

Supplementary Materials for

**Direct imaging of the disconnection climb mediated point
defects absorption by a grain boundary**

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1. Supplementary Note I: Discussion on the electron beam effect on α -Al₂O₃

The electron beam irradiation effect is a complex process, which damages the samples from several mechanisms, including knock-on, surface sputtering, beam induced heating, radiolysis and beam induced electric field^{1,2}. For the electron beam energy of 80 keV and probe current of 30 pA on α -Al₂O₃, the knock-on damage and beam induced heating could be neglected³. The main damages come from the radiolysis and beam induced electric field, which are discussed below:

Radiolysis

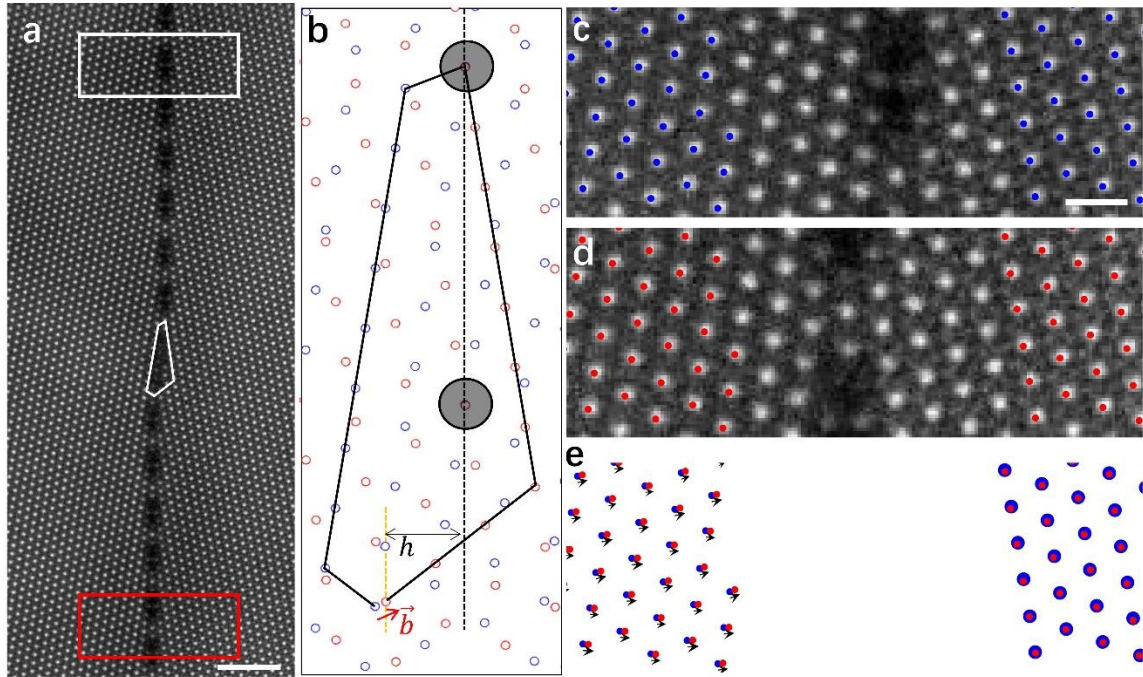
Radiolysis has been suggested to be pronounced in alumina⁴. For alumina, the atomistic process of this damage was suggested to occur via the Knotek-Feibelman mechanism^{1,4,5}: the O ions are suggested to be positively charged due to the Auger decay and these positive charged O atoms are repelled by the surrounding metal ions and ejected out from the irradiation areas, which may produce O vacancies and/or interstitials.

Beam induced electric field

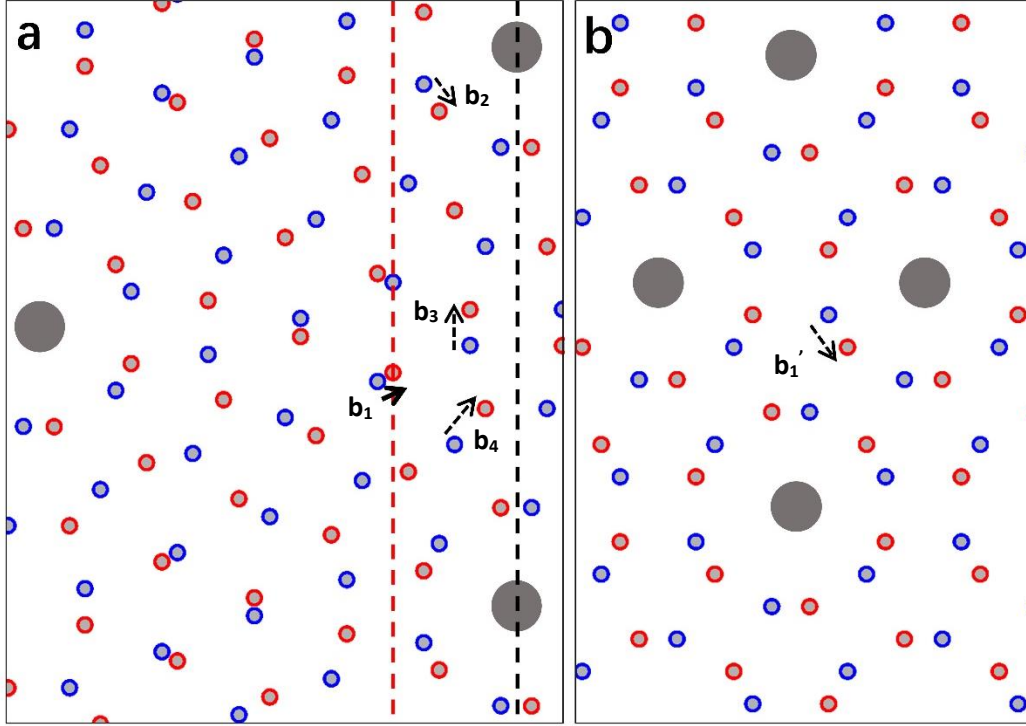
When the sample is under electron beam, the irradiated area might be positively charged because of the emission of the secondary and/or Auger electrons^{1,2}. When the positive charges in the sample cannot be quickly neutralized by electron conducting (most likely in electron insulating materials like Al₂O₃), ionic displacements would occur under the Coulomb forces, which induce the electron beam damage. It has been suggested that the cations with positive charges, such as Al³⁺ in our case, might be repelled out from the irradiation area which are positively charged². These cations ions would either eject to the vacuum or into the nearby bulk to become cation interstitials and leave the sample in the irradiation area enriched of vacancies.

Therefore, in our experiment, radiolysis and beam induced electric field should account for the beam damage, in which point defects and their clusters or aggregations (e.g. void) at and near the irradiation areas might be generated.

2. Supplementary Figures and Legends



Supplementary Figure 1. Atomic shear displacement of the disconnection. **a.** The high angle annular dark field image of the disconnection in pristine bicrystal. The scale bar is 2 nm. The image is taken by aligning and averaging of 30 frames, in which each frame was quickly acquired ($2.5\mu\text{s}/\text{pixel} \times 1024 \times 512 \text{ pixels}$) by the ARM 300CF to improve the spatial resolution and reduce the scanning distortions⁶. **b.** The dichromatic pattern of the GB, which shows the Burgers vector of the disconnection is same to the one in Fig. 1c in the main text. **c, d.** The enlarged images in the white and red boxes in **a**, which are before and after the disconnection, respectively. The scale bar is 5 Å. The two images are selected to have identical positions for the right crystal. The Al atomic positions are denoted by the blue and red dots, which are located by 2-deminsional Gaussian fitting of the intensity of the image. **e.** The overlaid of atomic column positions in **c** and **d**. The Al columns in the right crystal are set to be coincident. It is clear shown that the Al columns in the left crystal are displaced from the bule dots to the red dots, which indicates when the GB moves, there will be collective shear displacements. These displacements have same direction to the Burgers vector of the disconnection, which are corresponding to the atomic shear displacements in Fig. 3h of the main text.



Supplementary Figure 2. The comparison of potential disconnections between $\Sigma 31$ GB and the $\Sigma 7$ GB³. **a.** The dichromatic pattern of the $\Sigma 31$ GB. The blue and red dots correspond to the Al columns in the left and right grain, respectively. The larger grey circles are the CSL columns. The dotted vertical black and red line are the GB positions in the pristine GB and where the disconnection forms, which is also shown in Fig. 4 of the main text. The Burges vector of the disconnection observed in experiment is shown as the solid black arrow on the red line, of which $\mathbf{b}_1$ is about 0.5 Å. When the GB moves from the dotted black line to the red line, there are other disconnection candidates, among which three Burges vector candidates are highlighted by the dotted black arrows. The sizes of the three vectors are $\mathbf{b}_2=0.88$ Å, $\mathbf{b}_3=0.99$ Å and $\mathbf{b}_4=1.33$ Å, respectively. According to the dislocation theory⁷, the dislocation energy $E \propto \mathbf{b}^2$, where $\mathbf{b}$ is the Burgers vector, and the relative disconnection energies can be estimated as $E_{b2}= 3.10E_{b1}$, $E_{b3}= 3.92E_{b1}$, $E_{b4}= 7.08E_{b1}$. Therefore, only $\mathbf{b}_1$ is observed because it has much smaller disconnection energies compared with all the other disconnections. **b.** The dichromatic pattern of the $\Sigma 7$ GB. The shortest possible Burgers vector candidate $\mathbf{b}_1'$ (the DSC vector) is highlighted by the dotted black arrow. The size of the potential Burgers vector is 1.04 Å, but the disconnection energy is still much higher than that of $\mathbf{b}_1$ in the $\Sigma 31$ GB ($E_{b1'} = 4.33E_{b1}$). Therefore, the

disconnections in the $\Sigma 7$ GB should be also energetically unfavorable, which have not been found during the GB migration nor in the pristine bicrystal.

3. Supplementary References.

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