Electric Current Effect on the Materials Stability of Pure Aluminum and 7075 Aluminum Alloy: an *in situ* Study

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Abstract

Electric current is intimate to human's life and several corresponding effects have been well-discovered theoretically in history such as Joule heating. In the era of integrated circuit (IC) development, people found that electric current would alter materials' microstructure and its properties. The most significant issue is caused by the electromigration (EM) effect, which is the atomic migration induced by electric current. Atoms would move along the electron flow direction from the cathode to the anode, and therefore people observed the void and hillock formation on the interconnections. These voids and hillocks are detrimental to IC industry due to the open and short circuit issue. People also discovered that electric current would change the phase stability of materials, e.g. in Pb-Sn [1], Ag-Cu [2] binary system, and would directly change their properties. However, the fundamental understanding to the electric current effect on the materials stability is under development and still insufficient [3-4]. The aim of this study is to study the lattice stability under electric current of aluminum (Al) because Al is a key interconnection material in IC industry. We specifically revisited the mechanism of so-called "Blech critical product", which is the product of current density and strip length as the criteria for EM occurrence [5]. The key issue behind the mechanism is that the model seems not general to the extreme long strip length [6]. We found the critical product failed to predict the EM occurrence when the strips were 5000 microns long or longer. We further characterized the lattice strain of pure Al strip in a variety of lengths from microns to centimeters using *in situ* current-stressing synchrotron radiation-based X-ray diffraction. The results show that it seems to be a critical lattice strain value, i.e. 0.008, for EM occurrence, rather than current density, voltage, or Blech critical product. First principles calculation shows that the critical lattice strain would significantly lower the migration barrier. This could be the possible reason that cause the critical condition of EM occurrence. With the understanding of the electric current effect upon pure Al, we further applied electric current to 7075 Al alloy under high-speed impact, where *in situ* Hopkinson pressure bar was performed. Results showed that deformed AA7075-T6 samples with electric current passing through could endure larger plastic deformation, while the ones without electric current were severely shattered. We found precipitations formed at the sub-grain boundary diminished in the deformed alloy with electric current assisted with TEM analysis. The pole figure analysis via EBSD suggested that the alloys deformed without electric current assisted had a twin-like orientation while the ones with electric current assisted had a more random orientation. Overall, we show the potential of using electric current to enhance the impact-resistance of Al-alloy.

Keywords: in situ synchrotron radiation-based X-ray diffraction, electromigration, Blech critical product, lattice strain, high-speed impact.

References

[1] *S.-K. Lin et al., "Ab initio-aided CALPHAD thermodynamic modeling of the Sn-Pb binary system under current stressing", Scientific Reports 3, 2731 (2013).
[2] Y.-C. Liu et al., "Electromigration effect upon single- and two-phase Ag-Cu alloy strips: an in situ study", Scripta Materialia, 173, 134-138 (2019).
[3] Lin, S.-k., et al., "The electromigration effect revisited: non-uniform local tensile stress-driven diffusion." Scientific reports 7(1): 1-10 (2017).
[4] Y.-C. Liu, et al., "On the Schmid's Law for the electric current-induced deformation: An in situ EBSD study", International Journal of Mechanical Sciences, 168, 105295 (2020).
[5] Y.-C. Liu and *S.-K. Lin, "A Critical Review on the Electromigration Effect, the Electroplastic Effect, and Perspectives on Effect of Electric Current upon Alloy Phase Stability", JOM, 71(9), 3094-3106 P.1-13 (2019).
[6] Blech, I. A. "Electromigration in thin aluminum films on titanium nitride." Journal of applied physics 47(4): 1203-1208. (1976).