1. Introduction

When paramagnetic particles are placed on a substrate and a rotational magnetic field, the rotational plane of which is perpendicular to the substrate, is applied, the particles form chain clusters due to the dipole-dipole interaction and start to rotate on the substrate. The structures and motion of the clusters can be controlled by the rotational magnetic field [1]. It is very important from surface chemical and physical points of view to understand the interactions between nanomaterials since the ratio of surface to volume increases as the size of materials decreases down to nano scales. The presently existing analytical methodologies such as XPS, AES and AFM are extremely useful to understand the surface chemical and physical conditions [2]. However, it is necessary to develop some innovative in situ methodology to measure the surface conditions; e.g., the zeta potentials and chemical reactions, of nano/micro materials and devices without damaging their original morphologies.

In the present study, one basic methodology is proposed to evaluate the surface conditions of materials on nano/micro scales utilising the change in the dynamics of magnetic particles induced by a rotational magnetic field. The dependence of the velocity of clusters composed of the magnetic particles on the surface conditions of a substrate is investigated and clarified. It is supposed that the present methodology may well be utilised to biomedical studies such as the detection of diseases and allergies.

2. Experimental methods

A schematic diagram of the experimental system is shown in Fig. 1. FITC-labelled antibody molecules were immobilised onto one region of the surface of the microchannel. After the modification of the antibody molecules, the microchannel was removed from the glass substrate and PDMS was placed on the modified area. 100 µl paramagnetic particles’ solution was injected into the well. The particles were dispersed in water or buffer solution of pH = 4.0 to 9.0. The test well was placed at the centre of two pairs of coils and a rotational magnetic field, the rotational plane of which was perpendicular to the surface of the substrate, was applied to the test well. A cluster composed of two magnetic particles was moved from no antibody area to the antibody coated area. The motion of the cluster was observed and recorded by an inverted microscope and a camera. Then, the velocity of the cluster moving along the surface with or without the antibody molecules was measured.

3. Results and discussion

A snapshot of a glass substrate, which was modified with the FITC–labelled antibody molecules, is shown in Fig. 2. The image clearly shows that the antibody was successfully coated on the selected region of the microchannel.

The velocity of 5 clusters along the substrate with and without the antibody molecules is shown in Fig. 3. The velocity of the clusters moving along the substrate, which had been modified with the antibody molecules, was 7.5 % higher than that of the
clusters along the substrate without any antibody molecules, which suggests that the difference in the surface conditions can be detected by the measurement of the velocity of the clusters.

It is supposed that the difference in the velocity was caused by the difference in the electrostatic conditions on the surface of the substrate and therefore the zeta potential of the substrate was measured. The zeta potential of the substrate modified with the antibody molecules was -13.83 mV, whereas that without any antibody was -15.8 mV. Since the present magnetic particles were negatively charged, it is supposed that the difference in the velocity was induced by the repulsive forces acting on the magnetic particles.

The effect of the difference in the pH of the buffer solution on the velocity of the clusters was also investigated (see Fig. 3). The velocity of the clusters in the solution of pH9 was 1.6% higher than that in the solution of pH7, whereas the clusters did not move at all in the solution of pH4 since the clusters were attracted by the substrate via electrostatic force.

4. Summary
The dynamics of clusters composed of paramagnetic particles induced by a rotational magnetic field on a substrate with/without chemical modification was experimentally investigated.

The dynamics of clusters composed of magnetic particles was successfully controlled by the application of an external rotational magnetic field. The velocity of the clusters was highly sensitive to the surface conditions, in particular, the zeta potential of the substrate. A method of detecting the difference in the zeta potential may well be developed based on the present result.

References

Academic activities