Digital Fabrication Using Electrophotography for Conductive Patterning

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Abstract

We modified an electrophotography method used in digital fabrication so that it can eventually be used in a mass production process. Our modification involved partly covering a charge roller with an insulating medium to prevent it from charging at certain points. Therefore, this charge roller can form the same latent image each time directly on a dielectric substrate without a photoreceptor or an optical unit.

We demonstrated that our modification worked using a conventional charge roller that was partially wrapped with polyimide film that contained a 20-μm-width penetrating slit. The modified roller was used to charge a dielectric film. The formed latent image was developed with liquid developer of conductive toners. The obtained pattern width of the conductive toner was 20 μm, which is the same as the slit width in the polyimide film.

To form an insulating medium in an arbitrary pattern on the surface of a charge roller, we choose a chemical amplification photoresist as the insulating medium. The charge roller material and the photoresist were deposited onto a flat substrate and patterned using conventional photolithography. The results showed the possibility that the photoresist is capable of forming arbitrary patterns on the charge roller material.

Introduction

The demand for a simple method of fabricating conductive patterns has been growing. One method that is a likely candidate to meet this demand is digital fabrication, which involves using traditional printing technology. Digital fabrication technology has some advantages because it is a completely additive formation method for making conductive patterns. These advantages include simplicity, low material consumption, and economy.

There are several processes in which digital fabrication technology can be used for additive formation of conductive patterns. These processes are based on ink jet printing[1-3], electrophotography[4-6], and mass printing[7].

In an electrophotography process, a charged toner is attracted electrostatically to the latent image formed on a photoreceptor. Therefore, the resolution of the fine pitch pattern is determined by the toner size and the resolution of the latent image. This means electrophotography produces fine pitch patterns that have better resolution than those produced by other digital fabrication processes. For example, a conventional ink jet process has a width-limit of around 30 μm. Furthermore, electrophotography is suitable for fabricating a prototype because patterns are formed from digital data. However, electrophotography technology is not yet suitable for use in mass production, because even if the same pattern is being fabricated more than once, it is still necessary to form a latent image on the photoreceptor each time.

Research on using electrophotography technology for digital fabrication has focused on the developer, e.g., conductive toner[4], and metal nano-particles[6]. There has been limited research on modifying the imaging mechanism, i.e., the photoreceptor and the optical unit. The lack of research on the actual imaging mechanism of electrophotography means that its fabrication rate has not been increased enough for electrophotography to be used in mass production processes.

We modified a digital fabrication process based on electrophotography to improve its fabrication rate. In our modified process, a latent image is formed directly onto a dielectric medium, which removes the need for a photoreceptor and an optical unit.

A schematic diagram of the fabrication process is shown in Figure 1. A sample is first charged over the whole surface area by a first charge roller (shown in Figure (a)). A latent image is formed using a second charge roller, whose surface is patterned with insulating medium (Figure (b)). The surface pattern is the same with the inverted pattern of conductive toner. The insulating medium prevents charge roller material from discharging in the point. This roller stamps out the latent image, therefore, it is called latent image stamp (LIS) roller in this paper.

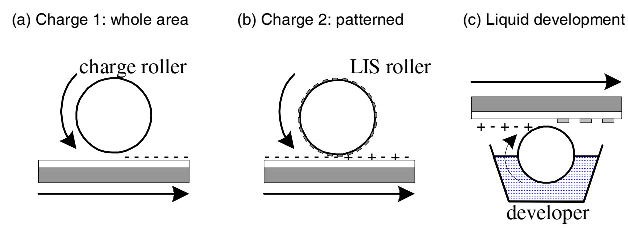

Figure 1. *Schematic diagram of digital fabrication process using LIS roller*

After formation of a latent image, the image is developed by using conductive toner in a conventional liquid development process (Figure (c)). The toner consists of silver particles coated with a charging medium of acrylic polymer.

Charge Mask with Insulating Medium

To test the charge masking ability of the insulating medium, a polyimide film (Du Pont, Kapton) was wrapped around a charge roller used in a conventional copier and its charge prevention properties were evaluated. The thickness of the polyimide film was 50 μm. A piece of the same polyimide film was fixed onto the aluminum substrate and used as a sample to be given surface potential.

Using this charge roller, several voltages were applied and surface potentials of areas with and without polyimide masking were measured. The applied voltage was based on a DC offset and overlapped with an AC voltage. The frequency and amplitude of the AC voltage is 1 kHz and twice that of offset voltage, respectively (e.g., V_{AC}= 1 kV @ V_{offset}= 500 V). The results are shown in Figure 2.

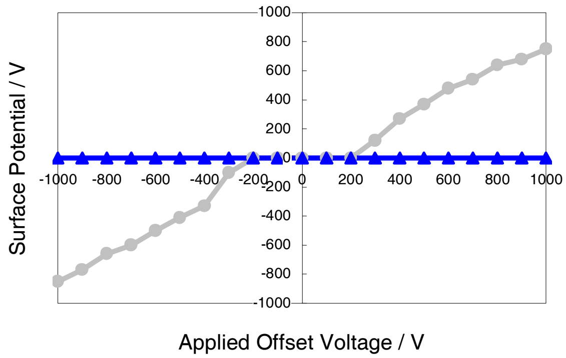

Figure 2. *Relationship between voltage applied to the charge roller and surface potential of the sample; triangle: with polyimide mask, and circle: without mask*

The results show that the surface potential in the area where there is a corresponding with polyimide mask on the charge roller (triangle symbol in Figure 2) is zero across the entire voltage range. This is true even in the voltage range where the surface potential was measured in a maskless area (circle symbol in Figure 2). This demonstrates that polyimide film acts well as a charge prevention layer.

To form a fine pattern latent image using this method, a penetration slit structure was fabricated by laser ablation[8] in the polyimide film that was wrapped around the charge roller for simple LIS roller. The slit size was 20 µm wide and 40 mm long. This LIS roller was then charged, and the charge transferred to the dielectric medium.

In this experiment, a negative charge was applied to the whole sample and then a partly positive charge was applied using the LIS roller. After latent image formation, the conductive liquid toner was dropped down onto the sample. A microscopic image of the result is shown in Figure 3.

The width of the obtained conductive toner pattern was 20 µm, which is the same as the slit width in the polyimide film. This width of 20 µm is narrower than the limit when a conventional ink jet process is used for the same purpose.

It is shown in Figure 3 that the conductive toner exists as well as a positive pattern of the latent image. In our present development method, a developer was simply dropped and no development bias or squeeze process was applied.

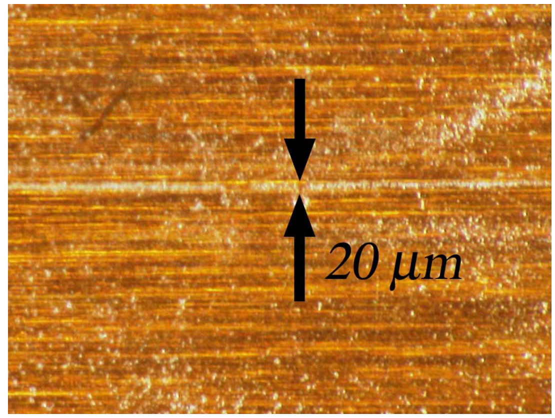

Figure 3. *Microscopic image of conductive toner pattern developed from a latent image formed with LIS roller*

As this toner consists of a silver particle covered with a polymer, it is necessary to combine the silver particles under pressure at a high temperature to improve conductivity. However, we did not subject the conductive toner to pressure at a high temperature because the toner density of this pattern was not enough.

Although there are some problems remaining, we have shown that a very simple method exists for forming narrow latent images and conductive patterns using an LIS roller.

Furthermore, it will be possible to fabricate much narrower patterns by forming a narrower slit in the insulating medium and optimizing several conditions, such as toner size dispersion, charging voltage, and the development process.

Arbitrary Patterning of Insulating Medium

We demonstrated that an LIS roller successfully worked by using a charge roller wrapped with polyimide film that contained a penetrating straight slit. However, it is not possible to form an arbitrary pattern as long as wrapping insulating film is used. Therefore, we tried using a photoresist to form an arbitrary pattern of the insulating medium on the surface of the charge roller material. A chemical amplification type photoresist (micro chem, SU-8[9]) was used. This photoresist produces a cured pattern that can be permanently used in micro electro mechanical system (MEMS). A sample was prepared by sequentially coating on a silicon wafer with a solution of charge roller material (a mixture of several polymers and metal particles) and then the photoresist. The photoresist was exposed to UV light and developed in the conventional way. A scanning electro microscope (SEM) image of the developed pattern is shown in Figure 4.

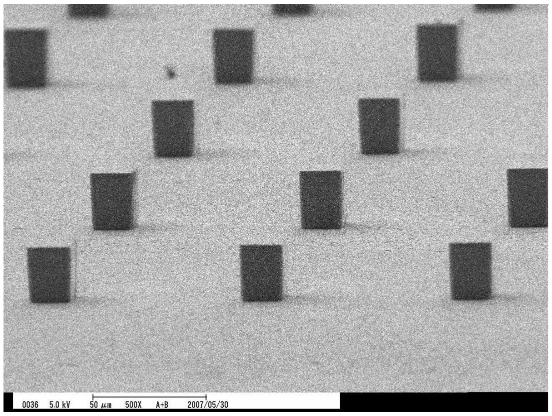

Figure 4. *SEM image of photoresist patterned on the charge roller material*

A square columnar array was formed on the charge roller material, as can be seen in the SEM image (Figure 4). The size of this structure was 20 μm on the upper surface and 30 μm in height, with an array pitch 100 μm in both directions. It is confirmed that this photoresist is capable of forming structures in the order of tens of microns on the charge roller material.

The next step is applying this photoresist patterning to the roller surface. However, conventional photomasks cannot be used for configuring rollers, so we investigated directly exposing the roller surface to laser beams. A schematic image of direct exposing apparatus is shown in Figure 5. The area exposed to a laser beam is controlled by a mechanical shutter and X-θ stage. The scanning speed of this apparatus is not high because of the photosensitivity of the photoresist. However, the purpose of this apparatus is to fabricate LIS rollers to be used as latent image master, therefore fabrication speed is not critical.

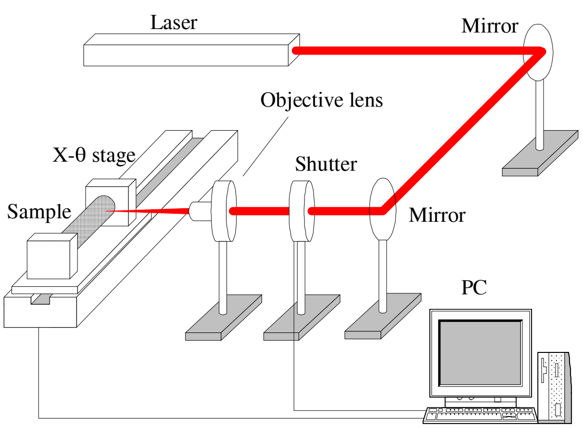

Figure 5. *Schematic image of direct exposing apparatus*

Summary

We have demonstrated that the idea of using a latent image stamp roller to replicate a latent image is practicable. An insulating medium is formed into a pattern on a charge roller. The insulating medium masks the charge and a latent image is formed with an inverted charge pattern to the pattern on the insulating medium. We demonstrated our idea by wrapping a charge roller with a polyimide film fabricated with a penetrating slit of 20 μm width and using the roller to charge a dielectric medium. The formed latent image was developed with conductive toners. The width of the obtained pattern was 20 μm, which corresponded well with the slit width in the polyimide film. This width of the obtained pattern is narrower than the minimum width produced using a conventional ink jet process.

We also showed that there is the possibility of arbitrary patterning of an insulating medium on the surface of a charge roller material using a photoresist.

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Author Biography

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