Construction of Fine Metallic Lattice Framework by Magneto-plating

Shinichi Yonemochi,*[1] Takuji Kondo,[2] Shiori Kubo,[3] Mikio Kawasaki,[1] and Toshio Nagoya[4]
[1]*Center for Environment Science in Saitama, 914 Kamitanadare, Kisai-machi, Kitasaitama-gun, Saitama 347-0115*
[2]*Industry-Academic Collaboration Support Center Saitama, 2-3-2 Kamiochiai, Chuo-ku, Saitama 338-0001*
[3]*National Institute for Advanced Industrial Science and Technology, 16-1 Onogawa, Tsukuba 305-8569*
[4]*Waseda University, 3-4-1 Okubo, Shinjuku-ku, Tokyo 169-8555*

(Received December 25, 2006; CL-061501; E-mail: a1073165@pref.saitama.lg.jp)

A fine metallic lattice framework was constructed by forming many fine projections on the upper and lower surfaces of a metal mesh by magnetoplating, in order to be used as an air purification material or a supporting material of a catalyst.

Recently, various emission regulations for air pollutants such as, particulate matter from diesel vehicles, exhaust gases from incinerations, and volatile organic compounds (VOCs) from various emission sources have been introduced. VOCs include different types of compounds. Therefore, various reduction methods such as burning with or without a catalyst and adsorption on activated carbons are used depending on the sizes of the source and the types of VOC. Burning requires heat control, and it poses the risk of an explosion. Adsorption requires the exchange of adsorption materials and recovering the activation in expense.

Titanium oxide, which is a typical photocatalyst,[1,2] has been considered to be an environmental catalyst[3,4] because it is activated by ultraviolet (UV) rays under mild conditions at room temperature and atmospheric pressure. However, it is not suitable for the decomposition of VOCs with high concentrations above the absorbed photon energy. In order to increase the decomposition rate, many researchers have created an effective shape for the photocatalyst or supporting materials. We have developed a material with many pillar-like structures on a flat metal surface under a high magnetic field in order to increase the surface area.[5] However, this shape poses two problems with regard to the decomposition of VOCs. The numerous projections block out many photocatalysts on the bottom surface and projection side from UV irradiation, and VOCs are accumulated near the bottom surface. To resolve these problems, shapes of the supporting photocatalyst should be modified.

We focus on a fine lattice shape. Lattice construction has two advantages: 1) VOCs are spread throughout the clearance of the lattice without accumulation, and 2) UV rays can be reflected by placing a mirror on the back side. Therefore, the back side of a material can be utilized for the decomposition of VOCs. As mentioned above, fine lattice construction is an attractive shape; however, it is difficult to create a three-dimensional shape by a machining process.

A commercially available metallic mesh was selected as the starting material. The objective was a development of a fine lattice structure by forming many fine projections in a direction perpendicular to the mesh plane, as shown in Figure 1. This paper reports a method for the formation of a fine metallic lattice structure by the application of the magnetic field effect and electroplating.

Figure 2 shows the schematic diagram of the magneto-plating apparatus. We used a neodymium magnet (Magna Co., Ltd.) with a diameter of 100 mm and a height of 15 mm, and the maximum magnetic flux density was 0.5 T. A homogeneous magnetic field should be used in order to form projections in a direction perpendicular to the mesh plane. Therefore, the distribution of the magnetic flux density of the neodymium magnet was measured first. As a result, the cathode was located at a distance of 3 mm from the upper surface of the magnet, where the magnetic flux density was 0.36 T. Copper meshes (60 × 60 mm) with mesh sizes of 32, 50, and 100 counts of clearance per inch were used. The test vessel was made of acrylic resin. Initially, the copper mesh with 32 counts of clearance per inch was rinsed with a mixture of nitric acid, sulfuric acid, and hydrochloric acid. After setting it in the vessel, 1.0 g of nickel particles with a diameter of 10 µm were spread directly over the copper mesh and arranged perpendicular to the mesh plane by using the neodymium magnet. The copper mesh was connected to a power supply (Potentio-galvanostat, PS-14, Tohogiken Co., Ltd.). A platinum plate (20 × 30 × 0.5 mm) was used as the anode. A hundred milliliters of 1.0 mol dm^{-3} copper sulfate solution was added, and electroplating was carried out at a constant current density of 8.4 A dm^{-2} for 120 min under the magnetic field. After plating, the sample was rinsed with ultrapure water. The samples thus prepared were observed using a scanning electron microscope with an energy-dispersive X-ray spectroscopy detector (SEM-EDX Type-N, Hitachi Co., Ltd.).

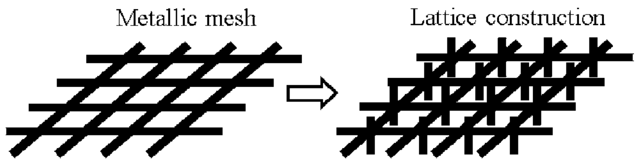

Figure 1. Concept of formation of the metallic lattice from the metallic mesh.

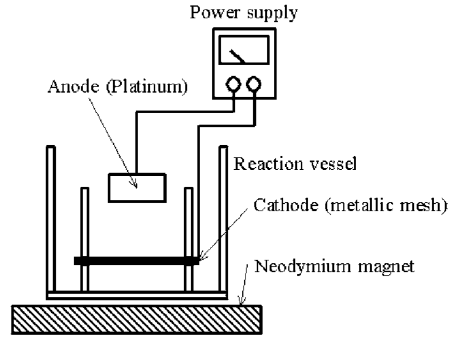

Figure 2. Schematic diagram of the magneto-plating apparatus.

(a)

(b)

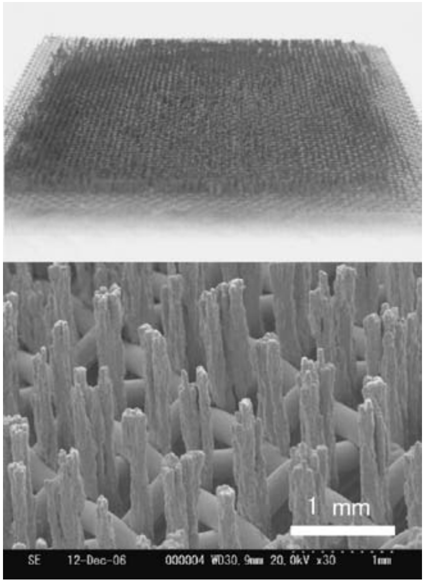

Figure 3. Photographs of the sample. A copper mesh (60 × 60 mm) with 32 counts of clearance per inch was used. (a) By CCD camera, (b) by SEM-EDX.

Photographs of the samples are shown in Figure 3. The fine metallic lattice framework was constructed successfully. Fine projections with a length of approximately 1 mm were formed on both sides of the copper mesh perpendicular to the mesh plane.

The mechanism of the formation of the lattice with many fine projections is shown in Figure 4. The electrolytic current flowed through nickel particles that were in contact with the copper mesh and arranged along the magnetic lines of force. Therefore, these particles were transformed into projections by the deposited copper crystals, which served as a binder. On the other hand, nickel particles that were not in contact with the copper mesh were not fixed and recovered in the form of powder by filtration or attraction by a magnetic force.

It is noteworthy that the projections were formed not only on the upper side but also below the mesh plane. This implies that electrolytic current flowed under the metallic mesh plane through the clearance of the copper mesh. Copper plating has often been used as a through-hole plating technique,[6] in which copper can be deposited in micropores using a supporting electrolyte with mechanical stirring. On the contrary, in our plating solution, only copper sulfate was used, and mechanical stirring was not carried out. Therefore, it is reasonable that another factor was effective in the absence of a supporting electrolyte and mechanical stirring. During the reactions on the electrode surface under the magnetic field, magneto-hydrodynamic (MHD) flow, and micro-MHD flow, which were induced by the current flow and the magnetic force,[7] were observed. The effect of these flows would be the same as that of the supporting electrolyte and mechanical stirring. It was reported that the size of the deposited copper crystals are relatively small and the plating surface is smoothened under the magnetic field.[8] Recently, this effect is known as the MHD effect or the micro-MHD effect.

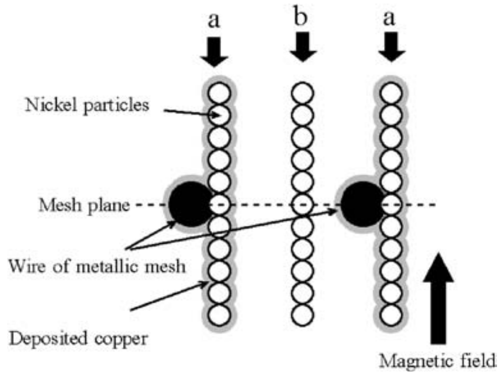

Figure 4. Formation mechanism of fine metallic lattice structure by magneto-plating. a) Nickel particles oriented along the magnetic lines of force were fixed by the deposition of copper metal. b) Nickel particles were not fixed because copper metal was not deposited.

In fact, the visible circulation of the plating solution, which was not thermal convection, was observed clearly during plating in the magnetic field. Therefore, under our plating condition, these flows could enable the formation of the lattice. Hence, the magneto-plating process had two effects on the formation of the fine metallic lattice structure; 1) alignment of nickel particles along the magnetic lines of force and 2) fixation of nickel particles in contact with the copper mesh by copper plating with MHD or micro MHD effects. We attempted to form the lattice by using copper meshes with 50 and 100 counts of clearance per inch and the same method. When the mesh with 100 counts of clearance per inch was used, the clearances were almost entirely filled with deposited copper crystals.

The fixation of a photocatalyst on this material and the decomposition of VOCs by this material are under investigation. These materials can be used in various fields, for example, in the manufacture of novel filters and heat sinks.

We thank the Japan Science and Technology Agency for providing financial support under Research for Promoting Technological Seeds.

References

1 A. Fujishima, K. Honda, *Nature* **1972**, *238*, 37.
2 R. Wang, K. Hashimoto, A. Fujishima, M. Chikuni, E. Kojima, A. Kitamura, M. Shimohigoshi, T. Watanabe, *Nature* **1997**, *388*, 431.
3 K. Takeuchi, T. Ibusuki, *Atmos. Environ.* **1986**, *20*, 1155.
4 R. M. Alberici, W. F. Jardim, *Appl. Catal., B* **1997**, *14*, 55.
5 S. Yonemochi, A. Sugiyama, K. Kawamura, T. Nagoya, R. Aogaki, *J. Appl. Electrochem.* **2004**, *34*, 1279.
6 M. Carano, *Plat. Surf. Finish.* **1994**, *81*, 23.
7 R. Aogaki, A. Tadano, K. Shinohara, in *Fluid Mechanics and Its Applications, Transfer Phenomena in Magnetohydrodynamics and Electroconducting Flows*, ed. by A. Alemany, Ph. Marty, J. P. Thibault, Kluwer Academic Publishers, Dordrecht, **1999**, Vol. 51, p. 169.
8 H. Takeo, J. Dash, S. Duan, *Proc. of the 2nd International Conference on Hydrometallurgy*, **1992**, Vol. 2, p. 821.

Published on the web (Advance View) March 3, 2007; doi:10.1246/cl.2007.492