doi:10.1017/S1431927619001260

Microsc. Microanal. 25 (Suppl 2), 2019

Quick Evaluation of Potential Difference on Al/Al_3Fe Interface in a Conventional Transmission Electron Microscope

Katsuhiro Sasaki[1*], Hirokazu Sasaki[2], Yuta Yamamoto[1], and Yoshiyuki Oya[1]

[1.] Chemical Analysis Research Section, R&D Division, UACJ Corporation, Nagoya, Japan, 455-8670.
[2.] Analysis Technology Center, Furukawa Electric Co. Ltd., Yokohama, Japan 220-0073.
*Corresponding author: khsasaki@nagoya-u.jp

The potential difference in material, which will cause the corrosion in a wet environment, has been imaged using electron holography [1], Lorentz microscopy [2] and DPC method [3]. We have been developing an alternative method to visualize the electric filed in a conventional electron microscope with a thermal electron gun [4-6]. We have tried to observe a metal and metallic compound interface Al/Al_3Fe in a polycrystalline commercial material.

The specimen used in this work is an A6000 type aluminium alloy including Al_3Fe precipitations. The cross-sectional transmission electron microscopy (TEM) specimen was prepared using focused ion beam (FIB) apparatus JEOL JEM-9310FIB and placed on carbon film Quantifoil 2/2 (Quantifoil Miro Tools GmbH, Germany) by the conventional lift out method. TEM observation was performed in JEM-2010 with the accelerating voltage of 200 kV. The specimen was observed in the imaging mode in which the objective lens was turned off and imaged by the objective mini (OM) lens. The largest size of selected area diffraction (SAD) aperture was used to obtain pseudo liner shape of the shadow aperture [5].

In the imaging mode named "Low Mag" used in this work, the SAD aperture i.e., the shadow aperture, is located between the OM lens and the image plane of the lens as shown in Fig. 1. When the electron beam has certain divergency, the shadow of the aperture edge has diffuse contrast, however, image of the specimen does not be affected. The intensity of electron beam focused on the image plane is determined by the ration of obstructed electrons in the diverged electron beam on the aperture plane as indicated by the lines 1, 2, and 3 as in Fig. 1a. When the electron beam 2 is deflected due to the potential difference in the specimen, the ratio of obstructed electrons is changed, which causes the deviation from the continuous intensity profile diffuse aperture shadow edge as shown in the lower part of Fig.1b.

Figure 2 shows the bright field image of the specimen including the contrast of precipitations, grain boundaries and dislocations. The left-hand side of the Al_3Fe particle in the centre of the image in Fig. 2 is selected for the observation due to the faceted interface running vertically in the image. Figure 3 is the enlarged image of the interface between Al_3Fe particle in right hand side and Al matrix in left hand side by putting the SAD aperture (a) in right hand side, (b) without the aperture, (c) in left hand side. Figure 3b shows the bright filed image of the absorption contrast between Al and Al_3Fe which confirms the position of interface. In the images of Fig. 3a and 3c, the diffuse contrast of the aperture edge running parallel to the interface is overlapped in the middle of the image. The additional dark and bright contrasts along the interface are observed in Fig. 3a and 3c, respectively. The contrast profiles across the interface are obtained in Fig. 3d, e, and f from the area marked by dotted lines in the corresponding images of Fig. 3a, b, and c. The apparent sharp decrease in Fig. 3d and increase in Fig.3f on the interface as indicated by arrows are observed compared to the profile of absorption contrast in Fig. 3e. The work function of the pure Al is measured to be between 4.06 and 4.26 eV [7] and of the Al_3Fe is estimated by the first-principles calculation to be about 4.59 eV [8]. At the contact of two metallic materials, fermi levels are aligned and then the potential difference corresponding to the difference of work functions will be formed. In order to compensate the potential difference, excess electrons and corresponding deficit of electrons are accumulated on the Al_3Fe and Al side of the interface, respectively. As the result, the electron beam is deflected from Al_3Fe to Al side, which will cause the difference of the obstruction ration of the electron beam at the aperture. As the result, when the aperture positioned right and left hand side, as illustrated in the insets of Fig. 3, the dark and bright lines will be formed, respectively. The result coincides the predicted phenomenon. The detected potential difference is the order of 0.2 eV which is one order lower than measured at the p-n junction of GaAs in our previous work [6].

The potential difference metal/metallic compound interface in a polycrystalline material including many defects was successfully imaged in a conventional TEM equipped with a conventional thermal electron gun. The quantitative value of potential distribution could be obtained from the measured value.

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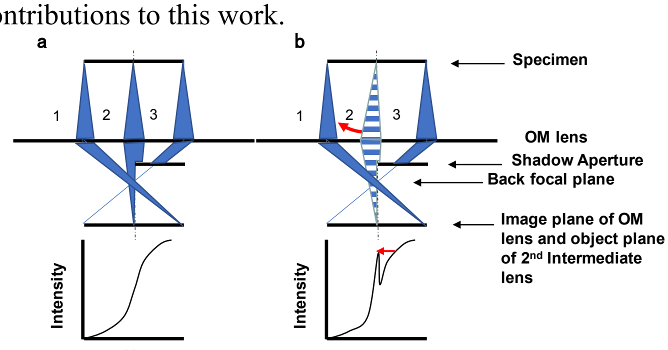

Figure 1. Geometrical optics and intensity profile of the aperture edge.

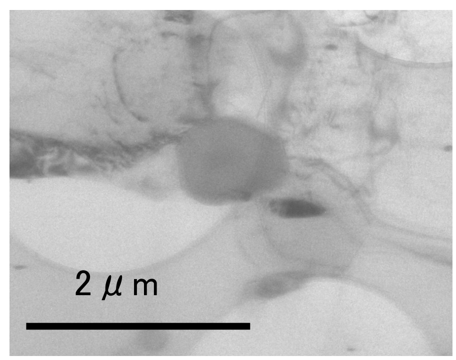

Figure 2. The bright field image of the specimen including precipitates

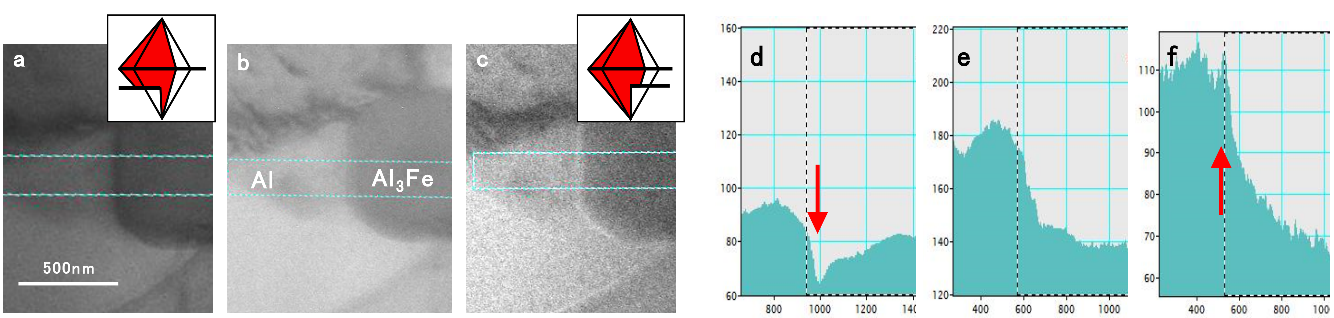

Figure 3. BF image of the interface with the aperture in (a) right, (b) without, (c) left hand side, and corresponding intensity profiles (d), (e) and (f), respectively. Insets are the schematic drawing of geometrical optics of the deflected beam with the aperture.

https://doi.org/10.1017/S1431927619001260 Published online by Cambridge University Press