JOURNAL OF MATERIALS SCIENCE **39** (2004) 2935 – 2936

Effect of an alternating magnetic field on the phase formation in Al-Cu couple

XIAOTAO LIU, JIANZHONG CUI, FUXIAO YU
The Key Laboratory of Electromagnetic Processing of Materials, Ministry of Education, Northeastern University, Shenyang 110004, People's Republic of China

Electromagnetic processing of materials (EPM) has been recognized as a crossing technology, especially in the fields of advanced materials processing. Several examples of EPM, for example, are the application of a high frequency magnetic field [1–3], a DC magnetic field [4], DC magnetic and electric fields [5], and a traveling magnetic field [6]. Recently, by the advance in super-conducting magnets, a high magnetic field has become readily available and is being applied in various fields of science [7]. Many interesting phenomena relating to EPM have been found [8]. The present investigation stems from the experimental observation of Cui *et al.* on the effect of an alternative electromagnetic field on solidification process of aluminum alloys. The liquidus and solidus temperature were increased [9], the solution of alloying elements was effectively promoted and the macrosegregation was reduced when solidification took place in alternating magnetic field [10]. To explain this it was proposed that the magnetic field promote the diffusion process which accompanies alloy solidification. The purpose of this study was to investigate the effect of low frequency alternating (AC) magnetic field on the formation and growth of intermediate phases in the system of Al-Cu couple. Thickness measurements of the intermediate phases were here employed following the annealing process to compare the difference of intermetallics formation and growth with and without the application of the AC magnetic field.

The diffusion couples of pure aluminum (99.9%) and oxygen free copper (99.9%) was employed in the present experiment. The pure aluminum and copper plate of a thickness of about 5 mm were cut and the bonding face of the couple halves were polished and cleaned. After that the plates stacked 10 mm in thickness were cold rolled to a thickness of nearly 2 mm. The specimens were cut into rectangular prism, $10 \times 10 \times 2$ mm^3 from the as received cold rolled diffusion couples described above and annealed at 803 K for 8 h in a resistance furnace with and without the application of low frequency AC magnetic field. The AC magnetic field was imposed on the diffusion couple by a 680 turns water-cooled copper coil surrounding the resistance furnace. The intensity of the AC magnetic field was determined by CT3-A Tesla Meter at room temperature and it can reach to 0.5 T when the frequency is fixed at 10 Hz. During annealing under the AC magnetic field the specimens were arranged with the interface of bonding perpendicular to the lines of magnetization. Fig. 1 shows the schematic drawing of the experiment arrangement. Following annealing the Al-Cu diffusion couples were cut normal to the bonding interface and the sections were polished and examined by electron probe microanalysis (EPMA). The thickness of the intermetallics layers was determined and the values were averaged over 10 different measurements.

Fig. 2 shows the intermediate phases in the diffusion zone of the Al-Cu couples observed by EPMA with and without the application of the AC magnetic field. It is seen here that the θ, η_2 phase and non-equilibrium phase layer were observed in the diffusion zone both with and without the AC magnetic field. The formation of non-equilibrium phase near the Cu side may be attributed to the annealing time of the diffusion couple not being long enough to form all the equilibrium phases given by the equilibrium Al-Cu phase diagram. So the composition of this phase layer may disagree with the Al-Cu phase diagram. With the application of the magnetic field the formation and growth of η_2 phase was promoted and the non-equilibrium phase layer was narrowed. The magnetic field affects the thickness of the diffusion zone and promotes the occurrence of the equilibrium condition of phases, the effect increasing with intensity of the field as shown in Fig. 3.

The alternate magnetic field has a significant influence on the formation and growth of intemetallic compounds in the Al-Cu diffusion couple and the effect depends on the intensity of the magnetic field although the exact mechanism(s) by which this occurs is not clear at this time. Some investigators [11, 12] have given theoretical analyses for the layer growth

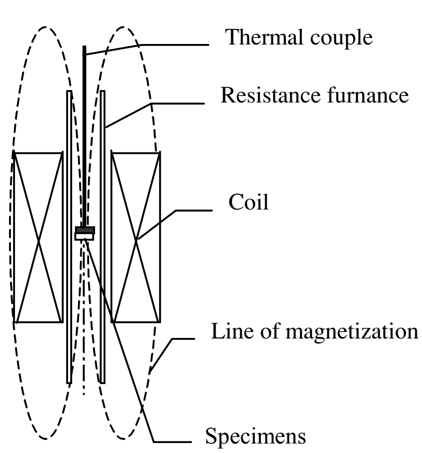

Figure 1 Schematic of experiment arrangement.

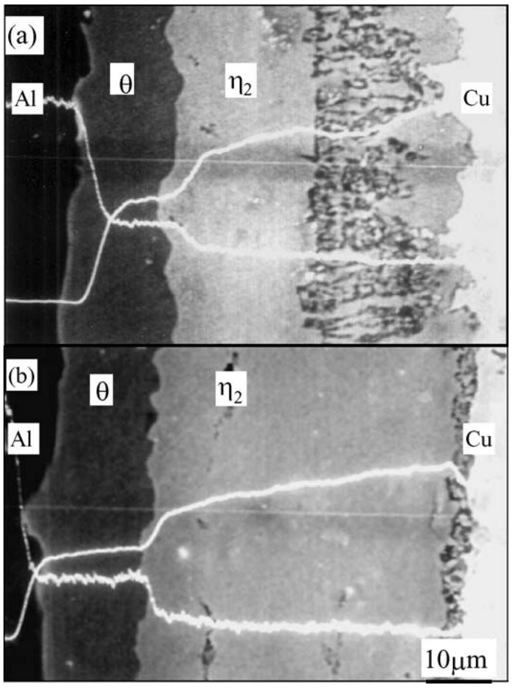

Figure 2 Intermetallic compounds growth in Al-Cu couple with the bonding interface perpendicular to the lines of magnetization: (a) B = 0 T and (b) B = 0.5 T.

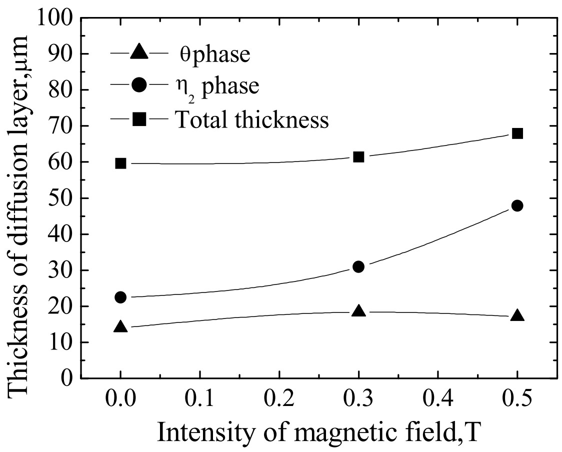

Figure 3 Thickness of diffusion layer vs. intensity of the AC magnetic field.

of the intermediate phases in a diffusion zone. An intermediate-phase layer will grow more rapidly as: (a) the diffusion coefficient in the layer is larger; (b) the coefficient in the adjoining phases is smaller. One might expect an influence on the diffusion of the atoms especially the interdiffusion of Al and Cu atoms in intermetallic compounds as a result of the force exerted by the magnetic field on the ions and electrons in the solids because the atomic transport is required during the formation and growth of intermetallic compounds. Under the AC magnetic field the interdiffusion coefficients of Al and Cu atoms in the η_2 phase layer is increased.

Additional work is in progress to develop an understanding of how an AC magnetic field influences the formation and growth of intemetallic compounds in diffusion couples.

References

1. M. FURUI, Y. KOJIMA and M. MATSUO, *ISIJ Intern.* **33** (1993) 400.
2. T. J. LI, S. NAGAYA, K. SASSA *et al.*, *Metall. Mater. Trans.* **26B** (1995) 353.
3. E. TAKEUCHI and K. MIYAZAWA, International Symposium on Electromagnetic Processing of Materials, April, ISIJ. (2000) p. 20.
4. T. FUJII, International Symposium on Electromagnetic Processing of Materials, April, ISIJ. (2000) p. 14.
5. P. MARTY and A. ALEMANY, Metallurgical Application of Magnetohydrodynamics Proceeding of a Symposium of the IUTAM, The Metal Society (1984) p. 245.
6. SHIGEO ASAI., *ISIJ Intern.* **29** (1989) 981.
7. J. S. BROOKS, J. E. CROW and W. G. MOULTON, *J. Phys. Chem. Solids* **59** (1998) 569.
8. M. SHIMOTOMAI and K. MARUTA, *Scripta. Mater.* **42** (2000) 499.
9. C. Y. BAN, Ph.D. thesis, Northeastern University, Shenyang, 2002 (in Chinese).
10. B. J. ZHANG, J. Z. CUI and G. M. LU, *Mater. Lett.* **57** (2003) 1707.
11. W. SEITH, "Diffusion in Metallen" (Berlin Springer Verlag., 1955) p. 185.
12. C. MATANO, *Acta Met.* **17** (1969) 99.

Received 4 June
and accepted 16 October 2003