Stress Creation During NiMn Electrodeposition

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Motivation—Stress creation during thin film deposition has been a concern for over a century due to the limits it places on applications. This is particularly true for electrodeposited films such as Ni and its alloys, for which stresses range from hundreds of MPa compression to hundreds of MPa tension depending on the bath chemistry and growth conditions. Recent efforts to increase the high-temperature (~600°C) strength of Ni have utilized co-deposition of 1 to 2 at% Mn during plating, but the resultant alloy possesses a significantly higher tensile stress. To overcome this, pulse plating procedures were developed that reduce the mean film stress. However, in these studies, there were no investigations into the actual stress evolution during deposition or the possible sources of these stresses. In this report, we have correlated the stress evolution during electrodeposition of NiMn with *ex-situ* microstructural measurements to examine the source of stress active during electrodeposition.

Accomplishment—The stress evolution and microstructure of NiMn electrodeposited from a sulfamate-based bath was investigated as a function of Mn concentration and current density. As shown in Fig. 1, the NiMn stress evolution with film thickness exhibited an initial high transitional stress region, followed by a region of steady-state stress with a magnitude that depended on deposition rate, similar to the previously reported stress evolution in electrodeposited Ni (Hearne and Floro, *J. Appl. Phys.* **97**, 014901-1 (2005)). Based on transmission electron microscopy (TEM) analysis, it was determined that the transition stress was a result of the (111) NiMn grains growing semi-coherently with the underlying (111) Au grains, which resulted in a tensile stress during the early stages of growth. The origins of the steady-state stress are more difficult to identify. Figure 2 shows that the incorporation of increasing amounts of Mn resulted in a linear increase in the steady-state stress. Neither x-ray diffraction (XRD) nor TEM found any significant change in microstructure as a function of Mn concentration. Additionally, the observed increase in resistivity with Mn content was consistent with the weighted average resistivity of the two constituents. The only other trait that was observed to track with the manganese content was the XRD measured micro-stress, which was likely the result of lattice distortions due to the substitutional incorporation of Mn. We are currently performing atomistic simulations to verify this hypothesis. To conclude, we observed that the origins of the steady-state stress were not due to the microstructure, but were likely the result of point defect generation, and/or grain boundary coalescence. Research is ongoing to validate this hypothesis.

Significance—Understanding the origins of stress is critical in setting the bounds for device fabrication and application. This is particularly true for systems such as NiMn, where the primary goal is enhanced mechanical strength. This work has provided a foundation for the understanding of the physical processes creating stress during growth as a function of deposition conditions. Through this enhanced understanding, we will help to make more reproducible microsystems from electro-deposited metals–like the components formed in precision molds by the LIGA process and metal MEMS structures used in RF communications.

Sponsors for various phases of this work include: DOE Office of Basic Energy Sciences, Laboratory Directed Research & Development, and Nuclear Weapons/LIGA

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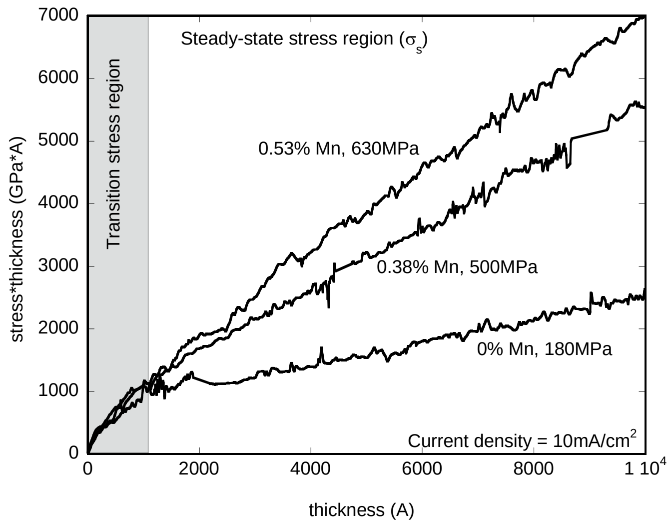

Figure 1. Stress-thickness versus thickness plot for three samples grown using a 5.0 g/L Mn bath. The upper and lower curves were deposited at constant rates of 15 mA/cm^2 and 3 mA/cm^2, respectively, and the current density in the middle curve was cycled between 15 mA/cm^2 and 3 mA/cm^2, for 0.67 sec. and 4.4 sec., respectively.

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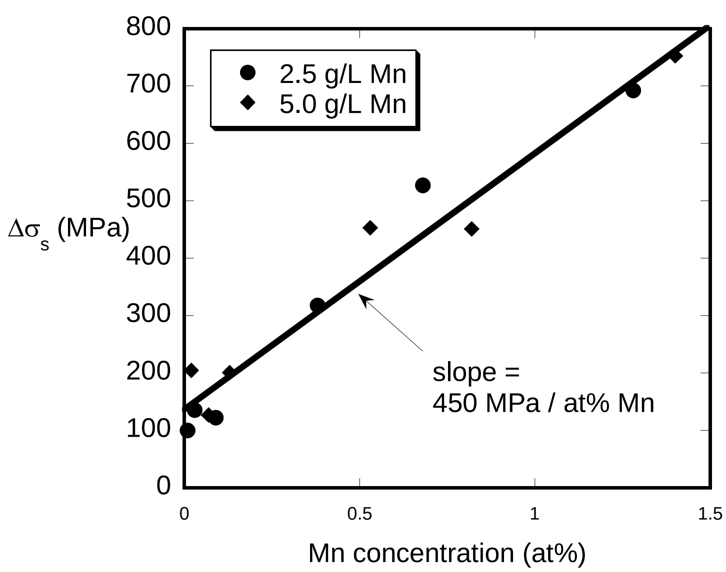

Figure 2. Difference between the σ_S stress as function of Mn concentration at constant current density for the three baths, 0 g/L Mn, 2.5 g/L Mn, and 5.0 g/L Mn.