

Colored Magnetic Janus Particles

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SUMMARY The aim of this research is realizing a high resolution and a fast color switching of electronic papers. In this report, we realized basis of electric papers comprised on magnetic Janus particles was established. Colored and magnetic Janus particles were successfully prepared, and magnetic Janus particles were introduced into honeycomb matrices. Introduced magnetic Janus particles quickly respond to an external magnetic field.

key words: *electronic papers, twisting ball, janus particles, magnetic, colored*

1. Introduction

Electronic paper is one of the thin, flexible and low energy consumption display devices [1]. There are many types of electronic papers depending on their driving systems of image displays. For example, one of the main electronic paper devices are using electrophoresis of dye pigments charged with negative or positive encapsulated in tens micrometer capsules [2]. Other system, using electrowetting [3], interference controlled by liquid crystals technologies [4] etc. have been reported. Twisting ball type electronic paper is one of the candidate for future electronic papers [5], in which the pixel color was changed by twisting charged Janus particles having two aspect hemispheres along to the electric field. This device requires simple architecture and low energy consumption, however, there are some drawbacks that low resolution due to the size of Janus particle are in tens micrometer scale, slow response due to the viscosity of dispersion media and monotone color. To improve these problems, Janus particles having small and quick response have been required.

The aim of this research is realizing a high resolution and a fast color switching twisting ball type electronic papers. Strong demand for high-resolution electric papers enforces developing materials, which allow realizing smaller pixels. The micron-sized Janus particles having reactivity for external stimuli can be applied to the particle rotation type electric paper that is one of the display methods in the electronics.

Many efforts have been done to create small, colorful, and stimuli-responsive Janus particles by using conventional emulsion polymerization and microfluidic devices. For example, Okubo et. al. have reported that Janus type of phase

separation was formed inside of the emulsion of two polymer solution and eventually solid Janus particles were obtained [6]. Furthermore, mixing two monomers by laminar flows in a microfluidic device followed by photo polymerization results in formation of polymer Janus particles [7]. We have also reported preparation of polymer Janus particles from two immiscible polymers by precipitating them into poor solvents from their solution [8]. Polystyrene and polyisoprene was dissolved in tetrahydrofane (THF) and then water was added as a poor solvent. After complete evaporation of THF, particles having PS or PI phase on each hemisphere were obtained. Furthermore, the Janus particles were functionalized polymer-stabilized iron oxide particles and titania particles [9], [10]. However, there is no colored Janus particles can be applicable to creating colorful displays.

In this report, we show colorful Janus particles responding to magnetic fields prepared from polystyrene (PS), polyisoprene (PI), and polymer-stabilized pigments and inorganic nanoparticles. Magnetic Janus particles were also introduced into micron-sized honeycomb matrices and their rotational motions along to the magnetic fields were demonstrated.

2. Experimental

Pigments (Pigment Red 5403, Phthalocyanine Green 3603, Cyanine Blue 6005) were kindly provided from SANYO COLOR WORKS, LTD. Pigments were solubilized in tetrahydrofane (THF) with polymer 1⁴. Fe₂O₃ nanoparticles were also solubilized in THF with polymer 2 (Fig. 1). The stabilized pigments or Fe₂O₃ nanoparticles were corrected with ultracentrifugation and supernatant was removed. The stabilized pigments or Fe₂O₃ nanoparticles were re-dispersed in THF at their concentration of 1.0 mg/mL.

Polystyrene (PS), polyisoprene (PI), were dissolved in

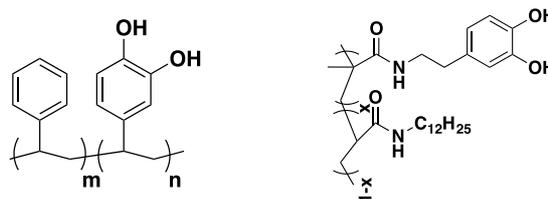


Fig. 1 Chemical Structure of Polymer 1 (left) and 2 (right).

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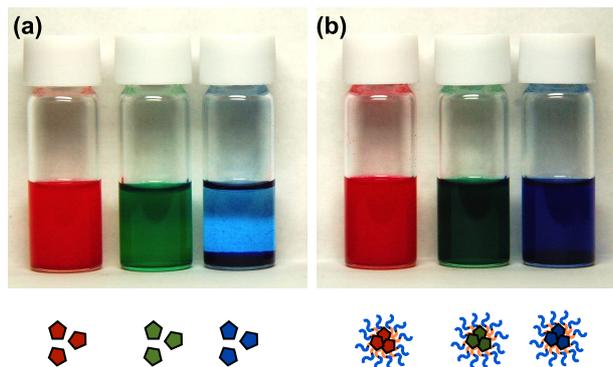


Fig. 2 Photographs of THF dispersion of non-stabilized pigments (left) and polymer-stabilized pigments (right).

THF to prepare 1.0 mg/mL solution and THF dispersion of pigments (red, green and blue) and Fe_2O_3 nanoparticles were mixed. Then, water was mixed into the THF solution and finally, a water dispersion of Janus particles was obtained after evaporation of THF. Three types of Janus particles colored with different pigments were prepared.

Particle size was evaluated by using the dynamic light scattering (DLS) method. The shapes and interior structures of prepared particles were observed by using a transmission electron microscope (TEM).

Honeycomb-structured matrices were prepared from PS by using the breath figure method. Typically, a chloroform solution of PS and amphiphilic molecules was cast onto a glass substrate and applied humid air blow. During the solvent evaporation, water droplets were condensed from humid air, and then, honeycomb-like porous films were obtained after complete evaporation of solvent. The surface structures of honeycomb matrices were observed by scanning electron microscopy (SEM). A sample cell was prepared by placed honeycomb film and a glass substrate with a small gap.

Magnetic Janus particles were prepared from PS, PI and Fe_2O_3 nanoparticles by same procedures shown in the previously. A water dispersion of micron-sized Janus particles was placed in front of a small inlet (shown in Fig. 2), and then, the ambient atmosphere was evacuated. After pressure recovery to normal atmosphere, the water dispersion of Janus particles was introduced into the sample cell. The interior structure of the cell was imaged by optical microscopy.

3. Results and Discussion

Figures 2 (a) and 2 (b) show photographs of THF dispersion of pigments non-stabilized and polymer-stabilized pigments after placed 1 hour, respectively. As shown in Fig. 2 (a), non-stabilized pigments can not be dispersed in THF. On the other hand, polymer-stabilized pigments well dispersed in THF since pigment particles were successfully encapsulated in polymer 1.

Figure 3 (a) shows aqueous dispersion of Janus par-

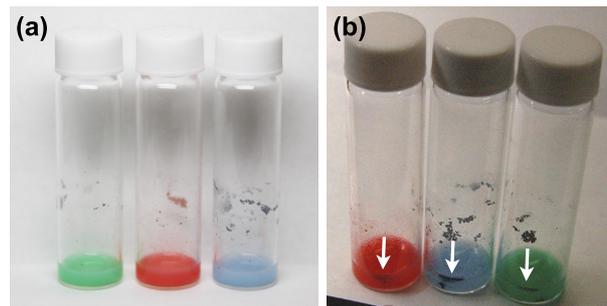


Fig. 3 Photographs of aqueous dispersion of prepared particles incorporated with pigments and iron oxide nanoparticles (a) and after accumulation of particles by using a neodymium magnet (b).

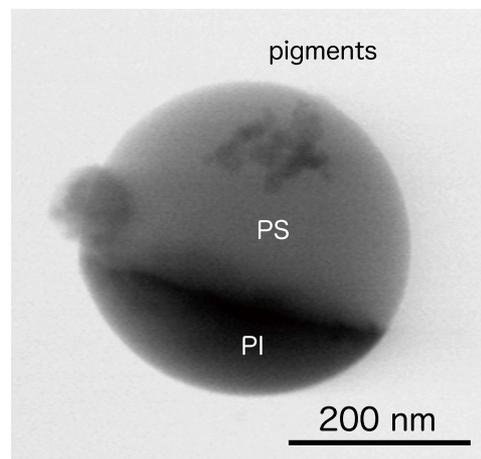


Fig. 4 TEM image of an obtained particle.

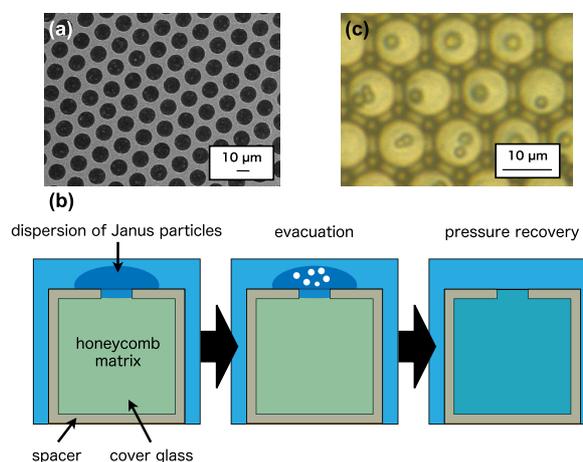


Fig. 5 SEM image of a honeycomb matrix (a), schematic illustration of introduction of particles in the honeycomb matrix (b) and optical microscope image of Janus particles introduced in honeycomb matrix (c), respectively.

ticles. All dispersions were colored with pigments, and opaque due to light scattering of micron-sized particle structures. Figure 3 (b) shows accumulated Janus particles by using a neodymium magnet. The dispersed particles were suc-

cessfully accumulated at the edge of the vessels by magnetic field. This result indicates prepared particles have magnetic responses.

Figure 4 shows typical TEM image of a prepared Janus particle. Janus type phase separation structure was clearly imaged and pigment particles were introduced into PS phase.

Figure 5 (a) shows typical SEM image of a honeycomb matrix. Uniform-sized porous structure was clearly imaged. Figure 5 (b) shows preparation procedure of a sample cell. After introduction of aqueous dispersion, the magnetic Janus particles were introduced into each pore (Fig. 5 (c)) and Brownian motion was clearly observed. Furthermore, introduced Janus particles can be rotated very quickly (less than 500 msec.) along to the external magnetic field.

From these results, basis of electric papers comprised on magnetic Janus particles was established.

4. Conclusion

In this report, we realized basis of electric papers comprised on magnetic Janus particles was established. Colored and magnetic Janus particles were successfully prepared, and magnetic Janus particles were introduced into honeycomb matrices. Introduced magnetic Janus particles quickly respond to external magnetic field. These results indicate that new type of electric papers, which can be driven by magnetic fields, can be realized based on these materials.

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