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Research on aging precipitation in a Cu–Cr–Zr–Mg alloy

Juan-hua Su[a,b,*], Qi-ming Dong[b], Ping Liu[b], He-jun Li[a], Bu-xi Kang[b]

[a] *College of Materials Science and Engineering, Northwestern Polytechnical University, Xi'an 710072, China*
[b] *College of Materials Science and Engineering, Henan University of Science and Technology, Luoyang 471003, Henan Province, China*

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Abstract

The effects of aging processes on the properties and microstructure of Cu–0.3Cr–0.15Zr–0.05Mg lead frame alloy were investigated. Aging precipitation phase was dealt with by transmission electronic microscope (TEM). After solid solution was treated at 920 °C and aged at 470 °C for 4 h, the fine precipitation of an ordered compound $CrCu_2$(Zr, Mg) is found in copper matrix as well as fine Cr and Cu_4Zr. Along the grain boundary, there are larger chromium. The hardness and electrical conductivity can reach 109 HV and 80% IACS, respectively. Sixty percent cold-rolled deformation prior to aging at 470 °C enhances the hardness of the alloy. The coherent precipitates Cr in copper matrix and the dislocations pinned by the fine precipitates are responsible for maximum strengthening of the alloy. So the hardness 165 HV and electrical conductivity 79.2% IACS are available.

Idt: TG146

Keywords: Cu–Cr–Zr–Mg alloy; Aging; Precipitation phase; Coherency; Properties

1. Introduction

Cu-base alloys are the most popular lead frames alloys used in plastic packaging application due to the high mechanical and operating properties [1–3]. Cu–Cr–Zr alloy has attracted considerable interest recently because of its superior combination of high electrical conductivity and high strength [4–8]. So, this situation has led to the application of Cu–Cr–Zr alloys to the lead frame of the integrated circuit.

Cold working is often carried out between the solid solution treatment and aging to assist in the aging hardening by introducing a high density of dislocation [9,10]. Aging is a commen heat treatment for many copper alloy, with the aim of raising their strength and hardness [11,12]. The high hardness of Cu–Cr–Zr alloys is due to precipitation along the dislocation and dispersion strengthening, and the excellent electrical conductivity is attributed to the very low solubility of Cr and Zr in Cu matrix. In order to control the microstructure and improve the properties of Cu–Cr–Zr alloy, it is of great value to optimize the aging process and identify the composition of the precipitates. There has been no unanimous agreement on the precipitation phase of the alloy. In [13], the precipitates within the grains were indexed to be Hesuler phase $CrCu_2$(Zr, Mg). At the grain boundary, Cu_4Zr was indexed. Huang and Ma [14] found $Cu_{51}Zr_{14}$ in matrix of Cu–Cr–Zr alloy. References [15,16] showed that three phases Cr, Cu_5Zr and Cu should exist in the system.

This paper deals with the microstructure and precipitation phases of aged Cu–Cr–Zr–Mg alloy with superior combination of hardness and electrical conductivity, in order to get better understanding of the strength mechanism and the composition of the precipitates of the Cu–0.3 wt% Cr–0.15 wt% Zr–0.05 wt% Mg lead frame alloy.

* Corresponding author. Tel.: +86 3794 221049; fax: +86 3794 222632.
E-mail address: sujh@mail.huast.edu.cn (J.-h. Su).

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2. Experimental procedure

The alloy Cu–0.3Cr–0.15Zr–0.05 Mg was produced in a vacuum induction furnace with electrolytic copper, pure chromium, zirconium and magnesium as charge materials. The billet was homogenized at 900 °C for 2 h and hot-rolled to a thickness of 5 mm. The specimens cut from plate were solution-treated at 920 °C for 1 h and water-quenched. The aging treatments were carried out in a tube electric resistance furnace under a fluid atmosphere of argon with temperature accuracy of ±5 °C. The electrical resistivity was determined by measuring the resistance of sample in 100 mm length using ZY9987-type standard direct-current four-probe technique. The mean value of three measurements had an estimated accuracy of less than ±0.0002 Ω. The Vickers micro-hardness was measured on a HVS-1000-type hardness tester under a 100 g load and holding for 10 s. Every sample was tested at five times with an accuracy of ±5%.

The transmission electronic microscope (TEM) samples were prepared by conventional electro-polishing method using an electrolyte of HNO_3:CH_2OH = 1:3. The electron microscopy for this study was carried out using a H-800 TEM at 200 kV.

3. Results and discussion

3.1. Effects of aging process parameters on hardness and electrical conductivity

Fig. 1 shows the effect of aging time on hardness of Cu–Cr–Zr–Mg alloy with and without deformation before aging at 470 °C. After aging, the hardness with 60% cold rolling is much higher than that with no deformation.

The dislocations resulting from the rolling deformation act as diffusion paths for solute atoms and provide nucleation site for precipitation during aging treatment and result in the precipitation hardening effect. After rolled 60% and aged at 470 °C for 1 h, the peak hardness of Cu–Cr–Zr–Mg alloy attains 165 HV. Solid solution treated and aged at 470 °C for 4 h, the peak hardness is 109 HV. At the peak hardness, the fuller precipitation is available and the hardening effect is

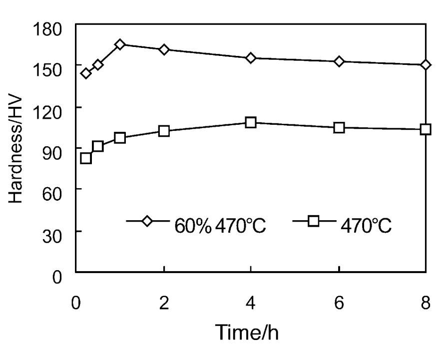

Fig. 1. Variation of hardness of Cu–Cr–Zr–Mg alloy with and without rolling before aged at 470 °C vs. aging time.

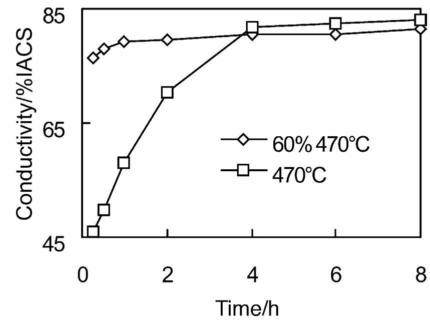

Fig. 2. Conductivity of Cu–Cr–Zr–Mg alloy with and without rolling before aged at 470 °C vs. aging time.

optimum. With increasing the aging time, the precipitates coarsen and lose coherency with the matrix. After the peak hardness, over-aging occurs.

Fig. 2 reveals that the electrical conductivity increases with increasing the time. The longer time brings about more precipitates. The growth of precipitates reduces the contents of solute atom in matrix and results in a continuous increase in electrical conductivity during the aging. So, the conductivity in Cu–0.3Cr–0.15Zr–0.05Mg lead frame alloy remains at a higher level. After 60% deformed and aged at 470 °C, at the initial stage of aging, the conductivity increases sharply. It is the precipitation along the dislocations that results in the initial sharp increase of conductivity.

At 470 °C aging for 4 h, the electrical conductivity is 80% IACS. After 60% deformed and aged at 470 °C for 1 h, the electrical conductivity is 79.2% IACS as shown in Fig. 2.

3.2. Analysis of microstructure

The hardness depends mainly on the microstructure of the materials, which in turn depends on the aging treatment.

The morphology of precipitates upon aging at 470 °C for 4 h is given in Fig. 3. The microstructure characteristic of Cu–Cr–Zr–Mg alloy is the fine dispersed precipitates in the

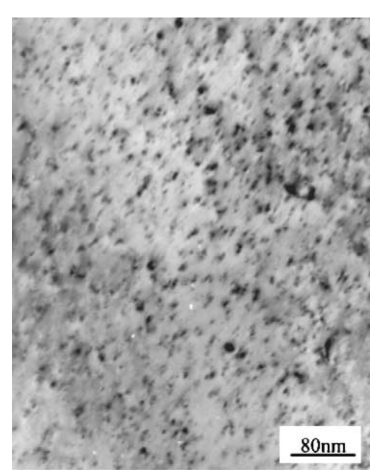

Fig. 3. Precipitation morphology of the Cu–Cr–Zr–Mg alloy aged at 470 °C for 4 h.