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Ink-jetting and rheological behavior of a silica particle suspension

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ABSTRACT

To understand the particle-suspended inkjet behavior better, silica particle solutions with different particle sizes were dispersed in ethylene glycol. The effects of the particle size on the jetting behavior was examined using a laboratory-developed drop watcher system in addition to their rheological properties determined using a rotational rheometer. The drying characteristics of the silica solutions with different particle sizes on a glass substrate were also investigated. The results revealed a similar size of deposition droplets after the evaporation of droplets at 5 wt%, whereas a smaller deposition size was observed at 1 wt%.

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Introduction

The application of ink-jet printing technology is broadening from a home printer to the electronic industry because of its inexpensive manufacturing and production cost compared to conventional manufacturing technologies [1–4]. The potential applications of ink-jet printing in engineering include printed circuit boards, textile products, color filters for thin-film transistors in the liquid crystal display, sensor fabrication and radio frequency identification [5–9]. On the other hand, it is crucial to optimize the jetting parameters to ensure that the printing process is error-free. The jetting characteristics, such as the jetting speed, ligament and satellites, as well as the morphological characteristics of the jetted droplet on a substrate should meet the requirements for various commercial applications [10,11]. The performance of ink-jet printing depends on the ink properties and other factors [12]. To understand the mechanism of the ink drop process more clearly, it is important to study the intrinsic characteristics of the inks, such as the rheological properties (shear viscosity and storage modulus), surface tension and evaporation characteristics. [13]. In particular, the rheological characteristics of the inks are critical due to the requirements from the jet stability and printed pattern uniformity after drying on the substrates.

In general, an ink-jet ink is composed of the appropriate portion of dispersant, functional particles and suspending medium [13]. Polymer solutions with an appropriate polymer concentration and molecular weights are also used as ink-jet inks [14,15]. Wang et al. [16] reported the ink-jet properties of a modified SiO_2 sol. Later, the different ink-jet properties between pure nano-SiO_2 and modified nano-SiO_2 with a silica coupling agent were studied [12]. The present study examined the ink-jetting behavior and drying characteristics of the silica particle solutions with different sizes from nanoparticles to mono-dispersed microspheres.

Experimental

Materials

Silica particles with different particle sizes (80 nm, 0.5 μm, 1.0 μm and 1.5 μm, obtained from Alfa Aesar) were dispersed in ethylene glycol (EG) (AMRESCO, high purity grade) by sonication for 1 h to obtain a homogeneous suspension of each particle size with two different (1 and 5 wt%) particle concentrations.

Rheological measurements

The rheological properties of the silica particle-dispersed suspensions were examined using a rotational rheometer (MCR 300, Anton Paar) equipped with a double Couette cylindrical system [DG 26.7 (the diameter of the cup was 27.59/23.83 mm and the diameter of the bob was 26.66/24.66 mm)/TEZ 150 P-C] at room temperature [17].

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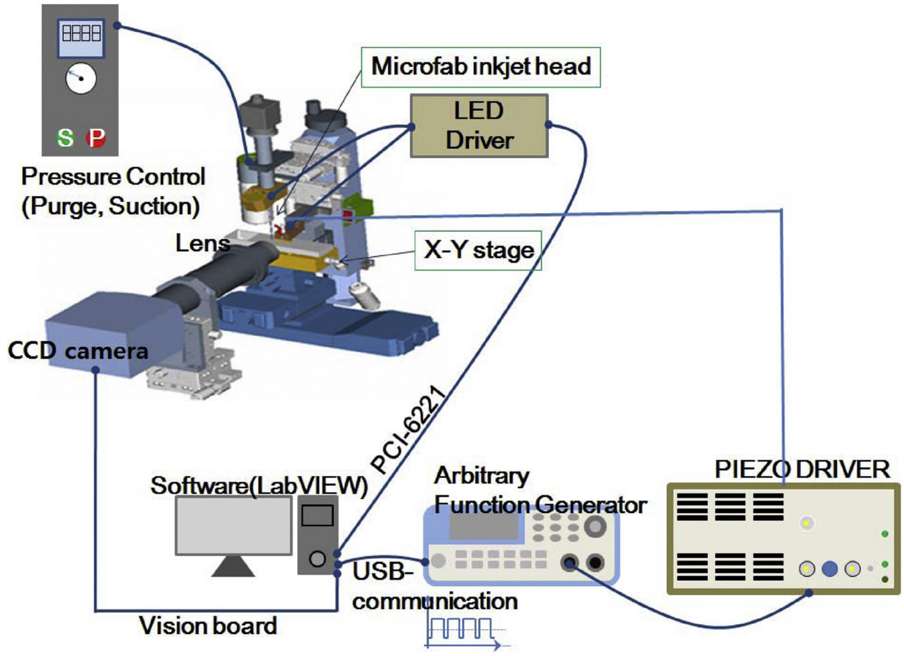

Fig. 1. Equipment for jetting and drying characterization—schematic of drop watcher system.

Measurement of the ink-jetting behavior

A laboratory-developed drop watcher system shown in Fig. 1 was used to characterize the jet. A single nozzle head (MJ-AT, Microfab, USA) was used as the jetting device. The nozzle diameter of the print-head used for the experiment was 50 μm. A CCD camera (XC ES 50, Sony, Japan) was used to obtain jetting images. An adjustable zoom lens (ML-Z07545, MORITEX, Japan) and a lens adaptor (ML-Z20, MORITEX, Japan) were used to acquire magnified images of the ink-jet behavior. To obtain a frozen jetting image, LED light was synchronized with respect to the jet triggers.

Two digital pulse trains from a counter board (PCI-6221, NI, USA) were used for the synchronization, as shown in Fig. 2. The first digital pulse train was used as a trigger signal to create the pulse voltage, whereas the second pulse train was exploited to control the LED light. The second pulse was triggered from the first pulse, and the trigger delay time between the first and second pulse was adjusted, such that the jet image at the delayed time can appear frozen [18]. In addition, it can be also noted that pure EG behavior was previously studied [18], in which the ligament of jetted pure EG tends to become spherical without forming satellites. However, the long ligament of jetted particle solution ink was likely to break into many satellites during drop formation.

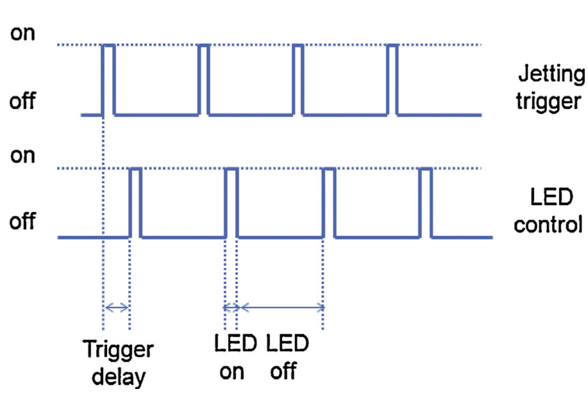

Fig. 2. Strobe LED control.

Measurement of drying behavior

The drop watcher system presented in Fig. 1 was also equipped with a substrate holder. As a result, the drying behavior of the droplet on a substrate can be measured by lowering the LED and camera position slightly downward to align the jetted droplet on the substrate with respect to the camera. Fig. 3 shows the droplet image from the side and top views after jetting on a substrate.

Unlike the drop watcher system for jetting visualization, the LED light should not be synchronized with respect to jetting when observing the drying behavior. For this purpose, the counter board was re-configured such that the LED light can be controlled

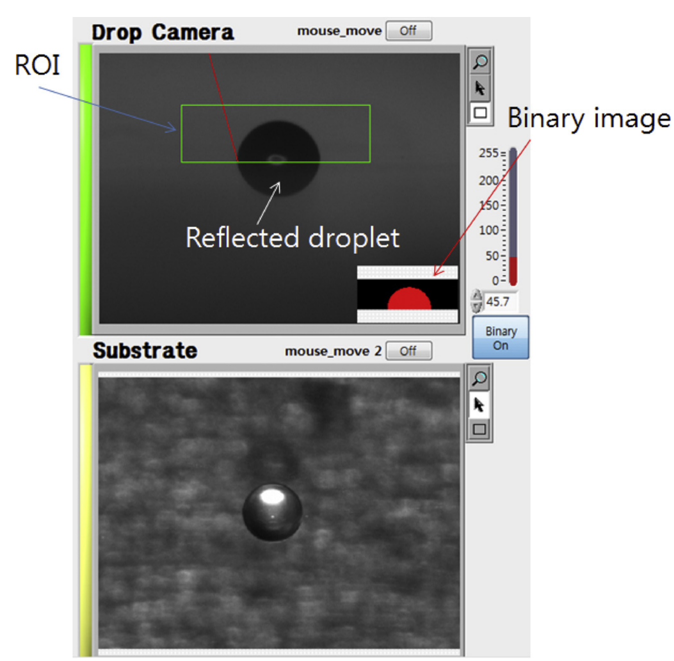

Fig. 3. Side view and top view after jetting.

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