tion and for his continued interest throughout the course of the work.

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The Crystallography of the Titanium Transformation

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The orientation relationships between hexagonal close packed and body-centered cubic titanium have been found to be $(0001)_{\text{h.c.p.}}$ parallel to $(110)_{\text{b.-c.c.}}$ and $[11\bar{2}0]_{\text{h.c.p.}}$ parallel to $[111]_{\text{b.-c.c.}}$. These were determined by noting the relationships between several large α grains which had been formed from a single β grain. These relationships agree with those reported for zirconium and lithium.

The habit plane of titanium has been shown to be $(331)_{\text{b.-c.c.}}$ within an experimental error of 2°. This was determined from the relief effects present in large α grains and the orientation relationships developed above.

Introduction

Titanium, like zirconium and lithium, undergoes a transformation from a body-centered cubic structure to a hexagonal close-packed structure. In each case, the cubic form is the higher-temperature structure. Burgers (1934) found that the orientation relationships for the zirconium transformation were $(0001)_\alpha$ parallel to $(110)_\beta$ and $[11\bar{2}0]_\alpha$ parallel to $[111]_\beta$. Barrett (1951) has reported the same orientation relationships for the transformation in lithium. Barrett's measurements indicated an angle of 3° between the close-packed directions, while Burgers's measurements indicated an angle of 0–2° for zirconium.

As a result of his study of the orientation relationship, Burgers (1934) proposed that the transformation, body-centered cubic to hexagonal close-packed, occurred by heterogeneous shear on (112) $[11\bar{1}]$. Inasmuch as the habit plane is a plane of zero distortion, it was thought that the habit plane of zirconium would be $(112)_{\text{b.-c.c.}}$. Bowles (1951) has reported that the habit plane of lithium is $\{441\}_{\text{b.-c.c.}}$. As a result of the investigation of Bowles (1951), Burgers & Ginneken (1952) have conducted a limited investigation which indicated the habit plane of zirconium to be possibly $\{569\}$ or $\{145\}$. These more recent results are similar to the habit planes reported for other shear transformations in body-centered cubic metals. In most instances, the habit plane is one of high indices or is irrational.

Experimental procedure

Materials

Iodide titanium which had been arc melted on a water-cooled copper block in an argon atmosphere was used throughout this investigation. In an attempt to grow very large grains of α titanium, it was noted that it was frequently possible to observe two, three, or four large α grains forming from a single β grain. For the present study, specimens were heated in evacuated quartz tubes at 850° C. for 24 hr., then held at 1100° C. for 4 hr. and furnace cooled.

Orientation relationship

Back-reflection Laue patterns were made with a precision camera in order that the orientations of the α grains could be determined. The α grains studied were 2–3 mm. in size. Specimens were chosen in which three or four α grains had formed from each β grain. In all, α grains transformed from eight β grains were studied. The orientations for all hexagonal grains resulting from the same cubic grain were plotted on a single stereographic projection and the angles between various planes and directions were measured.

In Fig. 1, the results for four α grains which formed from the same β grain are plotted. The poles of the four basal planes are shown in Fig. 1(*a*) at their positions with respect to the surface of the specimen. The plane of projection lies parallel to the specimen surface. In Fig. 1(*b*) the basal poles have been placed on a standard (011) cubic projection and have been rotated to show the coincidence of the basal and (110) poles. From this figure, it can also be shown that of the three $[11\bar{2}0]$ poles corresponding to a definite (0001) pole, one coincides with a [111] direction of the cubic lattice, and the other two lie in the corresponding {110} plane at 10° from the second [111] direction in this plane and 5° from the [100] direction.

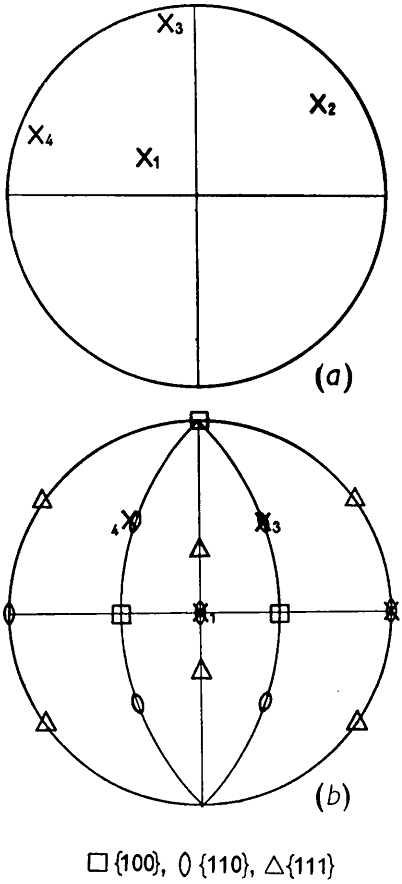

Fig. 1. (a) Orientation of basal poles (×) with respect to specimen surface. (b) Fig. 1(a) rotated to show coincidence of $(0001)_{\text{h.c.p.}}$ poles with $(110)_{\text{b.-c.c.}}$ poles.

The habit plane

The relief effects of the shear-type transformation are caused by a tilting of the surface about its intersection with the habit plane. The relief effects visible on the surface were intensified by an etchant composed of 1% hydrofluoric acid, 12% nitric acid and 87% water. The orientation of the α grains were determined as above and the orientation relationships were used to give the orientation of the former β grain with respect to the external shape of the specimens. The angular relationships between the observed traces and reference marks were measured. In a single stereographic triangle, the zone normal to each observed trace was plotted. The common point of intersection gave the habit plane. This is the procedure used by Bowles for lithium, and provides an unambiguous solution using the traces from only one surface. Fifteen trace normals in five different grains were plotted and intersected within the experimental error of 2° of the position of $(331)_{\text{b.-c.c.}}$.

Discussion of results

The basal plane poles of hexagonal grains descended from the same β grain were in the proper orientation to lie on (110) planes of the cubic lattice. This is illustrated for one set in Fig. 1(b). Orienting the (0001) planes parallel to (110) planes, it was found that one $[11\bar{2}0]$ direction of each α grain lay within 2° of a [111] direction of the cubic lattice. This orientation relationship is the same as that reported for zirconium and lithium, namely,

$$(0001)_\alpha \| (110)_\beta,\ [11\bar{2}0]_\alpha \| [111]_\beta\,.$$

The habit plane was found to be $(331)_{\text{b.-c.c.}}$, which is the same as reported for a copper–tin alloy (Greninger & Mooradian, 1935) and a gold–cadmium alloy (Chang & Read, 1951). As is shown in Table 1, these results are similar to those obtained for other body-centered cubic transformations.

Table 1. *Habit planes for* b.-c.c. *shear transformations*

System	Transformation	Habit plane
Cu–Zn	b.-c.c.–f.-c.t. (Greninger & Mooradian, 1935)	(551)
Cu–Sn	b.-c.c.–unknown (Greninger & Mooradian, 1935)	(331)
Cu–Al	b.-c.c.–distorted h.c.p. (Greninger, 1939)	(331)
Cu–Al	b.-c.c.–ordered h.c.p. (Greninger, 1939)	(221)
Au–Cd	b.-c.c.–orthorhombic (Chang & Read, 1951)	(331)
Li	b.-c.c.–h.c.p. (Bowles, 1951)	(441)
Zr	b.-c.c.–h.c.p. (Burgers & Ginneken, 1952)	(569) or (451)?
Ti	b.-c.c.–h.c.p.	(331)

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