Dissociated Dislocations in Low-angle Grain Boundary of Alumina

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Alumina (α-Al₂O₃) is widely used as structural materials because of its high temperature stability and resistance for deformation. It is known that two slip systems, (0001)1/3<1120> basal slip and {1120}<0110> prism plane slip, are activated at elevated temperatures [1]. However, the glide dislocations, \( b_1 = 1/3<1120> \) and \( b_2 = <0110> \), are not perfect dislocations but dissociated into partial dislocations with the stacking-faults in between as follows [1]

\[
\begin{align*}
1/3 &<1120> \rightarrow 1/3<0110> + 1/3<1010>, \quad (1) \\
<0110> &\rightarrow 1/3<0110> + 1/3<0110> + 1/3<0110>. \quad (2)
\end{align*}
\]

Recently, it was reported that the groups of five partial dislocations are formed due to the coexistence of two kinds of perfect dislocations in low-angle tilt grain boundary of alumina [2]. The dislocation dissociation can be described as follows

\[
1/3<1120> + <0110> \rightarrow 1/3<0110> + 1/3<0110> + 1/3<1010> + 1/3<0110> + 1/3<1010>. \quad (3)
\]

This dissociation is considered to be energetically preferred, because the strain energy of a dislocation is proportional to the square of its Burgers vector. However, it is still unclear why the configuration in EQ. 3 should be selected.

In this study, we fabricated an alumina bicrystal with a \{1120\}/<1100> 2° low-angle tilt grain boundary by diffusion bonding method at 1500°C for 10h in air. The fabricated grain boundary was observed by transmission electron microscopy (JEM-2010HC, operated at 200kV).

FIG. 1 is a bright-field image of the grain boundary fabricated in this study. It can be seen that the grain boundary is consisted of pairs of dislocations, a group of nine dislocations and a group of eleven dislocations. The structure of pair dislocations is based on the EQ. 1. On the other hand, it is considered that the structure of the group of nine and eleven dislocations is similar to the structure based on EQ. 3. To identify the dislocation configurations in these unique structures, we observed the grain boundary from [1210] axis and obtained a dark-field image using \( g=3030 \) (FIG. 2). In present condition, \( b_f = 1/3[1010] \) partial dislocations are enhanced more strongly than \( b_f = 1/3[0110] \). Therefore, the configuration of a group of nine partial dislocations is found to be \( b_1 b_2 b_2 b_2 b_1 b_2 b_2 b_2 \). This structure is similar to the group of five partial dislocations, and other characteristic structures should be also closely related. The characteristic structures are represented as follows

\[
n \times 1/3<1120> + <0110> \rightarrow 2 \times 1/3<0110> + n \times (1/3<1010> + 1/3<0110>) + 1/3<0110>, \quad (4)
\]

where \( n \) is integral number. Furthermore, eight kind of the characteristic structures, groups of three to seventeen partial dislocations (0≤\( n \)≤7), were found in the present extensive observations. The combination of EQ. 1 and EQ. 2 can form various dissociation structures based on EQ. 4. This implies that the excess energies due to introduction of different sizes (i.e. \( n \)) of the characteristic structures are similar. The strain energy by partial dislocations and the fault energy by stacking-fault forming between partial dislocations should be balanced in the stable structure. The multiplicity of partial dislocation structures may be caused
by slight fluctuations in the grain boundary. It was found that the characteristic structures include the same screw component of $1/2\langle 1\bar{1}00 \rangle$, the magnitude of which is $b=0.407\text{nm}$. The periodicity of the characteristic structure was about $d=250\text{nm}$. Using Frank’s equation ($\phi=b/d$), the twist angle of the grain boundary is estimated to be $\phi=0.1^\circ$. This indicates that the characteristic structures are introduced due to a small twist component in the grain boundary.

In conclusion, various characteristic partial dislocation structures are formed due to a slight twist component in a $\{1120\}\langle 1\bar{1}00 \rangle$ $2^\circ$ low-angle tilt grain boundary of alumina. Dark-field images revealed the configurations of the characteristic partial dislocation structures. The structure of low-angle grain boundaries in alumina is thus strongly affected by the misorientation of the boundary.

References

FIG. 1. A bright-field image of the grain boundary. Groups of nine and eleven dislocations are introduced between pairs of dislocations.

FIG. 2. A dark-field image of the grain boundary using $g=3030$. A group of nine partial dislocations are observed. In present condition, $b_1=1/3[1010]$ partial dislocations (black arrow) are enhanced more strongly than $b_2=1/3[0110]$ (white arrow).

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