

## Partial phase diagrams of the titanium-rich region of the Ti–Cu system under high pressure

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The Ti–Cu system is the base for commercial titanium alloys for parts of jet engines and gas turbine engines, and the phase diagram at atmospheric pressure (0 GPa) was reported by Murray [1]. However, the phase diagram at high pressure has not yet been reported. This letter describes the determination of the phase diagrams in the titanium-rich part of the Ti–Cu system at 0, 1.9 and 2.8 GPa, through microscopic examination and electron-probe microanalysis (EPMA) of heat-treated and quenched two-phase alloys and diffusion couples.

Alloys of Ti–1.83, 1.96, 4.92, 7.83, 14.85 and 25.11 at% Cu were prepared by melting together appropriate quantities of Ti (99.899 wt% purity) and Cu (99.99 wt%) in Cu crucibles in an Ar-arc melting furnace. These alloy ingots were homogenized for 259 ks at 1223 K in fused-SiO<sub>2</sub> tubes filled with Ar gas. Using a lathe and cutter, 5 mm square blocks 2.5 mm in height and 4 mm diameter cylinders 2.5 mm in thickness were produced from the ingots.

Some blocks of Ti and Ti–Cu alloys were metallographically polished and coupled with a stainless steel clamp to serve as diffusion couples for the atmospheric experiments. These couples and the other blocks of various alloys were sealed in fused-SiO<sub>2</sub> tubes filled with Ar gas, of which the pressure was 0.1 MPa at various annealing temperatures, to avoid their oxidation and vaporization. They were annealed and then quenched in iced water.

The 2.5 mm-thick cylinders of Ti and Ti–Cu alloys were metallographically polished, and the former was placed on the latter. They served as diffusion couples for the high-pressure experiments without joining before diffusion annealings. These couples and other cylinders of various alloys were inserted into high-pressure cells and annealed under a hydrostatic pressure of 1.9 and 2.8 GPa, generated by a cubic apparatus. They were cooled within 30 s and the average rates during the first 10 s of cooling were  $>60 \text{ K s}^{-1}$ . The annealing temperatures were controlled using Pt/Pt–13% Rh thermocouples placed on the specimens, and temperature calibration was carried out using a method similar to that of

Hanneman and Strong [2]. The pressure was calibrated through the measurements of the transitions of Bi I–II (2.55 GPa), Bi II–III (2.70 GPa) and Ti (3.67 GPa) at room temperature. (This method for the high-pressure annealing has previously been described in more detail elsewhere [3].)

The diffusion couples, blocks and cylinders annealed at various pressures were mounted in epoxy resin, ground and metallographically polished. They were observed with a scanning electron microscope (SEM) and analysed by EPMA to determine the diffusion profiles of the couples and the Cu concentration of  $\beta$ -phase in the blocks and cylinders. The measured  $\text{CuK}\alpha$  radiation were converted to concentrations through a calibration curve established experimentally from the three alloys [4].

Fig. 1 shows the SEM micrographs of Ti–1.96 at% Cu alloy annealed at 1148 K at 0 GPa (meaning 0.1 MPa) for 28.8 ks, at 0 GPa for 57.6 ks, at 0 GPa for 28.8 ks + at 1.9 GPa for 28.8 ks and at 0 GPa for 28.8 ks + at 2.8 GPa for 28.8 ks. It is evident that precipitates of  $\alpha$ -Ti phase exist in the alloy at 0 GPa (0.1 MPa), whereas only the solid-phase  $\beta$  exists in the alloy at 1.9 and 2.8 GPa.

Fig. 2 shows the diffusion profiles of couples annealed at 1173 K at 0 GPa (0.1 MPa) and at 2.8 GPa, in the vicinity of the boundaries between the  $\beta$  and the Ti<sub>2</sub>Cu phases. The solid solubility at 1173 K under 2.8 GPa is even lower than that at the same temperature under 0 GPa (0.1 MPa).

Fig. 3 shows the phase diagram in the Ti-rich part of the Ti–Cu system at 0 GPa (0.1 MPa). This atmospheric diagram assessed by Murray [1] is denoted by broken curves. Our data (designated by open circles) were slightly different from the assessed diagram. The eutectoid temperature in our study was about 10 K higher than that in Murray's diagram. The  $\beta$ -solubility at the peritectic temperature in our study was about 1.5 at% higher than that in Murray's diagram.

Figs 4 and 5 show the phase diagrams in the Ti-rich part of the Ti–Cu system at 1.9 and 2.8 GPa, respectively. Broken curves indicate the phase diagrams at 0 GPa, and full curves with open circles

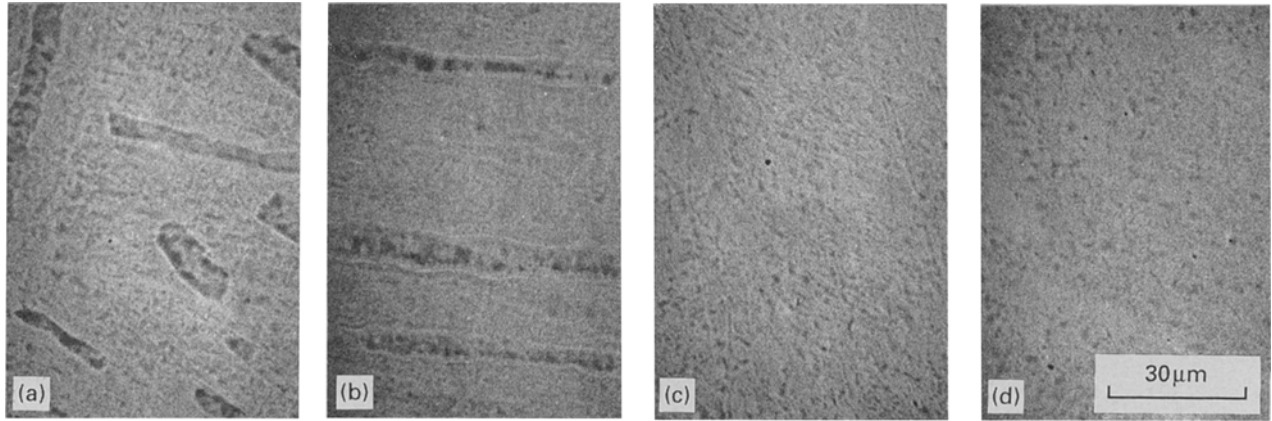


Figure 1 SEM micrographs of Ti-1.96 at% Cu alloy annealed at 1148 K: (a) at 0 GPa for 28.8 ks, (b) at 0 GPa for 57.6 ks, (c) at 0 GPa for 28.8 ks + at 1.9 GPa for 28.8 ks and (d) at 0 GPa for 28.8 ks + at 2.8 GPa for 28.8 ks.

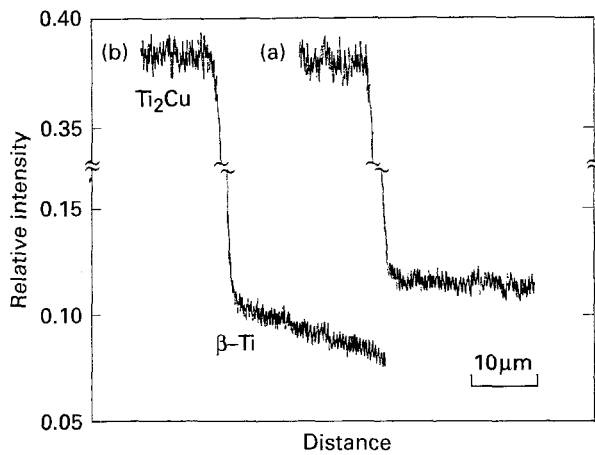


Figure 2 Diffusion profiles of couples annealed at 1173 K at (a) 0 GPa for 28.8 ks and (b) 2.8 GPa for 7.2 ks, in the vicinity of the boundaries between the  $\beta$ -Ti and the  $Ti_2Cu$  phases.

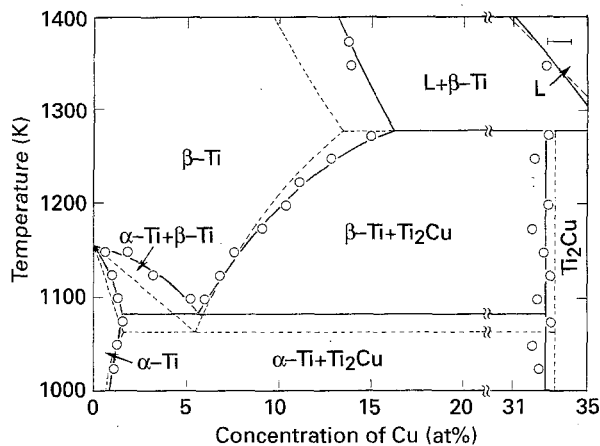


Figure 3 Phase diagram in the Ti-rich part of the Ti-Cu system at 0 GPa. Broken curves indicate the phase diagram assessed by Murray [1] and full curves with open circles indicate our data at 0 GPa.

indicate the phase diagrams at 1.9 or 2.8 GPa. The Cu concentration of the boundary between the  $\beta$ -Ti and the  $\alpha$ -Ti +  $\beta$ -Ti phases at 2.8 GPa was about 1 at% higher than that at 0 GPa. The Cu concentration of the boundary between the  $\beta$ -Ti and the liquid +  $\beta$ -Ti phases at 2.8 GPa was about 4 at% lower than that at 0 GPa. The Cu concentration of

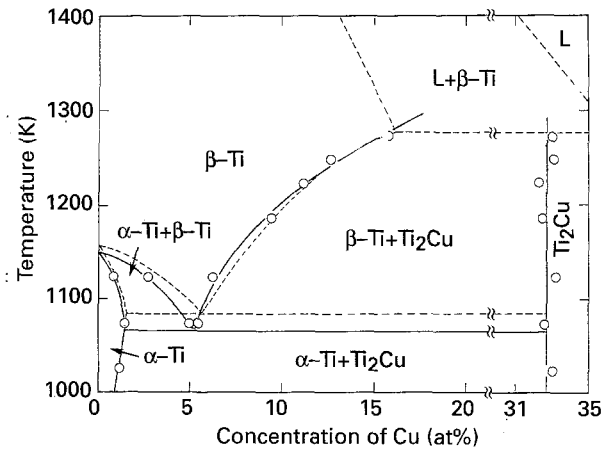


Figure 4 Phase diagram in the Ti-rich part of the Ti-Cu system at 1.9 GPa. Broken curves indicate the phase diagram at 0 GPa, and full curves with open circles indicate the phase diagram at 1.9 GPa.

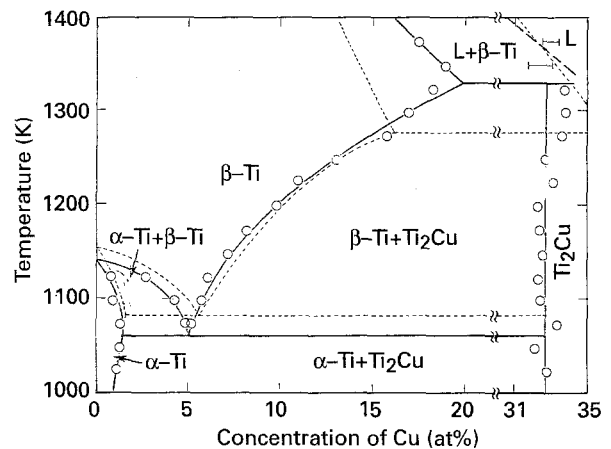


Figure 5 Phase diagram in the Ti-rich part of the Ti-Cu system at 2.8 GPa. Broken curves indicate the phase diagram at 0 GPa, and full curves with open circles indicate the phase diagram at 2.8 GPa.

the boundary between the  $\beta$ -Ti and the  $\beta$ -Ti +  $Ti_2Cu$  phases at 2.8 GPa was about 0.5 at% lower than that at 0 GPa. The Cu concentration of the phase boundary of the  $Ti_2Cu$  phase was not affected by high pressure. The eutectoid temperature at 2.8 GPa was about 16 K lower than that at 0 GPa. The peritectic temperature at 2.8 GPa was about

50 K higher than that at 0 GPa. The  $\beta$ -solubility at the peritectic temperature at 2.8 GPa was about 4 at % higher than that at 0 GPa.

### References

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