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# Optimization of a reverse-offset printing process and its application to a metal mesh touch screen sensor

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ABSTRACT

Reverse-offset printing provides an alternative method for manufacturing ultra-fine patterned devices, such as thin film transistors and touch screen sensors. In addition to enabling fine patterning on the scale of less than a few micrometers, the method ensures the preservation of high-quality surfaces, which are essential for multi-layer devices. Ultra-fine patterns may be obtained by finely tuning the reverse-offset printing process along several printing parameters, including the printing pressure and printing speed. These parameters affect the adhesion and cohesion of an ink film, which govern the patterning mechanism. In this paper, we analyzed the patterning mechanism and optimized the printing parameters to achieve good printability. Optical transmittance methods were used to quantitatively evaluate the printability in each printing test. Finally, we demonstrated the fabrication of a single-layer metal mesh touch screen sensor based on the optimized printing process.



## 1. Introduction

Electronics printing offers an attractive method for fabricating electronic devices using functional electronic ink. Unlike conventional photolithography and vacuum-based vapor deposition methods, printing involves a small number of production steps, which reduces both the time and cost needed for device fabrication. Most printing techniques operate on a roll-to-roll basis, which is optimal for integrating with flexible electronics manufacturing. Conventional patterning processes consist of many steps, including deposition, photoresist coating, photolithography, development, etching, stripping, and cleaning. Printing, on the other hand, can usually be used to fabricate patterns directly within one or two steps. Printing techniques are currently used commercially for radio frequency identification (RFID) and routing electrodes of touch screen panels. Printing can potentially be applied to the fine patterning required for thin film transistors [1] and touch screen sensors [2]. Touch screen sensors require transparent electrodes formed from ultra-fine metal mesh patterns that should be invisible to the human eye. Among the various printing techniques available, including gravure, gravure offset, inkjet, screen, and reverse-offset printing [1–7], the reverse-offset method offers the best approach to fabricating ultra-fine patterns less than 1 μm in feature size [2]. The reliable manufacture of ultra-fine patterns requires process analysis and optimization. Several studies have explored the transfer mechanism underlying the reverse-offset method by tuning the contact angle [5] and surface energy [6]; however, the reverse-offset printing mechanism is not yet fully understood. In this paper, we analyzed the patterning mechanism and optimized the printing process to improve the printability of functional ink. We proposed a quantitative method for evaluating printability using optical transmittance. The optimized results were used to fabricate and demonstrate the use of a single-layer metal mesh touch screen sensor.

## 2. Reverse-offset printing

Like many other printing techniques, reverse-offset printing is difficult to optimize. Printability is sensitive to the conditions of the polymer blanket and the ink, which change continuously during storage and processing. Printing processes are often optimized by the operator based on personal experience. The application of reverse-offset printing methods to the commercial manufacturing of printed electronics requires a better understanding of the printing mechanism and objective methods for optimizing a printing process based on the mechanism.

Fig. 1 illustrates the process underlying reverse-offset printing. First, an ink is coated onto a coating substrate to form a thin film by slot-die coating or spin coating. A blanket roll, usually composed of poly-dimethylsiloxane (PDMS) and wrapped around a metal cylinder roll, is then rolled over the coating substrate to transfer the thin

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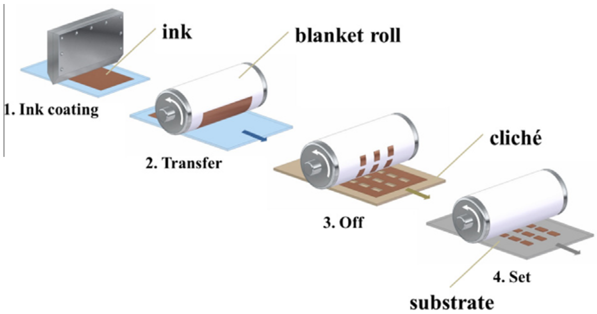


**Fig. 1.** Reverse-offset printing process.

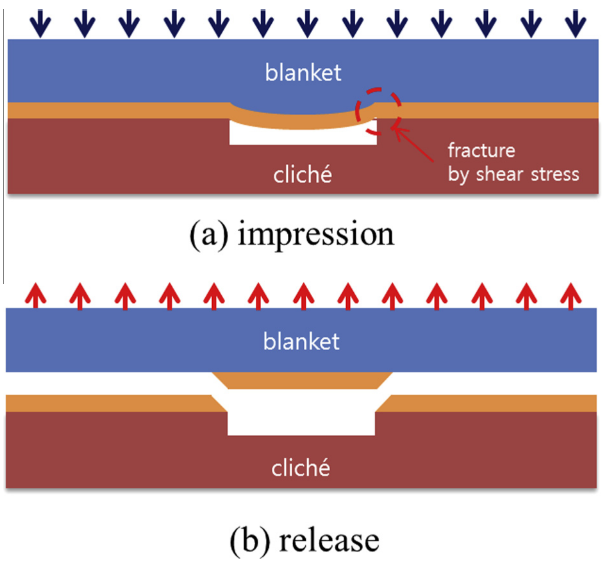


**Fig. 2.** Schematic diagram illustrating the patterning mechanism. (a) The blanket coated with an ink film is impressed onto the cliché. (b) The blanket is then released, leaving a patterned film.

film to the blanket roll. The ink can be coated on the blanket roll directly. After coating, the ink forms a semi-dried film by evaporation or the absorption of the ink solvent by the blanket roll [7]. During patterning, the blanket roll moves, with rolling, over a cliché engraved with an intaglio pattern. Because the cliché has normally higher adhesion than the blanket, all non-patterned ink films are removed from the blanket roll. Finally, the blanket roll rolls over a target substrate to transfer the patterned ink film.

Successful patterning requires that only a portion of the ink film in contact with the top surface of the cliché is transferred from the blanket, thereby maintaining the ink film over the intaglio pattern of the cliché. Fig. 2 illustrates the reverse-offset printing patterning mechanism. This mechanism occurs at the nip, which is a contact area created by the deformation of the blanket roll during impression onto the cliché. As shown in Fig. 2(a), the blanket coated with an ink film is impressed onto the cliché. Here, the impression of the blanket plays two significant roles in securing printability. First, adhesion between the ink film and the cliché develops under the printing pressure. A higher pressure produces conformal contact, resulting in stronger adhesion. Second, the softness of the blanket produces a bulge that penetrates the intaglio pattern formed by the impression, thereby causing shear stress on the edges of the ink film. This shear stress results in direct fracture or decreases the fracture energy of the ink film (reduces the cohesive energy), depending on the magnitude of the impression. The cohesive energy at the edges of the patterns can be controlled by the printing pressure. For patterning, during blanket release, as shown in Fig. 2(b), and adhesion must exceed the cohesion energy at the edges. A PDMS blanket displays a rate-dependent adhesion [8]; therefore, faster rolling speeds produce stronger adhesion between the blanket and the ink film during blanket release after contact. From the perspective of productivity, a faster printing speed is preferred, but the printing speed should be optimized to secure good printability.

Reverse-offset printing processes function by controlling the adhesion and cohesion of the ink film, which can be adjusted by two process parameters: the printing pressure and the printing

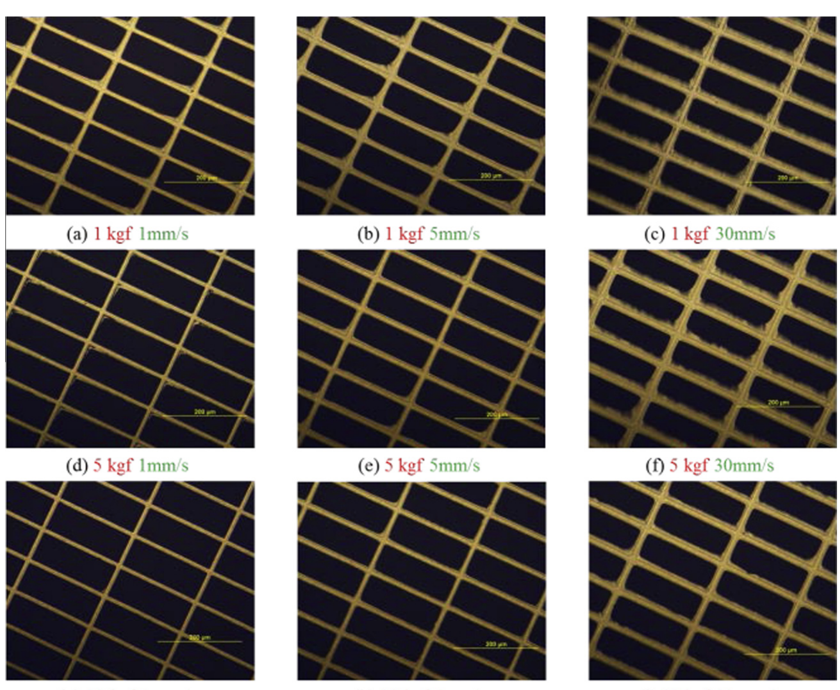


**Fig. 3.** Printed patterns obtained using a spin coating speed of 4000 rpm ($t = 1.5$ μm).