



Influences of strong magnetic field on interdiffusion behavior between Zn and Cu and dendrite growth

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ABSTRACT

Effects of a strong magnetic field (up to 16 T) on the interdiffusion behavior between Zn and Cu in the Zn/Cu diffusion couple and the growth behavior of the dendrite were investigated experimentally. Results showed that the application of the strong magnetic field caused the reduction of the diffusion layer thickness and retarded the interdiffusion between Cu and Zn. It was also found that the magnetic field coarsened the dendrite and enhanced the growth of the dendrite during the diffusion process. This might be attributed to the damping of convections and modification of the diffusion activation energy under a strong magnetic field.

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1. Introduction

As an effective method of mass transfer, diffusion plays an important role to modify the interface composition and microstructure in the solidification process. Moreover, the alloying layers may be resistant to the oxidation and sulfide corrosion for bulk materials and the properties of the alloying layers are often governed by the interdiffusion behavior between the diffusant and the bulk. Therefore, it is meaningful to control the interdiffusion between the diffusant and the bulk. Recently, owing to the development in the superconducting magnets, a strong magnetic field up to 10 T has been widely used to improve material properties during material processing, such as the solidification, the electro-deposition and the phase transformation [1–3]. Several researchers have shown that the application of a strong magnetic field can modify the diffusion process. Indeed, Youdelis et al. [4] found that the application of a 3 T magnetic field which was perpendicular to diffusion direction could retard copper atoms diffusion in Al/Al–3%Cu solid diffusion couple while there were no obvious effects when the strong magnetic field direction was parallel to the direction of diffusion. Nakajima et al. [5] did not find any influences of a 4 T magnetic field on the diffusion of Ni in Ti both perpendicular and parallel to the direction of diffusion. Nakamichi et al. [6] investigated the diffusion of carbon and

titanium in γ -Fe by an applied 6 T strong magnetic field. Results showed that the strong magnetic field reduced carbon in γ -Fe but no noticeable influence was observed on titanium in γ -Fe. Zhang et al. [7] found that the application of a strong magnetic field increased the lamellar spacing of pearlite by improving carbon diffusion. However, there were some ambiguities about the effects of a strong magnetic field on diffusion. Therefore, it is necessary and valuable to deepen the understanding on the diffusion behavior under a strong magnetic field.

The present work aims to investigate the effect of a strong magnetic field (up to 16 T) on the alloying layers and the interdiffusion behavior between Zn and Cu in the Zn/Cu diffusion couple. Results showed that the application of the magnetic field decreased the diffusion layer thickness and retarded the interdiffusion between Zn and Cu. It was also found that the magnetic field enhanced the coarseness of the dendrite. This might be attributed to the damping of convections and modification of the diffusion activation energy under a strong magnetic field.

2. Description of experimental device

The experimental apparatus consists of a static strong electric magnet with a 20 T maximum field strength at the Grenoble High magnetic field Laboratory (GHMFL) and a heating furnace equipped with a temperature controller, as shown in Fig. 1(a). The magnet can produce an axial static magnetic field with the adjustable intensity. The furnace, consisting of nonmagnetic material, has the negligible effect on field uniformity, as shown

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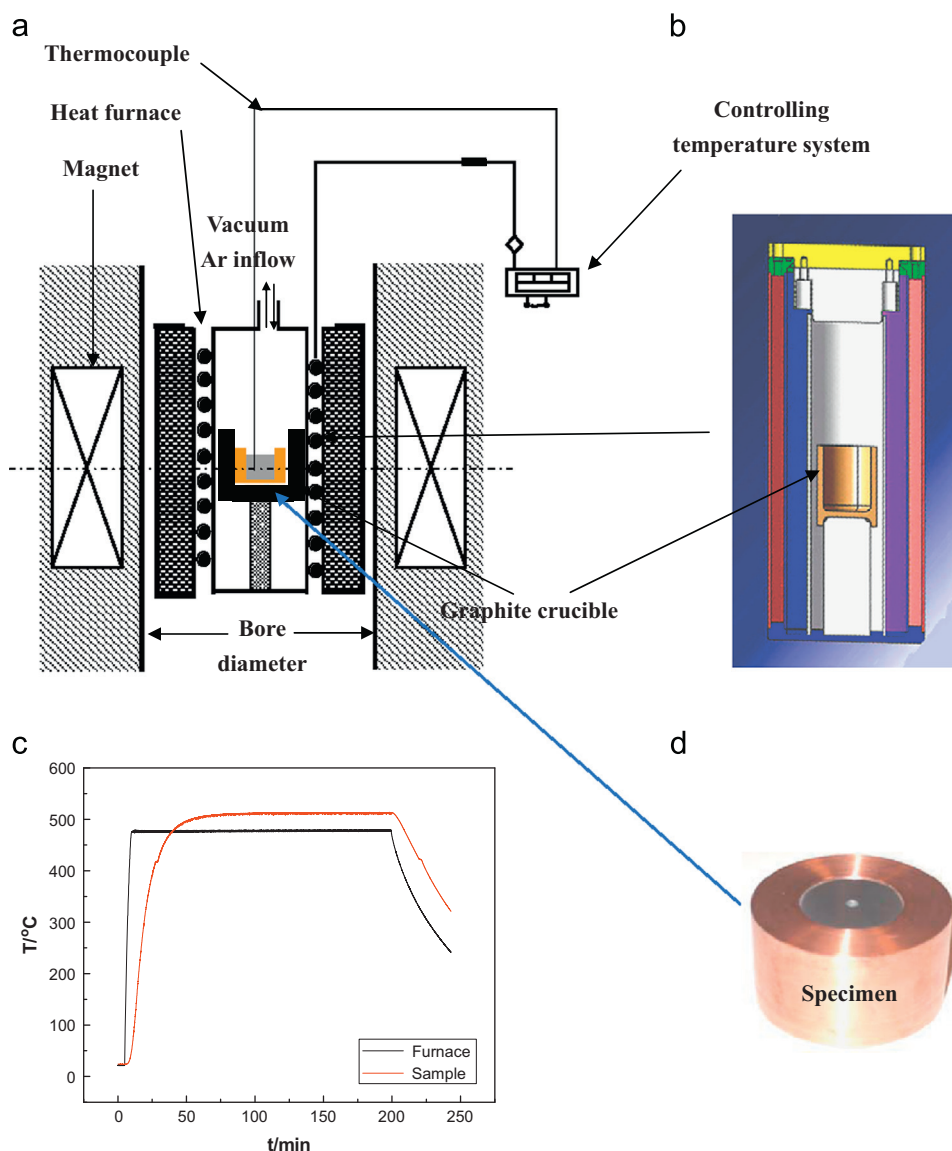


Fig. 1. Schematic diagram of experimental device: (a) schematic view of heating treatment system under a strong magnetic field; (b) heating furnace; (c) typical temperature profile of the heating treatment process; and (d) specimen.

in Fig. 1(b). The temperature in the furnace could reach 1200 °C and was controlled with the precision of ± 1 K by a NiCr–NiSi thermocouple which was in direct contact with the sample during the experiment. The apparatus containing the specimen was placed in the center of the bore mid length. The Zn/Cu diffusion couple consists of the Cu crucible (4 cm in outer diameter and 2 cm in inner diameter) of high purity (99.999%) and the Zn cylinder (2 cm in diameter) of high purity (99.999%). Inner surface of the Cu crucible and outer surface of the Zn cylinder were polished and cleaned. Then, the Zn cylinders were put into the Cu crucibles for the experiments, as shown in Fig. 1(d). Specimens were put into the furnace and vacuum was set. Atmosphere was controlled via an argon gas purge. The diffusion couples were heated to the target temperatures and held for a fixed time (around 2–5 h) with and without the magnetic field. Fig. 1(c) shows the typical temperature profile of the heating treatment process of the sample.

The samples obtained in the experiment were sectioned in half longitudinally and the diffusion surfaces were polished. The interface region between Cu and Zn layers was examined in an optical microscope and photomicrograph. Furthermore, the distribution

of Cu concentration in the Zn/Cu interface of the samples was measured by the energy-dispersive X-ray spectroscopy (EDS).

3. Experimental results

Fig. 2(a)–(c) shows the micrographs near the Zn/Cu diffusion interface in the samples annealed without and with a 16 T magnetic field under various temperature systems. There are three intermediate layers at the Zn/Cu interface, whether without and with a magnetic field, in three different annealing conditions. Apart from one intermediate layer, adjacent to the Zn matrix, which has irregular edges, the other two layers are flat. Comparison of the thickness of the intermediate layers without and with the magnetic field shows that the application of the magnetic field has modified the thickness of the intermediate layers significantly.

Further, the EDS was used to determine the nature of phases and the distribution of Cu content in the diffusion layers. Fig. 3(a)–(c) shows the EDS scanning analysis corresponding to the microstructure in Fig. 2(b). The temperature profile for heating the diffusion couple is shown in Fig. 3(d). It can be observed that the

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