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Technical note

Particle size separation by alternating electrophoretic deposition

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Abstract

This paper describes a study of the size distribution of the particles deposited under different frequencies by alternating electrophoretic deposition. A low concentration suspension of SnO_2 particles was prepared in acetone and particles of SnO_2 were deposited on electrodes by the low frequency alternating electrophoretic deposition method. Scanning electron microscopy (SEM) showed that increasing the frequency from 0 to 1000 Hz reduces the average size of the SnO_2 particles deposited. Particle size distributions obtained from the SEM images show the sizing capability of the alternating electrophoretic deposition method.

Keywords: Alternating electrophoretic deposition; ACEPD; Particle size separation

1. Introduction

Numerous research efforts in electrokinetics have focused on the interaction between an electric field and the particles in a liquid medium. Electrophoresis is a well known electrokinetics phenomena and forms the basis of electrophoretic deposition (EPD). The EPD technique has been in use over the last 100 years for the deposition and preparation of thick films from different materials.[1,2] In EPD, a uniform DC electric field is applied to a liquid medium whereby its particles migrate and deposit on one of the two electrodes. Techniques based on electrophoresis are also used for separation of organic macro-molecules,[3,4] but no studies have been reported of separation of fine ceramic particles with different EPD parameters.

In our previous work, we showed that low frequency ($0\,Hz < f < 1000\,Hz$) alternating electrophoretic deposition (ACEPD) is a cheap and an easy technique for thick film deposition on the surface of and in the gap between two parallel surface electrodes.[5] In this work, we show that the low frequency ACEPD technique is capable of separating particles of different sizes from each other.

2. Experimental

Two parallel surface electrodes on a non-conductive base were used for the deposition (Fig. 1). These electrodes were prepared on a borosilicate glass using commercial gold paste (Degussa, GZ117). The gold layer was dried and stabilized by firing at 610 °C for 1 h. A gap of about 150 μm was created by a sharp alumina tip on the gold layer. Misconnection and leakage of current between the two shaped electrodes was tested and measured at 400 °C. The current leakage between the two electrodes was found to be less than 0.2 μA.

SnO_2 nanopowder (MERCK #7818) and pure acetone (MERCK #12) were used as dispersing powder and liquid media, respectively. An SEM image of the SnO_2 nanopowder employed is shown in Fig. 2. XRD confirmed that the SnO_2 powder (Siemens, D500) was made up of a cassiterite structure. Our previous work carries a description of the technique for preparation of the suspension and a schematic illustration of the ACEPD cell.[5,6]

Particles were deposited in the suspension at 40 V for 10 min at different frequencies (1 Hz, 100 Hz, 500 Hz, and 1000 Hz). By means of ultrasonic vibration the deposited particles were separated from the electrodes and dispersed in deionized water. The suspended particles were deposited on an alumina foil by the sedimentation technique and dried at ambient temperature. These samples were examined by SEM. The average size of

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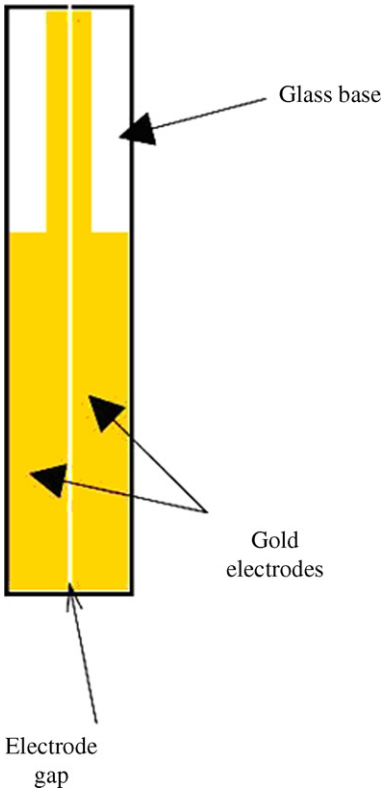

Fig. 1. Schematic illustration of the gold electrodes on a non-conductive base.

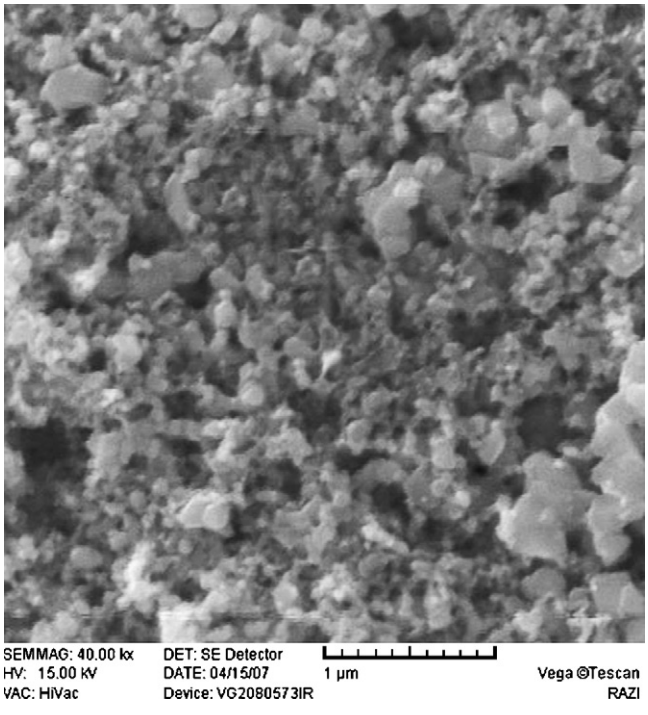

Fig. 2. SEM image of SnO_2 nanopowder.

deposited particles was read from the SEM images and the particle size distribution curves were plotted. For this purpose, each curve was constructed from at least 1000 measurements.

3. Results and discussion

The surface charge on a particle is due to an electrical double layer consisting of counter-ionic charges. By applying an electric field, particles accelerate from a net-zero speed to a constant velocity (limit speed) and attain a steady state condition. The force opposing the movement of particles is the viscous retardation force, which is commonly characterized by Stoke's law. This force compels the particles to move at a constant speed. Any change in this fixed velocity can only arise from a change in the force acting on the particles.

Application of an AC electric field makes the particles move an equal distance in each half cycle but in opposite directions. At high frequencies, the time needed for the particles to change the direction of migration is insufficient. But at low frequencies, the particles and the free charges have ample time to respond to reversal of the electric field. In an AC electric field, movement due to the coulomb force must be oscillatory and proportional to the applied wave form. This force is proportional to the charge of the particles and the applied electric field. Thus, by applying a low frequency AC electric field in the first half of the cycle, particles have the chance to migrate toward and deposit on one of the electrodes and in the next half cycle their destination changes to the other electrode. By changing the direction of the applied electric field, the direction of migration reverses and after the particles realign, the migration resumes and the particles again accelerate from zero to a limit speed. Compared to small particles, the coarser particles require more time to attain the mentioned limit speed and higher inertia causes more delay for particles motion to change direction. In DC electrophoresis the effect of time spent for starting acceleration is negligible in comparison to the total time required for the migration of particles; the time required for migration mostly depends on the mobility of the particles in the steady state condition according to the limit speed imposed on the particles in the media under the influence of the applied electric field. In ACEPD, the response of the particles to the alternating field plays an important role in their deposition. The distance moved by the particles in the ACEPD depends on the alternating electric field and the viscous retardation force may be a phenomenon that separates the particles based on their size, shape, surface characteristics, and their composition. The migration time particles require in each half cycle of the applied electric field is a characteristic for each particle and is different for different particle sizes. Thus, dynamic separation of the particles is achieved.

The SEM images of the particles deposited at different frequencies are shown in Fig. 3; they show that increasing the frequency of deposition resulted in deposition of smaller particles.

In other words, sizes of the deposited particles read from the SEM images and the particle size distribution curves obtained are shown in Fig. 4. According to Fig. 4, the particle size distri-

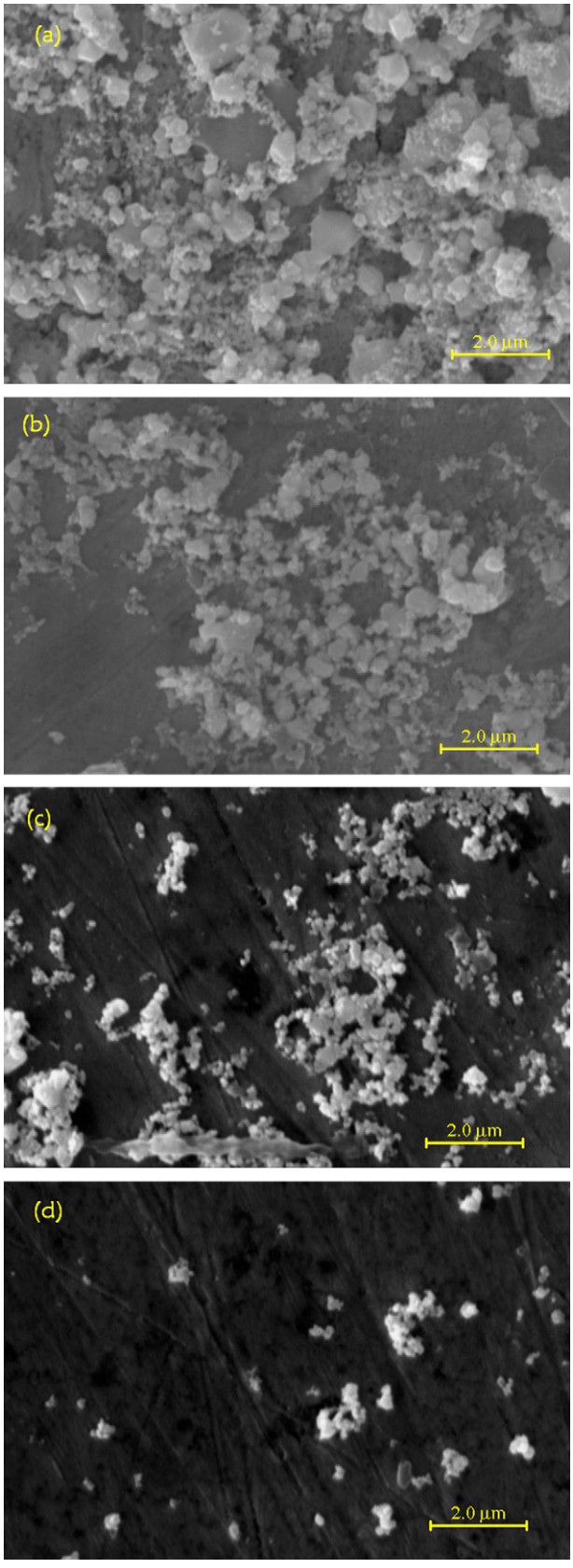

Fig. 3. SEM images of particles deposited at 40 V, 10 min and (a) 1 Hz, (b) 100 Hz, (c) 500 Hz, and (d) 1000 Hz.

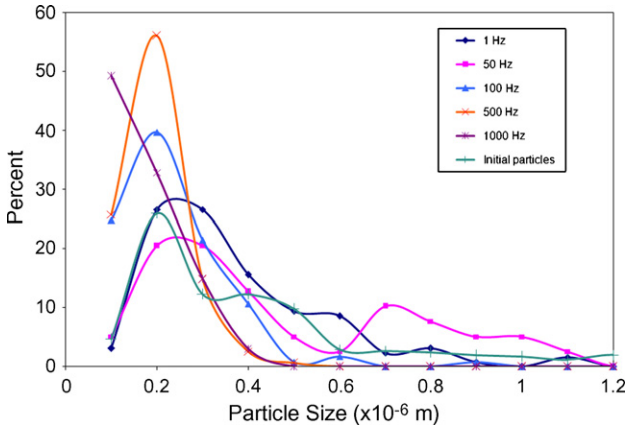

Fig. 4. Particle size distribution charts corresponding to SEM images shown in Fig. 3.

bution curve changes to smaller sizes with increasing frequency of the ACEPD deposition process. Thus, it is possible to separate the coarse particles using frequency. Hence, this is a method for sizing of nanoparticles.

4. Conclusion

The ACEPD method was used for deposition of SnO_2 particles. It was shown that by increasing the frequency of the electric field in the deposition process, the distribution size curve of the deposited particles changed to smaller sizes. This phenomenon is a consequence of the relation between the size and the displacement of the particles in liquid media that is determined by the applied electric field and the opposing fluid force. From this it can be seen that this method can be used for particle sizing.

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