HRTEM Study of Dissociated Dislocation Structures in Low-Angle Grain Boundaries of Alumina

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Alumina (α-Al2O3) is widely used for high-temperature structural applications. Since plastic deformation occurs by dislocation glides, it is important to understand the structures of dislocations with an atomic level. In alumina two major slip systems, (0001)<1120> and {1120}<1100>, are dominantly activated at elevated temperatures [1]. These slip dislocations are observed to be dissociated into 1/3<1010> partial dislocations as following equations.

\[
\begin{align*}
\frac{1}{3}<1120> & \rightarrow \frac{1}{3}<1010> + \frac{1}{3}<0110> \\
<1100> & \rightarrow \frac{1}{3}<1100> + \frac{1}{3}<1100> + \frac{1}{3}<1100>
\end{align*}
\]

Alumina possesses the so-called corundum structure, and the 1/3<1100> fault vector coincides with a translation vector in the anion sublattice but not in the cation sublattice. Thus, 1/3<1100> partial dislocation leads stacking faults in the cation sublattice. The stacking faults are formed on the {1120} or {1100} planes [2]; however their atomic structures and fault energies are not experimentally well characterized yet.

Low-angle grain boundaries consist of edge dislocations. Burgers vectors of the dislocation are usually selected to be normal to the grain boundary planes. In order to characterize the structures of 1/3<1120> and <1100> dislocations, we fabricated alumina bicrystals with the {1120}/<1100> 2° and the {1100}/<1120> 2° low-angle tilt grain boundaries and observed the boundary dislocations by high-resolution transmission electron microscopy (HRTEM).

FIG. 1 shows a HRTEM image of dislocation pairs formed in the {1120}/<1100> grain boundary. An analysis using Burgers circuit revealed that they are 1/3<1010> and 1/3<0110> partial dislocations formed by the dissociation reaction of Eq. 1, and it is found that the stacking fault is formed {1120} plane. The average interval of partial-dislocation pairs and width of the stacking faults were 14.7 nm and 3.3 nm, therefore the stacking fault energy are estimated to be 0.32 Jm⁻² by elastic theory (where the infinite dislocation configuration was considered [3, 4]). FIG. 2 shows a HRTEM image of dislocation triplets formed in the {1100}/<1120> low-angle grain boundary. From Burgers circuit the total fault vector of the triplet is found to be <1100> and each partial dislocation has the 1/3<1100> vector. This is consistent with the dissociation reaction based on Eq. 2. The partial dislocations are connected with two stacking faults on the {1100} plane. The average interval
of partial-dislocation triplets and width of the stacking faults were 22.4 nm and 5.3 nm, and the stacking fault energies are estimated to be 0.40 Jm$^{-2}$. It is noted that the right and the left stacking faults are different in structure [2, 5]. In the presentation, we will discuss the dissociated dislocation structure in detail, and we will also demonstrate dopant segregation behavior around the dislocation cores by HAADF-STEM.

References

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FIG. 1. A HRTEM image of $\{11\bar{2}0\}<1\bar{1}00> 2^\circ$ tilt grain boundary. The dislocations dissociate into $1/3<10\bar{1}0>$ and $1/3<01\bar{1}0>$ partial dislocations with a stacking fault on the $\{11\bar{2}0\}$ plane.

FIG. 2. A HRTEM image of $\{1\bar{1}00\}<1\bar{1}2\bar{0}0> 2^\circ$ tilt grain boundary. The dislocations dissociate into three $1/3<11\bar{1}0>$ partial dislocations with stacking faults on the $\{1\bar{1}00\}$ plane.