Electrostatic assisted formation of porous ceramic film

G. LI
Institute of Electrostatics, Dalian University of Technology, 116024 Dalian, People's Republic of China
E-mail: liguofeng@mail.eco.tut.ac.jp

K. TAKASHIMA, S. KATSURA, A. MIZUNO
Department of Ecological Engineering, Toyohashi University of Technology, Tempaku-cho, Toyohashi, Aichi 441-8580, Japan

Porous oxide ceramics are important for a variety of applications such as thermal insulation, filtration, biomedical, and catalyst substrates. These ceramics may be classified into four basic structures: tangled fiber networks, closed cell structures, open cell structures, and membranes [1]. The structures of porous ceramics are controlled by their processing. In some processes, electrostatic field is used to control the formation of porous materials. Yamamoto and Masuda [2, 3] reported a new method, Electrostatic formation of ceramic membrane (EFCM), in which ultrafine particles synthesized by thermally activated chemical vapor deposition (CVD) were deposited on a porous ceramic tube by electrostatic force. Chen *et al.* [4, 5] reported the use of electrostatic spray deposition (ESD) to fabricate various porous thin films with reticular structure from chemical precursor solution. Su and Choy [6] used commercial sol solution to fabricate porous films via EAAD (Electrostatic assisted aerosol-gel deposition) technique. In this letter, we report a novel method, termed Electrostatic dry deposition (EDD), which will be simpler than the above methods, to produce porous ceramic film.

In the EDD, well-dispersed fine Al_2O_3 particles are carried by ambient gas (N_2) into the gap between electrodes. Dispersion is achieved by accelerating particles within a compressed N_2 stream, together with particle and wall collision. Under the action of an electric field, dielectric particles become polarized, and at close spacing, form particle chains owing to the dipole–dipole interactions. A porous layer will be formed due to the deposition of the chain aggregates.

Al_2O_3 fine powders are chosen as coating materials, having average particle size 0.5 μm in diameter. Fig. 1 shows the schematic diagram of the experimental setup, which includes two parts: powder jet feeder and coating chamber. The powder jet feeder consists of a powder container (1) and a nozzle (4). The particles pass through the nozzle (0.5 mm in diameter) accompanied with a jet of carrier gas (N_2), and then impact onto the back of the substrate holder (6). Dispersed particles pass through the wall of a stainless steel sieve cylinder (5), 2 cm in diameter, 5 cm in length, 400 mesh in pore size. Then, the particles enter into the coating chamber in which DC high voltage is imposed. The electrode configuration is point-plane. The point electrode (8) is a 1 mm wire with hemispherical tip and the plane electrode (6), which also acts as the substrate holder, is 5 cm in diameter. Under this configuration, the onset potential of corona discharge is about 9 kV. The electrode assembly is sealed in a transparent plastic chamber (11), 10 × 8 × 14 cm in volume. Alumina substrate (7) (10 × 10 × 3 mm in size) is placed on the plane electrode.

Fig. 2 shows the SEM micrographs of Al_2O_3 particle layers deposited on alumina substrate using different particle concentration after sintering. It can be observed that a tangled fiber network composed of particle chains, a structure peculiar to electrostatic deposition, covers the substrate. The pore structure is influenced by the particle concentration. In the same deposition time, 1 min in this experiment, the structure of Fig. 2b is better than that of Fig. 2a, which was obtained under the particle concentrations 100 and 20 g/m^3, respectively while the N_2 gas pressure was kept at 1 atm. The deposition rate of Fig. 2b is about 10 μm/min, which is a very fast process. In the deposition process, one important operation is to control the applied voltage so that corona discharge does not take place. It is obvious that charged particles with the same sign repulse each other and hinder the formation of chain aggregates. To avoid corona generation, 8 kV, DC potential was imposed on the point electrode, which is lower than the onset voltage (9 kV) of corona discharge. The formation of such a unique structure can be explained with the physical model illustrated in Fig. 3. A polarized particle causes the distortion of the applied field in its vicinity, and attracts other particles owing to the non-uniform field

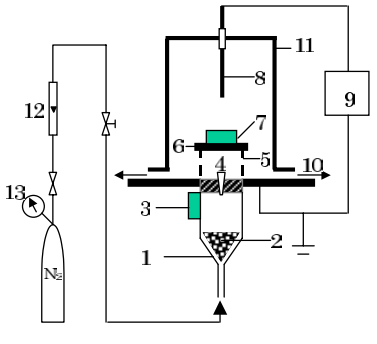

Figure 1 Experimental Setup. 1. Powder container, 2. Powder, 3. Vibrator, 4. Nozzle (0.5 mm inner diameter), 5. Sieve cylinder (Stainless steel, 400 mesh in pore size), 6. Substrate holder (Copper), 7. Substrate, 8. High-voltage electrode, 9. DC high voltage power supply, 10. Gas outlet, 11. Plastic chamber, 12. Flow meter, and 13. Gas regulator.

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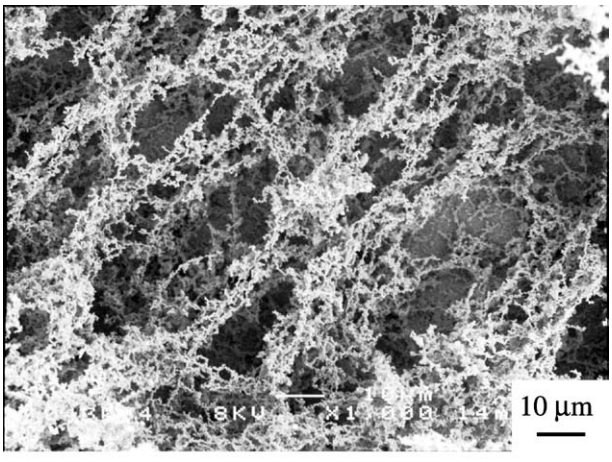
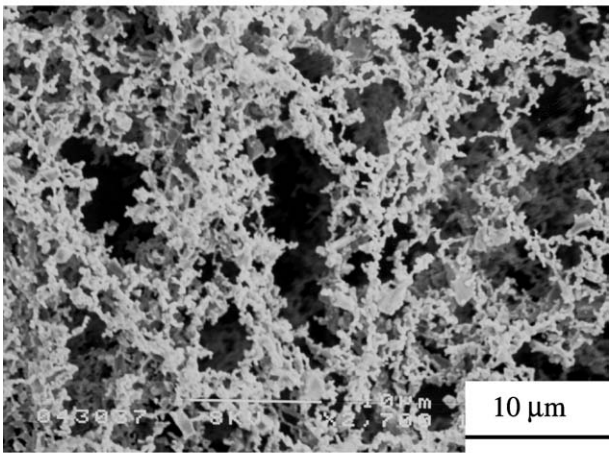


(a)



(b)

Figure 2 SEM micrographs of the particle layers with reticular structures. The layers were deposited at different particle concentration: (a) 20 g/m^3 and (b) 100 g/m^3.

produced by the polarized particle [7, 8]. It had been reported that in electric field the concentration of particles for chain forming in gas phase should be larger than 50 mg/m^3 [9, 10]. The particle concentration used in this experiment is much higher than this value. Consequently, closely spaced polarized particles attract each other and align parallel to the imposed electric field in the form of chain aggregates. Then the aggregates deposit onto the substrate under the action of the electrostatic force and gravitation force.

The deposition and sintering was carried out separately in this experiment. In the sintering process, the heating rate was 500 °C/h, the sintering temperature 1400 °C, and the sintering time 2 h. These parameters were determined in an empirical way by observing the resultant structure. The particle layer was tightly sintered on the substrate. After sintering, the field-induced chain aggregates became fiber-like. More importantly

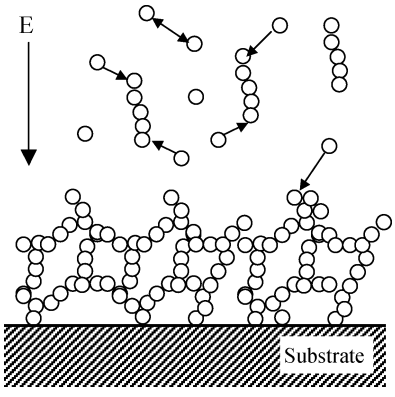


Figure 3 A schematic diagram of the formation and deposition of chain aggregates. ○: Represent polarized Al_2O_3 particle; E: external electric field.

the structure resulting from the electrostatic deposition remained.

In summary, the features of the method are: (1) Fine dielectric particles are prepared from dry powder dispersion. This means that many kinds of commercial powder products can be used directly in this method. (2) The formation of chain aggregates of fine dielectric particles can be controlled with electrostatic forces. The deposition of the chain aggregates onto material surface will provide a novel and promising option for the fabrication of porous ceramics. (3) Sintering is used to sinter particles together and increase the mechanical strength of the formed layer without using any additive.

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References

1. D. A. HIRSCHFELD, T. K. LI and D. M. LIU, *Key Engng. Mater.* **115** (1996) 65.
2. H. YAMAMOTO and S. MASUDA, *IEEE Trans. Ind. Appl.* **27** (1991) 307.
3. *Idem.*, *Ceram. Trans.* **31** (1993) 305.
4. C. H. CHEN, E. M. KELDER and J. SCHOONMAN, *J. Mater. Sci.* **31** (1996) 5437.
5. *Idem.*, *J. Electrochem. Soc.* **144**(11) (1997) L289.
6. B. SU and K. L. CHOY, *J. Mater. Sci. Lett.* **18** (1999) 1705.
7. T. B. JONES, R. D. MILLER, K. S. ROBINSON and W. Y. FOWLKES, *J. Electrostat.* **22** (1989) 231.
8. Y. NAKAJIMA and T. MATSUYAMA, *ibid.* **55** (2002) 203.
9. G. ZEBEL, *Staub* **23** (1963) 263.
10. R. FLOSSMANN and A. SCHÜTZ, *ibid.* **23** (1963) 443.

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