Journal of Alloys and Compounds 772 (2019) 288–297

Contents lists available at ScienceDirect

Journal of Alloys and Compounds

journal homepage: http://www.elsevier.com/locate/jalcom

Deformation mechanisms and mechanical properties of (0001) Mg-Zn-Y 18R-LPSO single crystals

W.S. Chuang [a], J.C. Huang [a, b, *], P.H. Lin [a], C.H. Hsieh [a], Y.H. Lin [a], K. Takagi [c], Y. Mine [c], K. Takashima [c]

[a] Department of Materials and Optoelectronic Science, National Sun Yat-Sen University, Kaohsiung, 804, Taiwan, ROC
[b] Institute for Advanced Study, Department of Materials Science & Engineering, City University of Hong Kong, Kowloon, Hong Kong
[c] Department of Materials Science and Engineering, Kumamoto University, Kurokami, Chuo-Ku, Kumamoto, 860-8555, Japan

ARTICLE INFO

Article history:
Received 10 July 2018
Received in revised form
31 August 2018
Accepted 9 September 2018
Available online 10 September 2018

Keywords:
Mg alloy
18R LPSO
(0001) plane
Deformation mechanism
Micro-pillar

ABSTRACT

A promising Mg-Zn-Y alloy with the long-period stacking ordered (LPSO) second phase has been developed for about twenty years. Because the LPSO phase has the unique 18R crystal structure, particularly for its packing sequence along [0001], as well as it plays an important role in strengthening mechanisms, it is interesting to clarify in terms of mechanical properties and deformation mechanisms. In this study, uniaxial micro-pillar compression tests are conducted on LPSO along the [0001] direction. At the same time, nanoindentation system equipped with the Berkovich tip is used to extract the basic mechanical properties of (0001) plane. The basal dislocations are found to be activated first, causing the bending of the sample. The bending would lead to the shear stress field downward and thus would cause the nucleation and movement of prism dislocations with [0001] Burgers vector. Prism dislocations can form the fatal 45° slip trace inside the micro-pillar and finally go through the whole sample causing fracture. The basal dislocations are found at the Zn_6Y_8-Mg interface which might be originated from the local strain field between them.

© 2018 Elsevier B.V. All rights reserved.

1. Introduction

In the past twenty years, a novel Mg-Zn-Y alloy ($Mg_{97}Zn_1Y_2$ in at %) has been developed [1] and a series of researches have been conducted in order to rationalize the reasons for the outstanding mechanical properties [1–4]. It has been demonstrated that the superior mechanical properties are mainly originated from the novel precipitates, namely, the long-period stacking ordered (LPSO) second phase [4,5]. Therefore, it is meaningful and necessary to examine the mechanical properties and deformation mechanisms in association with this LPSO phase individually.

Until now, the crystal structure of the LPSO phase has already been studied [6–11] in several kinds of ternary Mg-Zn-RE alloys. It has been identified that there are four kinds of LPSO structure, 10H, 14H, 18R and 24R [8], in Mg-Zn-RE alloys. It should be noted that we focus on the 18R structure in this study. By examining the diffraction patterns in accordance with atomic images of high resolution transmission electron microscopy (HRTEM), the structure of 18R LPSO has been clarified. With the period of stacking sequence, ACBCBCBACACACBABAB, the unit cell is proposed to be hexagonal with lattice constants $a = 0.321$ nm and $c = 4.86$ nm (c/a ratio of 15.14). Moreover, for every six HCP stacking layers, the periodical insertion of Zn/Y-enriched face-centered cubic (FCC) typed stacking fault appears [6–12]. Interestingly, Zn/Y-enriched layers are formed by $L1_2$-type Zn_6Y_8 and a contracted stress field appears [6,13].

As mentioned above, it is meaningful to conduct researches on 18R LPSO phase individually. In Mg-Zn-Y alloys, the volume fraction of 18R LPSO increases with increasing atomic percent of Zn and Y. When it comes to $Mg_{85}Zn_6Y_9$, the volume fraction can reach above 85% [14]. There have been limited literatures reporting the compression deformation mechanism in $Mg_{85}Zn_6Y_9$ poly-crystals along the growth direction of $[11\bar{2}0]$ in millimeter-scaled samples [15,16]. It was reported that there are deformation kinks, which are originated from the activated basal slip systems, observed in the deformed samples [12,15,16]. Moreover, with the help of extrusion, the highly oriented polycrystalline can be obtained. Thus, the deformation mechanism of different orientations can be clarified [17]. However, it can be found that the orientation of 18R-LPSO

---

* Corresponding author. Department of Materials and Optoelectronic Science, National Sun Yat-Sen University, Kaohsiung, 804, Taiwan, ROC.
E-mail address: jacobc@mail.nsysu.edu.tw (J.C. Huang).

https://doi.org/10.1016/j.jallcom.2018.09.091
0925-8388/© 2018 Elsevier B.V. All rights reserved.

cannot be aligned very well in polycrystalline samples. For example, there are still some (0001) plane spreading uniformly in the direction from ND to TD, causing numerous deformation mechanisms [17].

Therefore, in order to fully understand the mechanical properties and deformation mechanisms of the 18R-LPSO single crystal, it is necessary to shrink the experimental samples to tens of micrometers extracted from the 18R LPSO single crystal. In our previous results [18], we successfully found out the origin of deformation kinks during compression along the [11$\bar{2}$0] direction of the Mg-Zn-Y 18R LPSO single crystal.

So far, almost all the limited literatures are focused on deformation mechanisms and mechanical properties with respect to the (11$\bar{2}$0) plane, or along the [11$\bar{2}$0] direction. There have been minimum researches done for the (0001) close-packed plane. As mentioned above, an interesting characteristic of 18R LPSO is its periodic alternative stacking sequence with softer HCP Mg-layers and harder L1$_2$-type Zn$_6$Y$_8$-layers. This alternative stacking sequence is similar to the composite structure but is presented as a crystal structure. How the deformation mechanism would be influenced by the alternative stacking sequence should be explored in order to obtain the knowledge of this crystal structure. Thus, it is in fact important to examine the unique mechanical properties and deformation behavior of 18R LPSO single crystal with the loading axis directing along the [0001] direction. Once the detailed understanding is established, the promising application of Mg-Zn-Y 18R LPSO on the (0001) plane and along the [0001] direction would be more feasible. In this study, we thus focus on the deformation mechanisms and mechanical properties of 18R LPSO single crystal by conducting uniaxial micro-pillar compression and nanoindentation, respectively, on the (0001) plane.

2. Material and experimental methods

The material examined in this study is a directionally solidified Mg$_{85}$Zn$_6$Y$_9$ (at%) alloy, which was produced using the Bridgeman method. Crystals were grown at a rate of 0.5 mm/min under the argon atmosphere in a furnace. A sample approximately 1 mm in thickness was mechanically cut from the alloy, followed by emery papers grinding for both sides. In order to obtain high electron backscatter diffraction (EBSD) signals for accurate grain orientation determination, the flat sample surface was further polished by a cross-section polisher. The EBSD analysis was conducted by a JEOL field emission gun scanning electron microscope (SEM) equipped with an EBSD analyzer shown in Fig. 1(a). The orientations of coarse grains were determined by automatic beam scanning at 15 kV accelerating voltage with step a size of 1 μm. The crystallographic parameters for the EBSD analysis is a rhombohedral structure with R$\bar{3}$m space group with a = 0.3229 nm and c = 4.697 nm [19].

The micro-compression samples, i.e. micro-pillars, were machined from (0001) plane. By comparing the EBSD results and backscattered electron images (BEI), micro-pillars were machined in the area which is pointed out by the red square in Fig. 1(b). Fig. 1(c) shows the detailed crystal pole figures of the target area.

Micro-pillars were prepared using the SEIKO SMI3050 dual focus ion beam FIB system, following the method developed by Uchic et al. [20]. A Ga ion beam operated at 30 keV and 7–12 nA was initially directed perpendicular to the surface of the 18R LPSO, i.e. the (0001) plane, to mill a crater with 35 μm in diameter and 0.8 μm in depth. Then, a much smaller current of 0.7–0.09 nA was used to process the final machining pillars, so as to reduce the Ga ion damage on the resulting micro-pillars. The resulting micro-pillars measure 5.5 μm in height and 2.7 μm in diameter, with a minimum taper angle less than 2°.

The uniaxial micro-compression tests were conducted by the Hysitron nanoindentation system using a flat punch tip, under the loading rate control (LRC) mode. The loading rate was set to be 4×10^{-5} Ns^{-1}, and the corresponding strain rate is about 2×10^{-4} s^{-1}, well in the quasi-steady state. As for measuring the Young's modulus and hardness of 18R LPSO on (0001) plane, the Berkovich tip was used under the LRC mode in the Hysitron nanoindentation system.

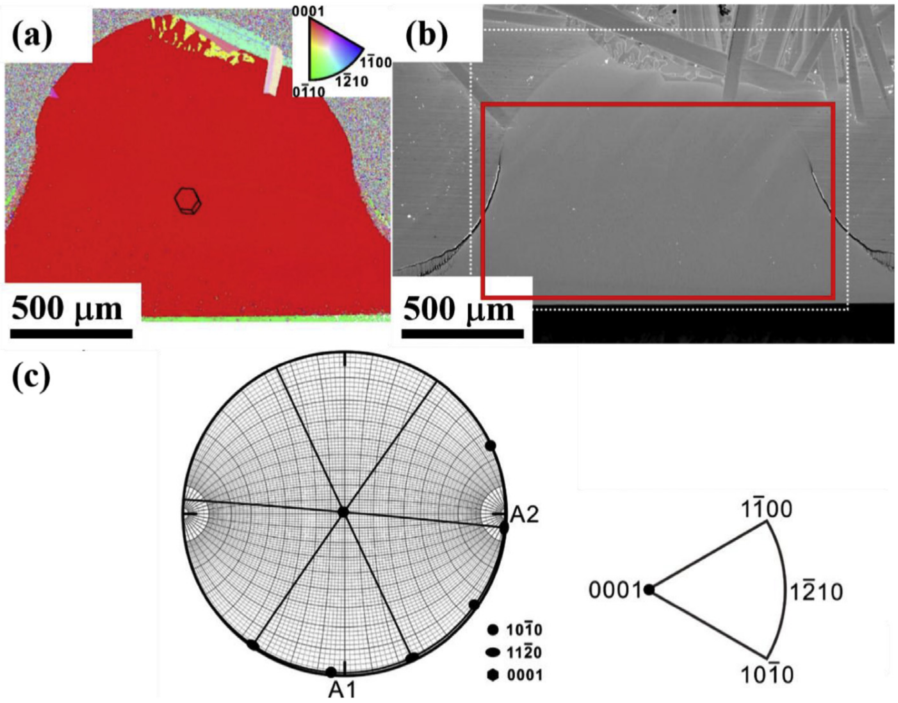

Fig. 1. (a) EBSD results and (b) BEI of the Mg$_{85}$Zn$_6$Y$_9$ coarse grain with the (0001) plane. (c) The detailed crystal pole figure information.

Download English Version:

https://daneshyari.com/en/article/10155964

Download Persian Version:

https://daneshyari.com/article/10155964

Daneshyari.com