## The Wire Beam Electrode: A Novel Method of Studying Nonuniform Electrodeposition and Electrodissolution

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Nonuniform electrodeposition and electrodissolution (NEE) result in a nonuniformly deposited or unevenly dissolved electrode surface that cannot meet functional and dimensional requirements. The ability to control NEE is the key to successful application of electrodeposition or electrodissolution techniques such as electroplating, 1 electroforming, electroetching, electropolishing and electromachining. NEE are resulted from nonuniform distribution of electrochemical reactions over an electrode surface, i.e. electrochemical It is critical to characterize such heterogeneity. electrochemical heterogeneity, however conventional electrochemical methods have major limitations in doing so since they are based on an ideally uniform one-piece The commonly electrode surface. employed mathematical modeling and the Hull cell methods <sup>2</sup> could not delineate clearly electrochemical heterogeneity.<sup>3</sup>

Attempting to solve this problem, an electrochemically integrated multi-electrode system, namely the wire beam electrode (WBE, Figure 1) 3-8 has been employed to simulate a conventional one-piece electrode surface under electroplating and to map copper electrodeposition currents.<sup>3</sup> Here the application of this novel method is further extended to include electrodissolution. Figure 1 shows an experimental setup where a WBE, made from 100 identical mild steel wires of 0.18 cm diameter, is used to detect local electroplating and electrodissolution reaction currents. Nickel electroplating was carried out under potentiostatic control with the WBE as cathode and a saturated calomel electrode (SCE) as the reference electrode. A fine platinum wire was used as an inert anode that exposed only its tip to the electroplating solution and was placed close to wire 1 (about 4 mm from wire 1). The WBE was immersed in 800 mL of Watts bath  $^1$  (329.79 g/L NiSO4·6H2O; 45.04 g/L NiCl2·6H2O and 37.94 g/L H<sub>3</sub>BO<sub>3</sub>) under static conditions at 47-52 °C. The distribution of impressed electroplating current (Ik for wire k) was measured by connecting a zero resistance ammeter in sequence between a chosen individual wire terminal and all other terminals shorted together using a computer-controlled automatic switch.



Figure 1. Electroplating and electrodissolution experimental setup.

Figure 2 shows typical maps of nonuniform current distribution of nickel electroplating. It is clearly shown that electroplating currents (cathodic reaction currents) are nonuniformly distributed over the WBE surface. A common feature is that higher cathodic currents were concentrated at the edges of the WBE surface and lower cathodic currents were recorded in the central area of the This clearly suggests that the geometry of WBE. electroplating cell was not the controlling factor of electroplating current distribution since electroplating currents did not center at wire 1 location, where the anode wire was closely placed. This result suggests that 'secondary' current distribution played a major role in determining electrodeposition current distribution. The edges of the WBE surface had a more sufficient supply of cathodic reaction species through 3-dimensional diffusion and thus they allow higher cathodic reaction rates. This electroplating current distribution pattern is in agreement with a well-known phenomenon that electroplating currents tend to concentrate at edges of a workpiece.



(Fig. 2a)

(Fig. 2b)

Figure 2. Current distribution maps from a WBE after nickel electroplating for approximately (a) 0.5 hour and (b) 1.5 hour (Polarization voltage: -40 mV)

After electroplating was completed, the polarization was changed from cathodic to anodic and thus the WBE surface was under anodic dissolution (in the same bath). Figure 3 shows typical anodic current distribution maps recorded from the nickel-plated WBE. No specific pattern was observable although active dissolution spots were clearly observed. The active dissolution area appeared to be under expansion over the electrodissolution period.



Figure 3. Current distribution maps from a nickel-plated WBE under anodic dissolution (+40 mV) for approximately (a) 10 minutes and (b) 1 hour.

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