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RECRYSTALLIZATION EXPERIMENTS IN TENSILE DEFORMED <100>-ORIENTED SINGLE CRYSTALS OF COPPER-PHOSPHORUS AND COPPER-MANGANESE ALLOYS

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ABSTRACT

The recrystallization process in specimens of dilute CuP and CuMn alloys was investigated to determine those orientation relationships between recrystallized grains and deformation microstructure, which favour rapid grain growth. The specimens were prepared from tensile deformed <100>-oriented single crystals. In the CuP alloy the largest recrystallized grains have near 20° <94,30,7> or 53° <73,63,25> orientation relationships to the deformation microstructure. In the CuMn alloy only the two orientation relationships 30° <73,56,39> and 48° <71,61,35> were found.

INTRODUCTION

The formation of annealing textures is controlled by several processes. Annealing twinning creates those orientations of the recrystallization texture, which are not present in the deformation microstructure (DM) (1,2). The second essential process for recrystallization texture formation is the grain boundary migration. The new orientations formed by twinning can dominate the recrystallization texture only if the grain boundaries (GB's) have a sufficient mobility (3).

Information about highly mobile GB's separating the recrystallized grains and DM as well as the appertaining OR's can be gained by so called "Beck experiments", i.e. recrystallization experiments in a particularly simple DM. Nuclei with a random orientation distribution were created by additional deformation (4). Because of the homogeneity of the DM the OR's can be determined with great accuracy.

Foreign atoms strongly influence the recrystallization process because they change the GB mobility, GB energy and the stacking fault energy (5). The influence of phosphorus and manganese on the recrystallization of copper is of special interest, because the deformation behaviour of dilute CuP-alloys indicates, that small additions of P lower the stacking fault energy (7). Dilute CuMn-alloys, however, have the same stacking fault energy as pure Cu (8). The Beck experiments described in the present paper shall elucidate the influence of P and Mn on the growth of the recrystallized grains during primary recrystallization.

EXPERIMENTAL

As the complete experimental procedure is described elsewhere (9,10), here only the essential details are summarized. The DM was created by tensile deformation of cylindrical <100>-oriented single crystals grown by the Bridgman techniqe. The deformation degrees were 20 % (CuP) and 16 % (CuMn), respectively. Halves of the deformed crystals cut along (100) planes were used as specimens. Their final composition was Cu-0.03 at% P, Cu-0.09 at% P and Cu-0.20 at% Mn. After grinding at one end the specimens were annealed under Ar for 90 min. The annealing temperatures for the three alloys were 783 K , 818 K and 873 K.

In the annealed specimens the orientations of all recrystallized grains with a diameter of more than 2 mm were determined by the Laue back reflection technique. The accuracy of the OR's between the DM and the recrystallized grains is estimated as 3° because of the limited precision of specimen preparation and Laue diagram evaluation.

RESULTS

The deformation microstructure

The DM of tensile deformed <100>-oriented single crystals is described elsewhere (11). The essential characteristic of the DM is its extreme homogeneity. The DM consists of subgrains with diameters near 1 μm separated by dislocation rich layers of about 0.25 μm thickness. The orientations of all subgrains deviate less than 1° from the initial orientation. TEM investigations of the deformed CuP and CuMn crystals yielded that their DM's coincide with the DM of the pure Cu single crystals. The dislocation densities of the deformed specimens are estimated to be $2*10^{10}$ cm^{-2}.

The recrytallized microstructure

The recrystallized specimens showed the typical microstructure of Beck experiment specimens: The grain size is small at the abraded end and becomes larger with increasing distance from the nucleation region. The largest recrystallized grains have diameters up to 1 cm.

Orientations of the recrystallized grains

In our specimens the <100>-axes of the specimen reference system are parallel to the <100>-directions of the DM. Therefore, the orientations of the recrystallized grains coincide with their OR's to the DM. In the following, only the OR's are investigated. The results are presented in the homochoric space proposed by Frank (12). An OR characterized by a rotation of a certain amount about an axis is described by a vector. Its direction represents the direction of the rotation axis and its length the rotation angle. Because of the crystal symmetry in the cubic lattice there exist 1052 eqivalent descriptions of an OR. For a comparison of different OR's it is convenient to consider only the combinations with the smallest rotation angle and the rotation axis in the standard triangle 100-110-111. In the homochoric space these combinations lie in one subspace which is shown in fig. 1. Each OR is represented by one point.

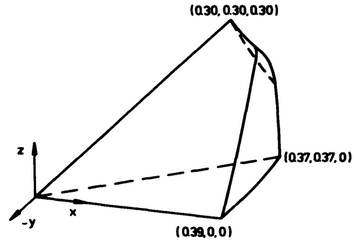

Figure 1 Subspace of the homochoric space used for the presentation of the observed OR's

Fig. 2 shows a series of sections through this subspace with the OR's observed in the Cu-0.03 at% P alloy. A prominent maximum in the orientation distribution is evident in the left corner of the first section. In the upper corner of the third and fourth section a weaker maximum is visible. The first maximum can be characterized by a 20° rotation about a <94,30,7>-axis (near <310>). A rotation of 53° about a <73,63,25>-axis (near <331>) desribes the second maximum. These two ideal OR's named CuP1 and CuP2 in the following characterize 90 % of the observed OR's with an accuracy of 10°. This value is the maximum misorientation between the two orientations created by lattice rotations corresponding to the observed and the ideal OR's. The same two maxima were found in the orientation distribution of the Cu-0.09 at% P specimens. Here the CuP1 maximum still is dominating but its intensity is weaker. Both maxima characterize 88 % of the observed OR's within the 10° misorientation limit.

The OR's of the Cu-0.2 at% Mn specimens are presented in fig. 3. Compared with the Cu-P specimens the OR distri-

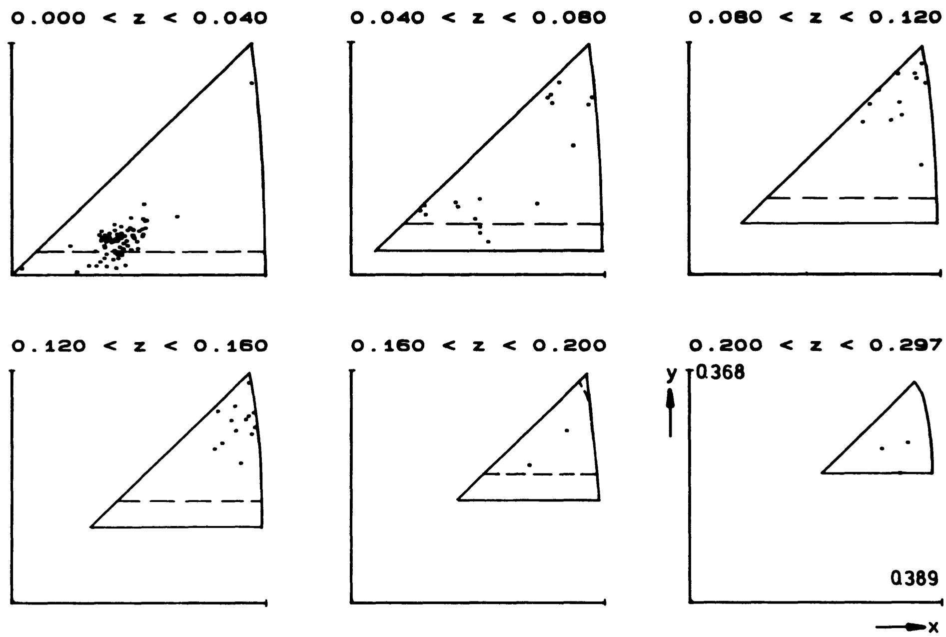

Figure 2 OR's between recrystallized grains and DM in the Cu-0.03 at% P specimens. The dashed lines mark the subspace boundary for the upper z-values

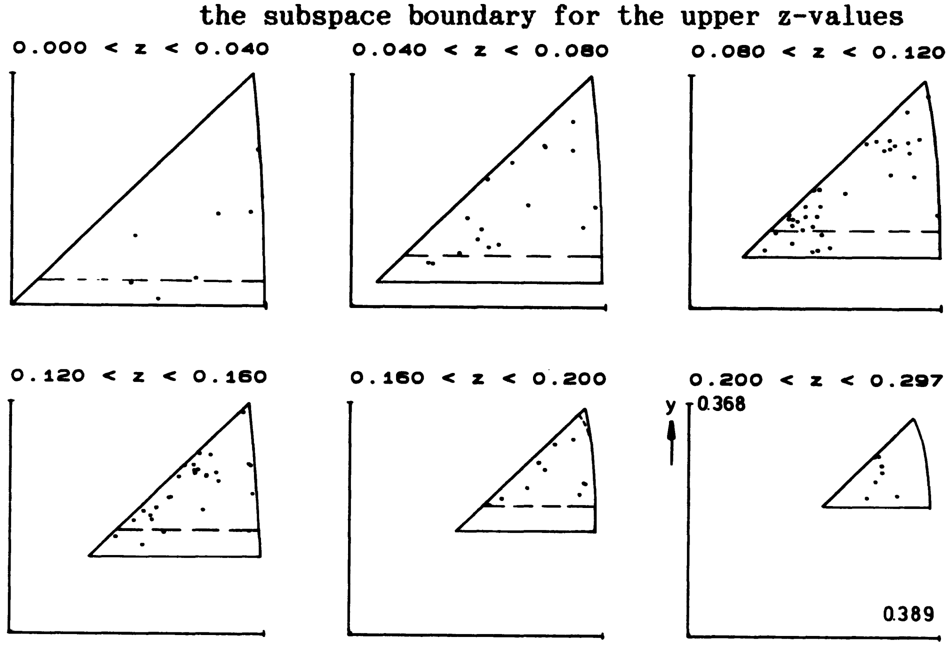

Figure 3 OR's between recrystallized grains and DM in the Cu-0.2 at% Mn specimens

bution is more uniform. Two broad maxima are visible in the third and fourth section near the left corner and in the vicinity of the diagonal line with x=y. They were idealized by a 30° <73,56,39>-rotation (CuMn1) and a 48° <71,61,35>-rotation (CuMn2), respectively. The two rotation axes are nearly identical (angular difference 3.9°) and can be approximated by a <764>-direction. In this way 78 % of the observed OR's can be classified with an accuracy of 10°. The two ideal OR's are related by twinning. Evidence for this twin OR was found by the metallographic investigations, too. Frequently, grains with orientations corresponding to CuMn1 and CuMn2 were sepatated by coherent twin boundaries.

DISCUSSION

The results of the Beck experiments with the CuP and CuMn alloys reveal that in both alloys the dominating recrystallized grains show completely different OR's to the DM. Furthermore, the sharpness of the OR distributions differs. Despite of the slight differences in degree of deformation and annealing temperature this result is considered to be mainly the result of the different alloying elements. A calculation of the misorientation distribution function for the results of Beck experiments in Cu (13) yielded that an increase of the degree of deformation from 10 % to 20 % leads only to variations of the different maximum values in the OR distribution. The same observation was made for increasing the annealing temperature from 750 K to 1080 K.

The two alloying elements P and Mn influence the growth of the recrystallized grains in a different way. Alloying Mn leads to a preferred growth of grains with the CuMn2 OR to the DM. This is evidenced by the metallographic observations (10). In most cases the fastest growing grains showed this OR. A similar OR (45° <773>) was already identified in pure Cu as favouring rapid grain growth if the annealing temperature is sufficiently high (13). The OR CuMn1 has no counterpart in pure Cu. The corresponding orientations are regarded as links of twin chains leading from the orientations of the nuclei to the final orientations with the OR CuMn2, because adjacent grains with OR's CuMn1 and CuMn2 are separated frequently by coherent twin boundaries.

The OR CuP1 most frequently observed in the CuP alloys was found neither in pure Cu nor in the CuMn alloys. The second OR CuP2 is nearly identical with the 55° <652> OR detected in the <111>-oriented Cu single crystals deformed 4 % before annealing (13). This OR was assigned to the early recrystallization stages because grains with this OR were most freqently observed near the nucleation region. Calculations reveal that CuP1 and CuP2 are twin related, too.

To judge the role of the different OR's for recrystallization texture development the OR's between the components of the deformation and the recrytallization textures were calculated for texture measurements in CuP and CuMn alloys described elsewhere (14,15). With one exception each component of the recrystallization textures was related to the components of the deformation texture by at least one of the OR's detected in our Beck experiments. The exception is the cube orientation found in the deformation and recrystallization texture of CuMn. Such a stability of one orientation was already observed in Cu-0.7 at% P alloys (5). It is caused by the high phosphorus content which leads to a relatively high mobility of small angle GB's. The same explanation can be applied to the texture results of the CuMn alloy because the Mn content was 1.19 at%.

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