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In Situ TEM Investigation of the Electroplasticity Phenomenon in Ti-6Al

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Since 1950, applied pulsed electrical current during deformation of metals were found to result in reduced flow stress and increased formability. This phenomenon is named as Electroplasticity (EP) and was explained by two possible mechanisms: (1) localized Joule heating at defects and (2) the electron wind effect causing vacancy migration [2]. With the more advanced transmission rlectron microscopy (TEM) technique, observations of this behavior at the level of individual defects, i.e. dislocation dynamic, can be achieved today. In this work, Ti-Al alloys was selected with the purpose of observing dislocation motion change and the protentional directional effect due to applied current. Titanium alloys are widely used as structural materials due to their high specific strength and excellent corrosion resistance, especially with Al as a solid solution strengthener [4]. The chemical short-range ordering (SRO) of Al atoms were directly observed by Zhang et al. together with their strain distribution and the “wavy to planar” slip transition, which could potentially confine the dislocation motion and easier for observation [5].

In this work, *in situ* TEM electromechanical tests of Ti-6Al samples on electrical push-to-pull device (EPTP) were performed, as shown in Figure 1 (a) [6]. A Bruker, Inc. Picoindenter with Nanoscale Electrical Contact Resistance (nanoECR) TEM holder was used within a JEOL 3010 TEM. Specific loading and observation directions were selected for the Ti-6Al dog-bone shaped specimens with electron back scattering (EBSD). Focused ion beam (FIB) lift-out is then used to attach the sample to the E-PTP device as shown in Figure 1 (b-c). The specimens were deformed uniaxially in tension, with the special “markers” designed to precisely measure the elongation. A sequence of tests was carried out by load control and with variable electrical current pulsing during the mechanical test. An example load function vs time is shown in Figure 1 (d). After each test, videos of the dislocation behavior could be directly compared to the electrical and mechanical data. This setup and control of parameters enabled us to correlate direct observations of dislocation dynamic change with both mechanical data and applied electrical pulses to provide clarity on the true origin of this phenomenon.

By analyzing the frame-by-frame videos with collected mechanical and electrical data, we found that deformation mechanisms and dislocation behaviors were changed during the pulsing period. Relatively large slip traces with existed and nucleated dislocations movement were seen during the tests. During pure mechanical tension, less slip directions is activated, and dislocation motions tend to be concentrated at a single stress localization area, shown in Figure 2 (a). Upon applying electrical current, other slip directions in the HCP system are activated, shown in Figure 2 (b). With the increasing of current density, plastic deformation in the form of dislocation motion can be seen in more slip planes, indicating the effect of electrical current can make the plastic deformation on the metal piece more uniform, as shown in Figure 2 (c). Other observations aiming to separate the electron wind effect and Joule heating effect will be discussed later [6].

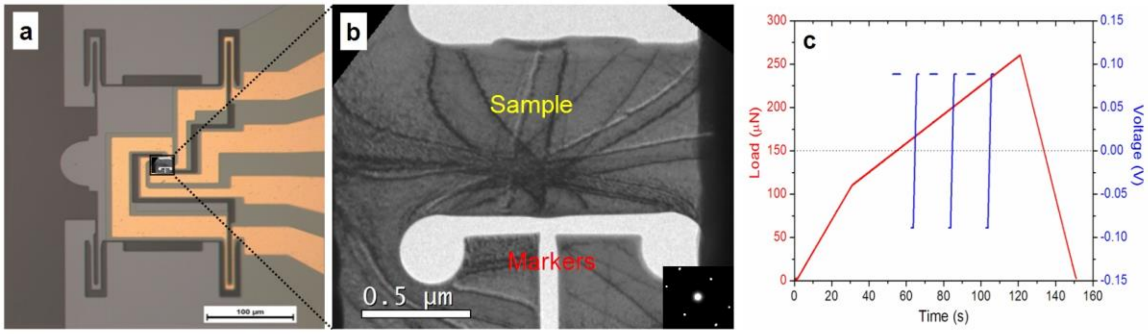

Figure 1. Experiment setup. (a) The electric push-to-pull (E-PTP) device, (b) lift-out metal thin Al foil and (c) modified dog-bone shape with a hole for localization of stress for dislocation observation in TEM. (d) Load function vs time with current pulse applied during the tension test.

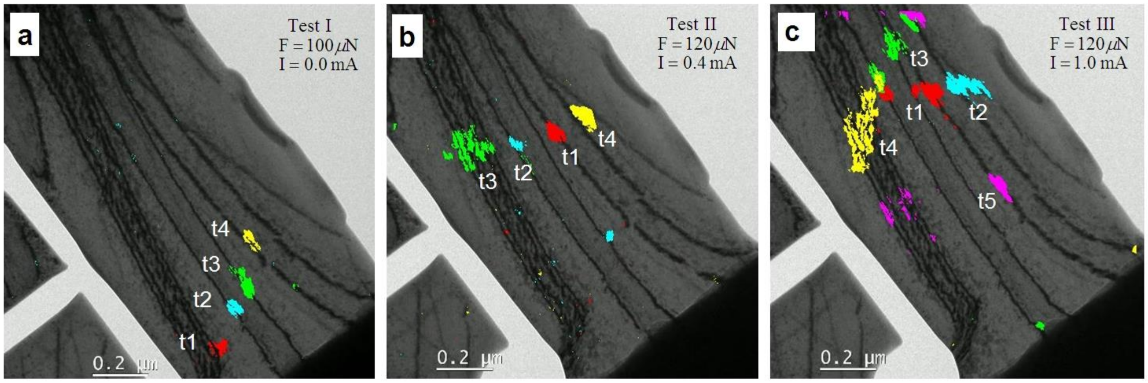

Figure 2. Dislocation pattern in selected frames with different applied current density. The red and green color mark out the change of contrast between two frames, indicating dislocation motion. (a) frame with no current, dislocation glide is activated in one slip direction, (b) frame with a current density of 100A/cm^2, (c) frame with a current density of 250A/cm^2.

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