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Enhancement of printing overlay accuracy by reducing the effects of mark deformations

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ABSTRACT

The roll-based high-speed printing process has the two major advantages of high productivity and a simple process over the conventional electronic device manufacturing process. There have been several attempts to commercially apply the roll-based high-speed printing process to various electronic devices. While such attempts have sought to improve the performance of electronic devices, these devices require multi-layered structures to be printed with high overlay accuracy between each layer. Printed patterns always appear to be deformed compared to the designs on the master plate because the printing process is solution based. Given variations in ink transfer volume, the accuracy of the overlay measurement can be degraded by mark deformations. This means that these deformations caused by the printing mechanism should be taken into account. In this paper, we provide the details from a simulation study and experiment carried out using gravure offset printing to investigate the effects of mark deformations on overlay measurement accuracy. We analyzed and optimized the pattern registration algorithms and the type of overlay marks in order to improve the measurement accuracy of the positions of the printed patterns. As a result, the repeatability measuring the positions of the printed patterns can be reduced to 1.0 μm and 2.0 μm in the CD and MD directions in the gravure offset printing process, respectively.

1. Introduction

Printed electronics are electronic devices whose complex electronic circuitry is created by the printing method, just as a newspaper is printed with ink. Printed electronics have recently attracted a lot of attention because they can be used to manufacture large flexible electronic devices at a low cost due to the simple process steps and low facility investments. There have been various attempts to apply printed electronics to various industrial applications, such as thin-film transistors (TFTs) [1,2], radio frequency identification [3], organic photovoltaics [4], and touch screen sensors [5]. Most studies have focused on the performance enhancement of printed electronic devices by optimizing their processes and materials. As most applications require multi-layered structures to be printed, the performance of printed electronic devices is largely limited by overlay accuracy, which is about how accurately each layer is overlapped over other layers [3]. In developing printed TFTs, performance improvements, including mobility and transition frequency, depend on the overlay accuracy of the printing process. This is because reductions in the channel length are limited by overlay accuracy [2]. In addition, overlay accuracy is related to the degree of integration in manufacturing the array of TFTs [6,7]. Currently, the target overlay accuracy for printed electronics stands at 5 μm or less [8,9].

A systematic approach is required to analyze where an overlay error comes from and to what extent it can be compensated in order to efficiently enhance overlay accuracy. This is because overlay accuracy is affected by various factors, such as the misregistration of the overlay marks on the master plate, the variation in printing pressure, synchronization errors between the printing roll and the substrate, the measurement accuracy of the overlay marks, the precision of the printing machine, the deformation of the substrate due to high temperatures during sintering, and the control accuracy of the web transport mechanism. There have been a few studies that have been carried out for improving overlay accuracy. However, most of these studies have been limited to certain factors. In the roll-to-roll printing system, most studies have been focused on developing the control algorithm of the web transport system in order to correct overlay errors [10–12]. The effect of synchronization errors between the printing roll and the substrate was investigated by using the offset printing system [9,13].

The first step for analyzing the accuracy of a printed overlay is to secure an accurate measurement method for determining the positions of the printed patterns. Generally, the machine vision method is used for determining the positions of the micron-sized patterns [14,15]. Measuring the overlay accuracy of the printing process using the machine vision method requires that mark deformations be taken into account.

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The mark deformations are the phenomena where the shapes of the printed overlay marks are deformed from their original shape due to printing quality. In the printing process, the mark deformation will have a severe effect on measuring the positions of the printed patterns because the ink is transferred in the solution state, which means that the boundaries of the printed patterns cannot be uniformly maintained at all times. There are several examples in which the shape distortion of the patterns is 10% larger than their critical dimensions [16]. Even in the photo-lithography process, mark deformations have been viewed as a significant contributor for the error budget of the overlay accuracy because target accuracy is much lower in that process. However, it should be noted that these mark deformations are much smaller than the ones that occur in the printing process [17].

In this paper, we investigate the effects of mark deformations on overlay measurement accuracy and propose a method for improving overlay measurement accuracy in the printing process in view of the pattern alignment algorithm and the mark types. We used the gravure offset printing process because it is beneficial when printing micron-sized patterns on large areas. The remainder of the paper is organized as follows: The printed shape deformation of the overlay marks in the gravure offset printing process is introduced in Section 2. In Section 3, we compare two pattern alignment algorithms, the edge-based shaping finding method and area-based image registration method, in order to find out which algorithm is less sensitive to the mark deformations. In Section 4, it is validated that the effect of the mark deformations on measuring the positions of printed patterns has been quantitatively demonstrated. Mark deformations cause the random errors in measuring the positions of printed patterns and these random errors can be effectively averaged out by using the marks in which a large number of boundaries and regions are included. By using the results of Sections 3 and 4, the grating marks, which we combined with the area-based image registration algorithm, are recommended for reducing random measurement errors that occur due to the mark deformations and the measurement repeatability of the proposed "grating" mark that we verified by comparing the measurement repeatability of the most frequently used marks of "o" and "+." The conclusions are given in Section 5.

2. Mark deformations

In the gravure offset printing process, the ink is first applied onto the plate by the doctoring process. A blanket roll picks up the ink from the plate in the off process, and the blanket roll then transfers the ink to the substrate in the set process. A schematic of the gravure offset printing process with the roll-to-plate system is shown in Fig. 1. Polydimethylsixane (PDMS) was used as a blanket material. PDMS helps the ink to be picked up from the intaglio on the master plate in the off process as the PDMS is easily deformed due to it having less stiffness than the master plate. In addition, PDMS helps the ink transfer from the blanket roll to the substrate by absorbing the solvent in the set process.

The printed shapes of the overlay marks are generally different from their shape on the master plate in gravure offset printing. These phenomena are defined as mark deformations in this paper. The examples of the mark deformations of "o" and "+," which are mostly used as the overlay marks in the printing process, are shown in Fig. 2. When the positions of the deformed marks are measured via the machine vision method, the deformed boundaries of the printed patterns will result in a measurement error of the positions of the printed patterns because the machine vision method calculates the positions of the patterns using the pattern shapes. The mark deformations in gravure offset printing are mainly caused by the variations in the amount of ink that is picked up in the off process. However, it is not easy to accurately control the amount of ink transferred from the plate to the blanket in the off process because there can be a lot of process variations that affect the transferred volume fraction of ink in the off process [18–20]. In the following sections, the measurement methods are discussed in order to obtain the most representative positions of the deformed patterns in view of the pattern alignment algorithms and mark types.

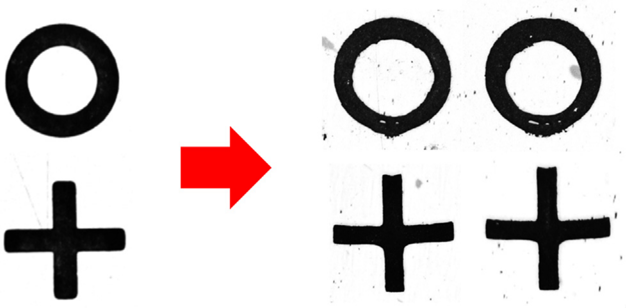

Fig. 2. Examples of mark deformations of "o" and "+" marks in the gravure offset printing.

3. Effects of pattern alignment algorithms

Generally, the positions of the patterns are calculated in the machine vision method by applying the pattern alignment algorithms to the image of the patterns captured by the vision system. In this section, we compare two types of pattern alignment algorithms, which are usually used to measure the positions of the printed patterns in the printing processes, in order to identify which algorithm can calculate the most representative positions of the deformed marks. The first algorithm we looked at is an edge-based shape finding method, which is shown in Fig. 3 [21]. The concept of our algorithm is similar to the algorithm given in Ref. [21]. However, the detailed procedure to search for the edge points is different from that of Ref. [21]. In our algorithm, the edge points of the mark are recognized by searching for the maximum gradient of the signal intensity on the search lines. The recognized edge points are fitted to the shape function by the least-square method and the position of the mark is then calculated by the centroid of the fitted shape function. The shape function, the directions of the search lines, and the number of the search lines differ according to the type of mark. For example, the circular shape function and the 64 search lines pointing inward from the rectangular boundary of the search area were used for the "o" mark and only outer boundary of the mark

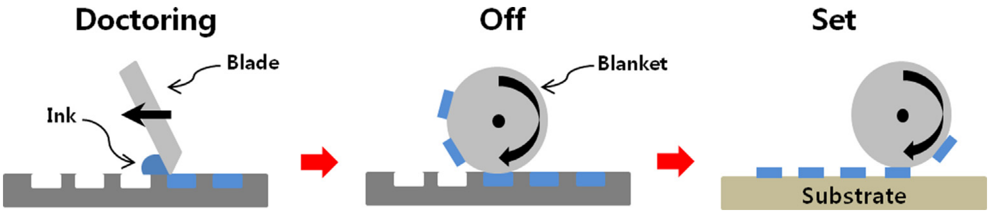

Fig. 1. Schematic of the roll-to-plate gravure offset printing.