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Register control algorithm for high resolution multilayer printing in the roll-to-roll process

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ABSTRACT

Roll-to-roll (R2R) printing process is a key technology for achieving low-cost mass production of multilayer printed electronic devices. A register control, which maintains position accuracy between layers, is essential in the R2R multilayer printing process. In this study, a register control algorithm is developed to achieve microscale resolution in the register. The dominant factor behind machine direction register error is determined. Furthermore, an adequate register model is determined to estimate the register error according to tension disturbances. Permissible tension error is achieved for accomplishing the objective register and minimized for register control. The effect of the developed algorithm on the resolution of the register control is verified experimentally. Experimental results indicate that applying the proposed register algorithm achieved resolution below ± 30 μm. This suggests that the proposed register algorithm is an essential application for a microscale resolution register. Finally, an application of the algorithm was introduced using examples considered in previous researches.

1. Introduction

In the technology of printed electronics, it is very challenging to manufacture next-generation electronic devices such as organic thin film transistors (OTFTs) or organic light emitting diodes (OLEDs) [1]. Flexible printed electronic devices have the advantages of light weight, flexibility, and low-cost production [2–5]; therefore, many studies have attempted to achieve these goals [6,7] printing is an essential technology for mass producing printed electronic devices. Fig. 1 shows the R2R printing machine considered in this study. It consists of unwinding (a), infeeding (b), 1st layer printing (upstream printing) (c), drying (d), 2nd layer printing (downstream printing) (e), outfeeding (f), and rewinding (g) sections. In the unwinding section, the substrate is unwound and transferred. The transferred substrate is passed through the infeeding section, then printing is conducted by the 1st layer printing roll. During this process, various printing methods may be applied, such as direct gravure [8], gravure offset [9], or flexography [10]. The substrate where patterns are printed by the 1st layer printing roll is dried and cured in a dryer. Hot-air [11] or infrared (IR) [12] heating methods can be applied in this section. After the 2nd layer printing, the substrate on which single or multilayer patterns are printed is rewound. To accomplish the manufacturing of printed

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Fig. 1. Photo of R2R printing system considered in this study. (a) Unwinding, (b) infeeding, (c) 1st printing, (d) drying, (e) 2nd printing, (f) outfeeding, and (g) rewinding sections.

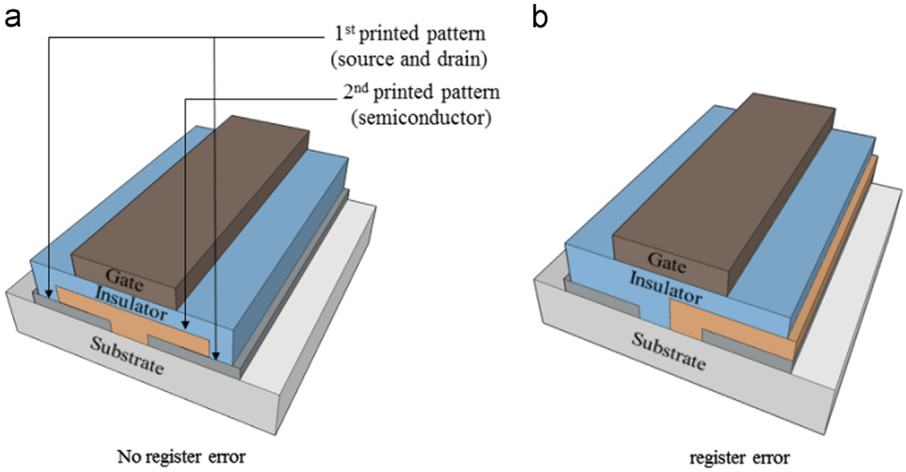

Fig. 2. Schematics of register error in printed TFT. (a) No register error and (b) register error.

electronic devices in the R2R printing process, the ink transfer between the printing roll and substrate has to be optimized [13,14]. In particular, a register control has to be created, which maintains position accuracy between the patterns printed in upstream and downstream printing sections [15]. Fig. 2(a) and (b) shows printed thin-film transistors (TFTs) with and without register error, respectively. As shown in Fig. 2(b), register error causes disconnection between the source and the drain in the printed TFT, generating a serious defect in the device. Therefore, the register control is essential in the production of printed electronic devices that are composed of multilayered patterns; using the register, it is necessary to maintain microscale resolution below 30 μm [16]. Although study on the register control was begun in the graphical printing field [17], more researches have been conducted in the printed electronics. In printed electronics, the high resolution multilayer printing is required for high volume production of printed electronic parts [4,15]. Brandenburg developed a linear register model based on the mass conservation law [17]. Yoshida et al. designed a nonlinear register model using the state variable of printing press dynamics for a sectional rotogravure printing press [18]. Liu et al. developed a nonlinear register model of a multilayer gravure printer [19]. Pagilla et al. proposed a register model including variations of span length by the motion of an accumulator [20]. Kang et al. proposed a compensation method for register error using the Brandenburg model [21]. A study on the enhancement of printing location accuracy in a stop-and-go substrate feeding process was conducted by Noh et al. [22]. They designed equipment for precise overlay printing. Moreover, a compensation algorithm was proposed, considering the synchronization error between a flat gravure plate and a blanket roller. Previous studies have indicated that the dominant factors causing register error change according to the overlay printing method and the operating condition of the printing machine. Furthermore, different register models have to be applied to determine the primary reason for register error. This is because the estimation ability of the register models may change according to the primary characteristics of the register error. Therefore, to maintain register control in the R2R printing process, it is necessary to first determine the primary factor in register error and improve it below the range permissible for the register control. In this study, a register algorithm was suggested to determine the dominant factors behind machine direction register error. Furthermore, an adequate register model and its input were determined by the proposed algorithm to calculate the permissible tension error for accomplishing the objective register. The effect of the proposed algorithm was verified by comparing the resolution of register error according