dispersed particles has been described by Ashby [5]. These cracks have a decisive influence on the elongation. If we suppose that necking of a specimen starts at a given void volume and that void formation is favoured by higher temperatures, then uniform elongation must decrease with rising temperature. This corresponds to the experimental findings.

Further deformation will be controlled by creation of new cracks, by growth of existing ones, and, mainly, by necking-down of aluminium zones: these zones are now separated from the oxide particles by the cracks spreading from the oxide particles and are hence free to deform, which leads to local ductile fracture. Elongation before and after necking are therefore controlled by different mechanisms. The final brittle fracture is composed of a multitude of microscopic ductile fracture zones.

This mechanism, proposed for tensile deformation, apparently cannot be transferred completely to the creep test. In this case, cracks should grow slowly (as shown for other materials [6]) and should give rise to microscopic necking and elongation similar to that in tensile testing. Fig. 2 showed, however, that, after creep tests of more than 1 h, void volume is lower than after tensile testing. Probably there is some phenomenon which stops crack-growth in long-time tests. This could, in part, be explained by the following hypothesis.

Owing to the complex fabrication schedule, it is most probable that, in SAP, there are inclusions of air trapped by the oxide particles, as has been found for many powder metallurgy materials [7]. Activation analysis has shown [8] that, in the 7% alloy, there is 10 ppm argon which, if it came mainly from included air, would indicate a high initial air content of 0.1 wt %. When a crack starts at a particle where an air bubble is trapped, the gas may enter into the cavity, and internal surfaces of oxides and nitrides will be formed which should hinder the further growth of the crack. In this way, most of the cracks should remain small and could, therefore, not liberate the extensive aluminium zones which could give rise to appreciable elongation.

Such a mechanism of gas-transport and oxidation must be a time-dependent process. This hypothesis can explain the findings of fig. 2b, that fast testing leads to high void volumes and slow testing to low void volumes.

Acknowledgement

We would like to thank Dr H. W. Schleicher for helpful discussions.

References

1. A. GIARDA and M. PAGANELLI, *Mem. Sci. Rev. Met.* **62** (1965) 921.
2. H. KELLERER, G. SAUR, and H. BORCHERS, Euratom Report EUR 3497 (1967).
3. P. GUYOT and E. RUEDL, *J. Matls. Sci.* **2** (1967) 221.
4. A. KOCHENDÖRFER, *Z. angew. Phys.* **14** (1962) 129.
5. M. F. ASHBY, *Phil. Mag.* **14** (1966) 1157.
6. R. C. BOETTNER and W. D. ROBERTSON, *Trans. AIME* **221** (1961) 613.
7. I. JENKINS, *Powder Met.* **7** (1964) 68.
8. F. GIRARDI (Euratom, Ispra), private communication.

8 September 1967

H. KELLERER
G. PIATTI
Metallurgy and Ceramics Division, Euratom
Ispra (Varese), Italy

The Growth of Strain-Free $Y_3Al_5O_{12}$ Single Crystals

Vertically pulled single crystals of yttrium aluminium garnet ($Y_3Al_5O_{12}$) characteristically exhibit a central core of elastically strained material which is associated with the formation of {211} type facets, (fig. 1), on the solid/liquid interface during growth. Because this defect impairs the crystalline and optical perfection of the material, high quality laser rods can only be cut from the outer regions of such crystals [1, 2].

In this laboratory, recent studies of mixed rare-earth aluminium garnets [3] have shown that if such crystals can be grown with a flat solid/liquid interface, faceting does not occur, and the optical quality is greatly improved. The results of these studies have been successfully applied to the growth of $Y_3Al_5O_{12}$ single crystals, and it is now possible to grow crystals of this material entirely free from the strained central core. The technique employed is simply to reduce the temperature gradients across the interface by rotating the crystal at high speed. Hitherto, crystals have been grown at rotation speeds in the range 10 to 50 rev/min when the solid/liquid interface is approximately conical

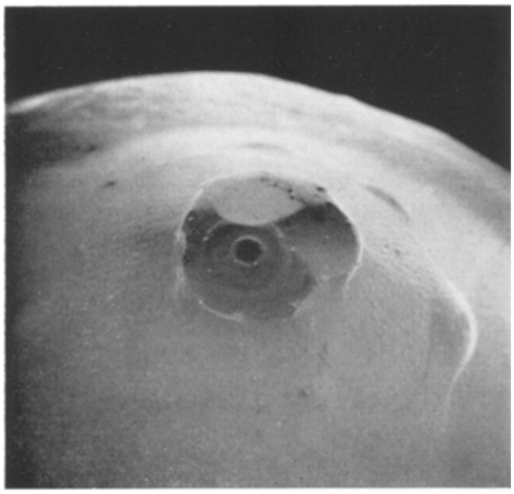

Figure 1 Scanning electron micrograph of the three {211} type facets observed on <111> axis $Y_3Al_5O_{12}$ single crystals (×16).

in shape and facets readily form. If, however, the rotation speed is increased to 150 rev/min the interface is flattened considerably, no facets form, and the strained central core is absent. Fig. 2 shows a Twyman-Green interference pattern of a faceted crystal, polished with the ends plane parallel, whilst fig. 3 shows the fringe pattern observed through a facet-free crystal. The improvement in optical perfection may be clearly seen. Both these crystals were doped with 0.6 at. % Nd but corresponding effects have also been observed in pure $Y_3Al_5O_{12}$ crystals. The apparatus and general conditions used for the growth of these crystals have been fully described in previous papers [2, 4].

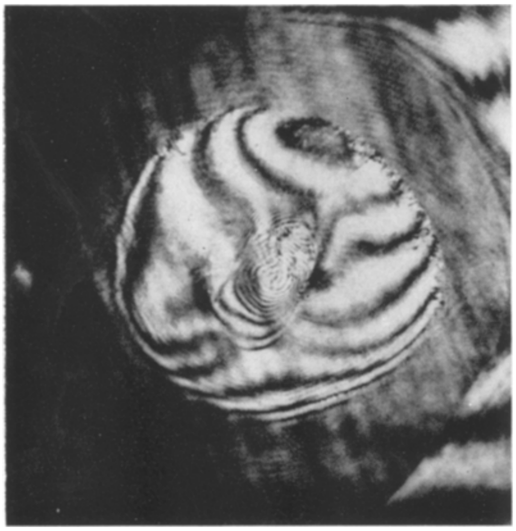

Figure 2 Twyman-Green interference pattern taken through a faceted crystal, 10 mm in diameter.

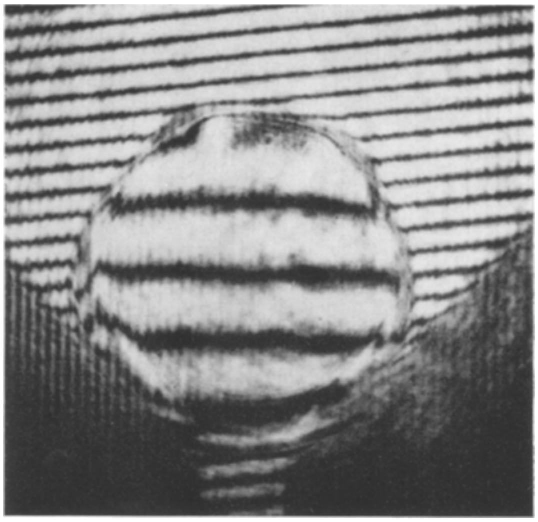

Figure 3 Twyman-Green interference pattern taken through an unfaceted crystal, 8 mm in diameter.

Acknowledgements

The authors wish to thank Dr J. D. Filby and Mr G. W. Fynn for their respective assistance with the scanning electron microscope and crystal polishing.

This letter is published by permission of the Director, Royal Radar Establishment, and the Copyright Controller, HMSO.

References

1. W. BARDSLEY and B. COCKAYNE, "Crystal Growth", Proceedings of International Conference on Crystal Growth, Boston, 1966 (Pergamon Press, 1967) p. 109.
2. J. BASTERFIELD, M. J. PRESCOTT, and B. COCKAYNE, *J. Matls. Sci.* 3 (1968) 33.
3. B. COCKAYNE, M. CHESSWAS, and D. B. GASSON, to be published.
4. *Idem, J. Matls. Sci.* 2 (1967) 7.

27 September 1967

B. COCKAYNE
M. CHESSWAS
D. B. GASSON

Royal Radar Establishment,
Malvern, Worcs