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# Grain Structure Evolution in 1-d Rods and 2-d Strips of Polycrystalline Aluminium

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## ABSTRACT

The paper presents data on the motion of grain boundary system with individual triple junction in aluminium and data on the grain structure evolution in one-dimensional (1-D) rods ("bamboo" structure without triple junctions) and two-dimensional (2-D) strips ("columnar" structure) of polycrystalline aluminium. Influence of triple junction motion on the grain growth in polycrystalline aluminium is discussed.

## INTRODUCTION

Triple junctions and grain boundaries are the main structural elements of polycrystals. However, little studies have been carried out so far on the triple junction influence during grain growth of polycrystalline materials. The first data available on triple junction mobility were obtained for Zn tricrystals [1]. It was shown that triple junction can drag the boundary motion and that its role and properties should be taken into consideration in theories of grain growth.

The main goal of the current work is the determination the triple junction influence on the grain growth in 1-D "bamboo" structure and 2-D "columnar" structure.

## EXPERIMENTAL

Experiments were carried out using rods with the 1-D "bamboo" structure, strips with 2-D "columnar" structure and tricrystals with triple junction. All samples were made of Al 99.999%. The term "bamboo" structure is used for the description of a system in which two dimensions are smaller than the third one (Fig.1a). Each grain in this structure has only two neighbours along the sample axis. Rods have a square cross section 1×1 mm$^2$ .The rods were cut from rolled aluminium polycrystals and single crystals ($\varepsilon$ = 75%). They were annealed at 823 K for 0.5 hour to obtain the initial "bamboo" structure. 2-D "columnar" structure labels a system where grain boundaries are perpendicular to the sample plane and where sample thickness is of the order of the mean grain size. The third dimension remained homogeneous (Fig. 1b). Strips thickness is 1 mm. They were cut from rolled aluminium polycrystals and single

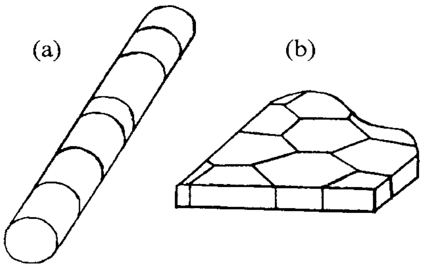
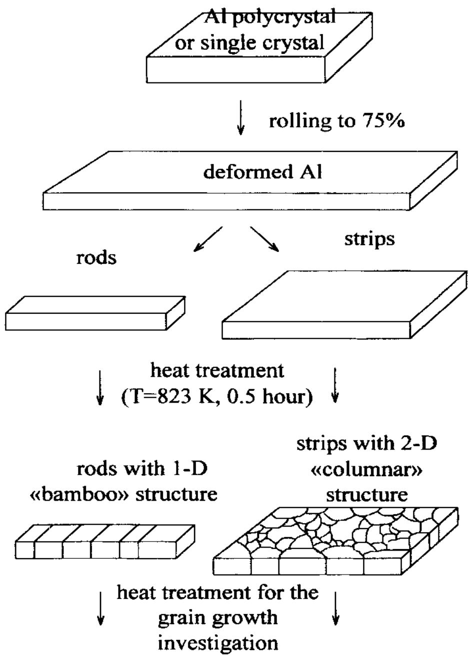


Fig. 1. The schematic view of: (a) 1-D "bamboo" structure, (b) 2-D "columnar" structure.

crystals (ε = 75%). Strips were annealed for 0.5 h at 823 K to obtain the "columnar" structure. Thus, the initial material, both rods with "bamboo" and strips with "columnar" structures, received the same heat and mechanical treatment. Sample preparation scheme is shown in Fig.2. Finally rods and strips were annealed at the same conditions at 773 K for 0.5, 1.5, 3 and 6 h.



| | Mean grain growth velocity, mm/s | | |
|---|---|---|---|
| initial state of samples | «bamboo» structure | «columnar» structure | |
| | | in cluster | the whole |
| polycrystal | $4.54 \times 10^{-5}$ | $1.41 \times 10^{-5}$ | $6.06 \times 10^{-6}$ |
| single crystal | $3.03 \times 10^{-5}$ | $5.56 \times 10^{-6}$ | $5.56 \times 10^{-6}$ |

Fig.2 Scheme for obtaining rods with "bamboo" structure and strips with "columnar" structure

To study the kinetic of the grain growth in the 1-D rods and 2-D strips the mean grain size was measured for each annealing time. It is known that grain boundaries are etched to a different degree depending on their crystallography. The low angle grain boundaries produce a weak contrast and it is practically impossible to reveal them during metallographic investigations using optical microscope in bright field conditions. But we can not ignore these low angle grain boundaries in our consideration, because it may lead to incorrect results. There are some papers, where this question was discussed. Therefore we decided to use dark field conditions and inclined beam with a large aperture. Rotating of the microscope stage varies the angle of incidence of the light beam on the specimen surface. This causes a variation in intensity of the grain colouring and permits to obtain data on the grain boundary distribution in specimen, including the low angle grain boundaries [2]. Determination of grain misorientations was performed using selected area channelling pattern technique (SAC) in the scanning electron microscope (SEM).

The Al tricrystals with triple junction were grown by a directed crystallization technique (Fig. 3). A graphite crucible in a high purity argon atmosphere was used. The orientation of three adjacent grains in each sample was also determined by SAC technique. In order to study the triple junction motion we fix the displacement and the angles in a vertex of the half-loop.

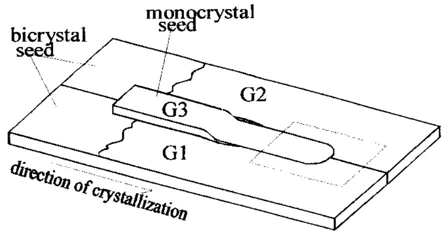


Fig3. The scheme of Al tricrystal growth; the square with thin line indicates the used tricrystal. G1, G2, G3 are grains with different crystallography.

Al <111> tricrystals contain <111> tilt grain boundaries with different misorientation angles. We used tricrystals with <111> tilt grain boundaries, because these boundaries in Al bicrystals have a high mobility [3]. We assumed that <111> tilt triple junctions would have a high mobility too. The experiments on triple junction mobility were carried out in the temperature range 380°C–510°C.

We also supposed that driving forces for grain boundary migration in bicrystals, in system with individual triple junction, in "bamboo" structure and "columnar" structure can be: difference in surface tension between two grains ($p \approx 10^4$erg/cm$^3$ [4]) and decreasing of grain boundary energy ($p \approx 10^3$–$10^4$ erg/cm$^3$ [5, 6]).

## RESULTS AND DISCUSSION

1. Triple junction mobility.

Experimental data on triple junction migration in Al <111> tricrystals are obtained for the first time. Triple junction mobility may be calculated using the expression for boundary and triple junction kinetics as shown in [1]. As we did not observe sharp change in angle at the triple junction vertex, we used the formula of triple junction mobility $A$ for boundary kinetics:

$$A = \frac{a \cdot V}{2\theta} = A_0 e^{-\frac{H}{kT}},$$

where $a$ is the width of consumed grain, $V$ is triple junction motion velocity, $2\theta$ is vertex angle, $A_0$ is pre-exponential factor, $H$ is activation enthalpy.

The obtained data on triple junction mobility for Al tricrystals are shown in Table 1. Activation enthalpy for the different triple junction differs one from another by one order of magnitude. Triple junction mobility differs by two orders of magnitude. These differences are determined by triple junction crystallography. Triple junction crystallography determines also the temperature, at which they become mobile. So, as the triple junction mobility varies with the change of temperature triple junctions enter into recrystallization process at different stages. It is resulted in changes not only of mean grain size, but also of grains shape during grain growth. Interval of triple junction motion velocity is shown in Fig. 4.

Table 1. Crystallography and activation parameters of triple junction mobility in Al <111> tilt tricrystals. $T_m$ is melting point.

| | H, eV | <111> | | | $A_0$, m$^2$/s | T, °C | $T/T_m$ |
|---|---|---|---|---|---|---|---|
| | | $\varphi_{1\text{-}2}$ | $\varphi_{2\text{-}3}$ | $\varphi_{1\text{-}3}$ | | | |
| T1 | 4.14 | 8° | 56° | 56° | $8.60 \times 10^{19}$ | 440 – 460 | 0.76 |
| T2 | 2.60 | 5° | 25° | 20° | $1.74 \times 10^{11}$ | 380 – 420 | 0.70 |
| T3 | 0.36 | 30° | 20° | 10° | $3.93 \times 10^{-6}$ | 470 – 510 | 0.80 |

2. "Columnar" structure.

We investigated grain growth in Al strips with 2-D structure. The data on grain growth in "columnar" structure are shown in Fig. 2. It was found that there are grains with different normal orientation to their surface. Grain boundaries spatial arrangement is far from random one. There is <111> microtexture in Al. The clusters of like-textured grains can be recognised readily. There are many low angle grain boundaries, fewer large-angle grain boundaries and only isolated special grain boundaries into the clusters. Large angle grain boundaries divide mainly grains with normals to the strips surface <110> and <100>. Mean grain size growth velocity in clusters is higher than in specimen as a whole. It can be associated with the fact, that triple junction with a configuration *large angle/low angle/large angle* tilt grain boundaries are significantly more mobile then those with other configurations. Migration of such triple junctions resulted in increase of cluster area. Intervals of change in mean grain size growth velocity are shown in Fig. 4. All data were obtained at the same driving forces.

3. "Bamboo" structure.

There are no triple junctions in rods. Low angle boundaries are not observed in them. Mean grain size growth velocity in rods is lower than migration velocity of individual grain boundary in Al [3] (Fig. 4). However mean grain size growth velocity in "bamboo" structure is about one order of magnitude higher than in 2-D structure (Fig. 2). Triple junctions are absent in 1-D rods and do not drag the motion of the grain boundary in "bamboo" structure.

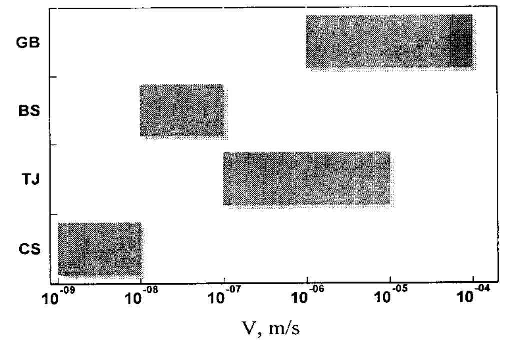


Fig.4. Interval of change: GB-individual grain boundary migration velocity; BS-mean grain size growth velocity in "bamboo" structure; TJ-triple junction motion velocity; CS- mean grain size growth velocity in "columnar" structure. All data were obtained at the same driving forces.

## CONCLUSIONS

1. Triple junctions have a considerable influence in the processes of grain growth.
2. Grain growth velocity in 1-D system without triple junctions is higher than in 2-D strips, obtained by the same preprocessing.
3. Grain growth velocity in 2-D system with triple junctions ("columnar" structure) is determined by drag of triple junctions.

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