Sputter Deposition of Porous Nanostructured Metals

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Porous films are of interest in several electrochemical systems, as in polymer exchange membrane and solid-oxide fuel cells. Thin film fuel cells by microfabrication processes have progressed to demonstration.[1,2] Porous thin films are used to reform hydrocarbon fuels and to function as conductive electrodes. For catalytic functions, in particular, the control of a three-dimensional structure at the nanoscale provides the means to produce materials with an ideal surface area to volume ratio. A ratio much greater than found in materials as produced by either conventional powder processing or as produced using photolithographic patterning and etching.[3]

Recently, a physical vapor deposition method has been developed to produce metallic films with continuous open porosity at the nanoscale.[4] The experimental parameters needed to control the porous nanostructure are found to be tractable and generic for many metals. In general, structural morphologies found for conventionally sputtered coatings can range from porous columnar to dense polycrystalline. The transition in morphology through four zones of growth occurs with increasing substrate temperature and sputter gas pressure. Zone 1 has a structure consisting of tapered crystallites separated by voids. A transition Zone T has a structure consisting of densely packed fibrous grains and a smooth surface. Zone 2 features continuous columns from the substrate to a surface characterized by crystalline facets. Lastly, Zone 3 represents the recrystallized grain structure. The primary effect of increased temperature is an enhancement of surface and bulk diffusion.

A new growth zone for the stabilization of a porous nanostructure is seen as a variant of Zones T and 2.[4] A three-dimensional polycrystalline deposit with continuous open porosity is produced under the general conditions of an increased working gas pressure and a substrate temperature approximately half the absolute melting point. The open-porosity morphology is demonstrated in as-deposited nanostructures of gold, silver, nickel, and aluminum.[4] New results are presented for copper – a base metal used in several catalytic materials for the direct reformation of methanol. The use of a moderate sputter gas pressure and an elevated substrate temperature yield a nanostructured metal with open porosity, i.e. *a metallic sponge*. The moderate sputter gas pressure creates a range of incident angles for deposition and the elevated temperature promotes a faceted crystalline growth. Results for a 5 μm thick copper coating are seen in plan view (Figs. 1-2) and cross-section (Figs. 3-4). Of interest, is the coarsening in grain size that occurs from the substrate to the surface. In summary, thin film deposition by sputtering provides a means to control the synthesis of a nanocrystalline metals with open porosity for use in energy conversion devices.

This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

1. A.F. Jankowski and J.D. Morse, *MRS Symp. Proc. 496 (1998) 155*.
2. A.F. Jankowski, et al., *ECS Proc. 99-19 (1999) 932*.
3. J.D. Morse, et al., *MRS Symp. Proc. 575 (2000) 321*.
4. A.F. Jankowski, “Sputter Deposition of Metallic Sponges”, *LLNL UCRL-JC-145843 (2002)*.

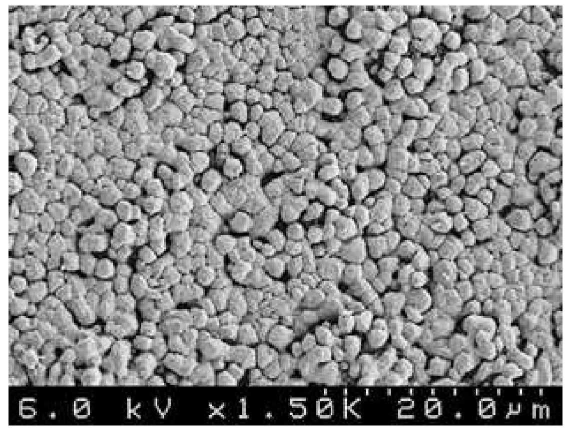

Fig. 1. The plan view image of copper produced from deposition at high temperature and sputter gas pressure.

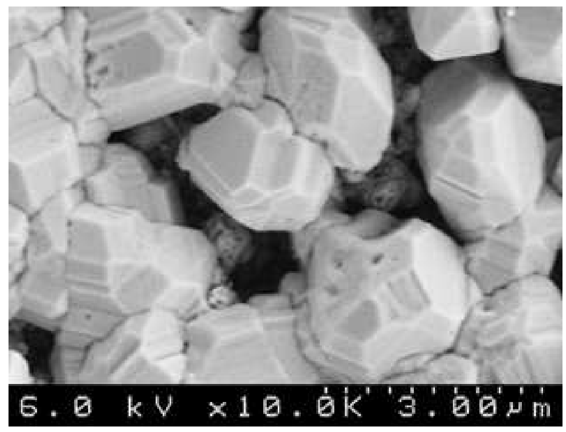

Fig. 2. A high-magnification plan view image (of Fig. 1) shows the open porosity of the porous copper coating.

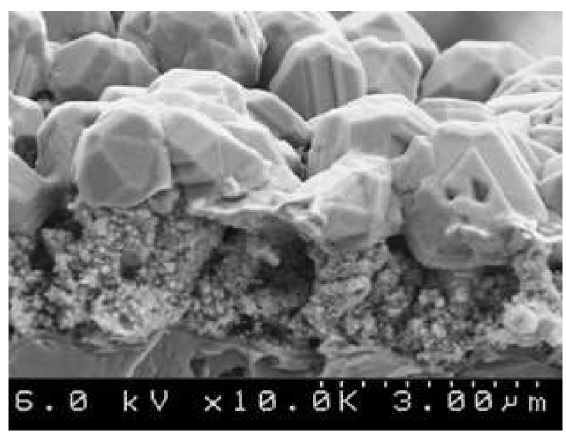

Fig. 3. A fracture cross-section shows the coarsening in crystal size through the porous copper coating.

Fig. 4. A higher magnification view (of Fig. 3) reveals the porous assembly of copper nanocrystals that forms at the base of the sputter deposited coating.