fig. 1.

In order to maintain a temperature gradient sufficiently steep for growth to be induced the

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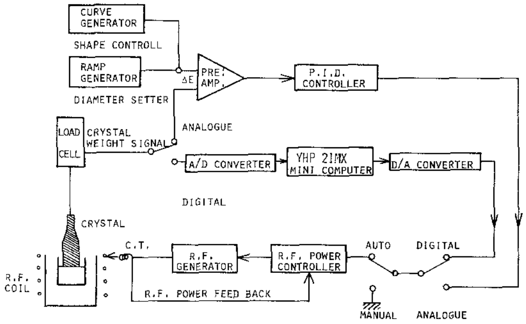

Figure 1 A simplified block diagram of the ADC system.

diameter of the crystal was set to a small value of 15 mm compared to the crucible diameter of 47 mm and a very low crystal rotation rate of 1 r.p.m. was used. The crystal was grown on a ⟨1 1 1⟩ axis at a pulling rate of 4 mm h^{-1}. It was grown automatically from seeding. A photograph of an as-grown crystal is shown in Fig. 2. A photograph of striations taken under polarized light is shown in Fig. 3. It is interesting to note that even with a rotation rate as low as 1 r.p.m., the solid–liquid interface was almost flat, and, as observed previously [1], the ⟨2 1 1⟩ facets usually found in many garnet crystals are not present under this condition. It was extremely difficult to keep an adequate temperature gradient for growth as the melt level was lowered due to the interface becoming concave towards the melt.

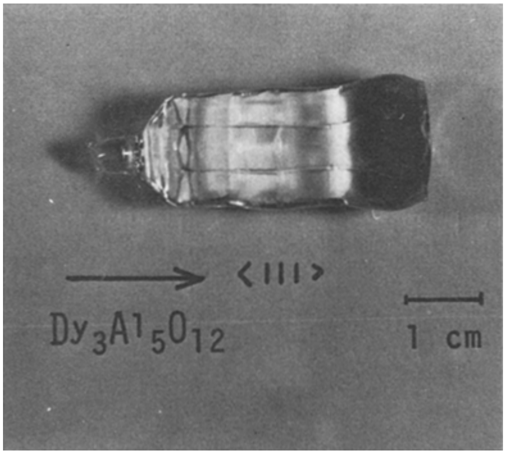

Figure 2 A photograph of a DyAG crystal grown at 4 mm h^{-1} pulling rate and 1 r.p.m. rotation rate.

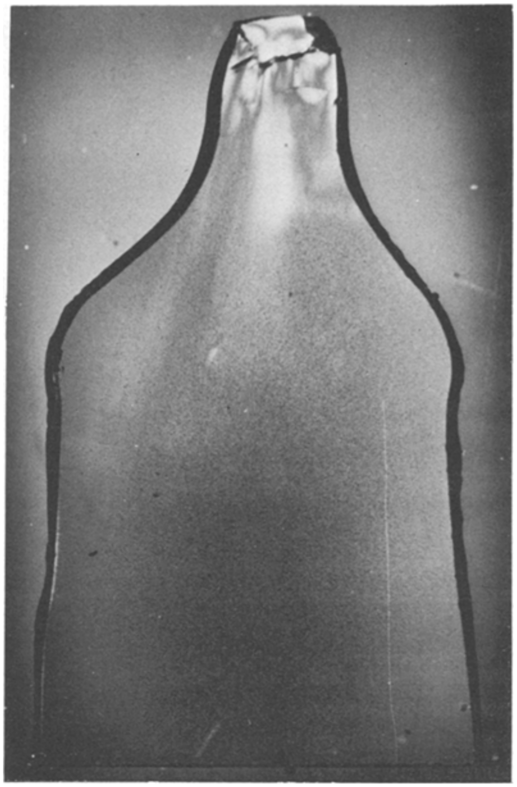

Figure 3 A longitudinal section of DyAG crystal showing striations.

In conclusion, we have demonstrated that ADC is useful for the growth of DyAG, but due to the very low effective thermal conductivity of this material [1], it is necessary to maintain a moderate temperature gradient in the melt if large crystals are to be grown.

Reference

1. B. COCKAYNE, M. CHESSWAS and D. B. GASSON, *J. Mater. Sci.* 4 (1969) 450.

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