

Ultra-thin coating with tensioned-web method and defect analysis by real-time thickness measurement method

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INTRODUCTION

Printable electronics is a relatively new field that combines printing and coating technology with conductive inks to produce thin and flexible electronic circuits. Printable electronics require uniform and ultra-thin coatings. The wet thickness varies from sub-micron scale to a few microns. High speed precision coating technology is therefore needed to mass-produce these products and reduce the manufacturing costs. Tensioned-web-over-slot die coating is one of the suitable methods for such ultra-thin and high speed coating process.

Figure 1 shows the difference of conventional slot coating and tensioned-web slot coating. Unlike conventional slot coating, the tensioned-web coating does not have a backup roll to support the substrate and the gap between the coating die lip and the substrate is regulated by the force balance of the coating liquid and the curved substrate under tension. In general, this method can maintain an extremely small gap height without scratching the die lip surface. Because of this, the minimum possible wet thickness can be significantly reduced by this method [1].

¹ Unpublished. ISCST shall not be responsible for statements or opinions contained in papers or printed in its publications.

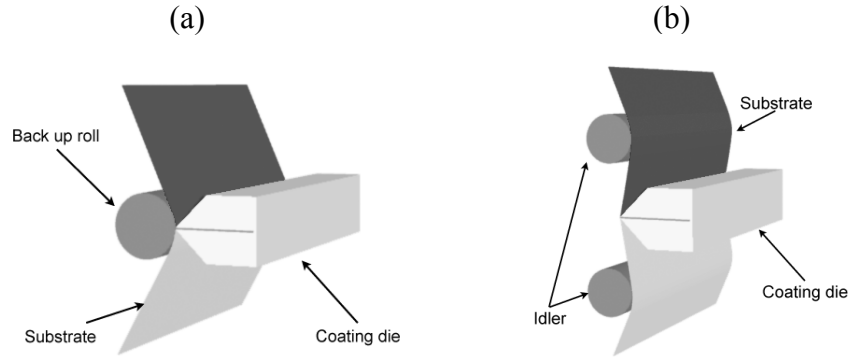


Figure 1: Schematic illustrations of conventional slot die coating (a) and tensioned-web-over-slot die coating (b).

Tensioned-web slot coating flow has been analyzed by both flow visualization and computer-aided theory [1-3]. These analyses were focused on 2D flow behavior and the uniformity of the coating layer was not discussed. In this study, the analysis is focused on the uniformity of the coated layer and streak formation at wet film thickness in the range of 1 micron. A simple real-time thickness measurement method was developed to evaluate the coating uniformity at different conditions. The method only uses a camera and a LED light source. The thickness of the coated layer was directly related to the light absorbance using the Beer-Lambert equation. Thickness variations and streaks were observed by this method.

SETUP OF COATING

The apparatus of tensioned-web coating station is shown in Fig. 2. The coating die was designed by Wieslaw Suszynski at the University of Minnesota and manufactured by PREMIER DIES Co., Chippewa Falls, WI. The web transport machine was designed and donated by IMATION Co., St. Paul, MN. A camera was installed in front of the die lip and the coating bead was observed through the transparent moving substrate.

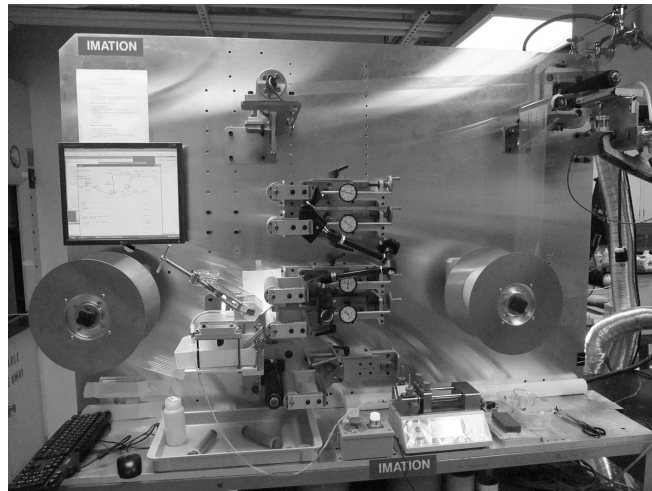


Figure 2: Apparatus of tensioned-web coating station

THICKNESS MEASUREMENT METHOD

The schematic illustration and actual setup of thickness measurement method are shown in Fig.3. This system consists of LED line light source and digital camera. Food grade color dye Blue #1 was added to the coating liquid as light absorber. The thickness of the coated layer was directly related to the light absorbance using the Beer-Lambert equation.

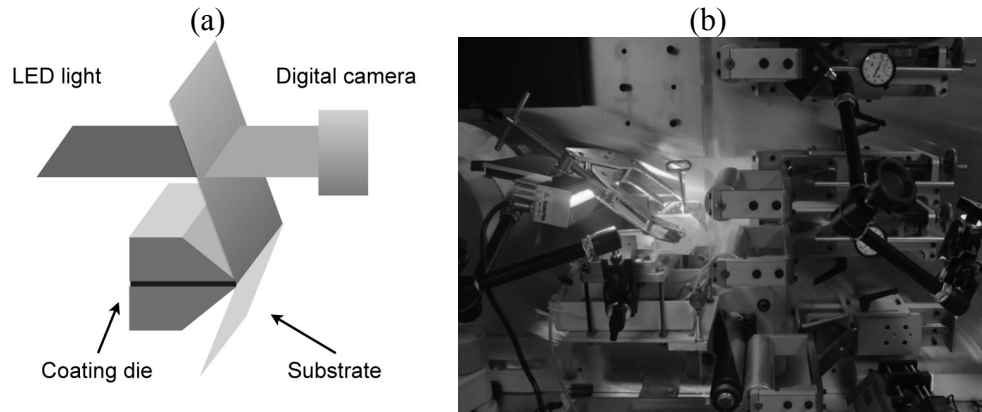


Figure 3: Schematic illustration (a) and actual setup (b) of thickness measurement system

Tensioned-web coating is a pre-metered coating method. The amount of fed liquid through a pump is equal to the coated liquid on the web. The average thickness of coating layer can be calculated from flow rate, web speed and die width. The calibration between the thickness and light absorbance was done by the average thickness and average light absorbance. The ten standard conditions for calibration are listed in Table 1. The result of the calibration is shown in Fig. 4.

Table 1: Standard conditions for calibration

Web speed	Flow Rate	
	9 m/min	0 ml/min
3 m/min	0.3 ml/min	0.4 ml/min
4.5 m/min	0.65 ml/min	0.8 ml/min
6 m/min	1.3 ml/min	1.5 ml/min
9 m/min	2.8 ml/min	3.2 ml/min

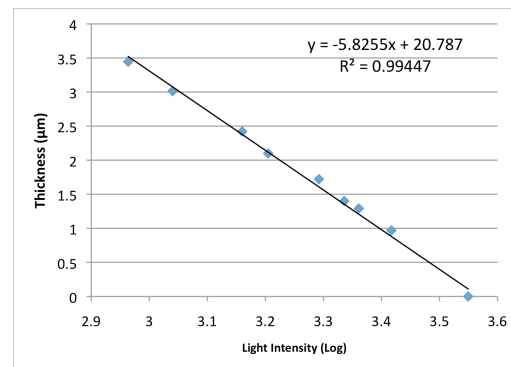


Figure 4: Result of calibration

UNIFORMITY OF CROSS WEB DIRECTION

The results of thickness measurement are shown in Fig. 5. Streaks in the coated layer could be easily observed and measured, as indicated in Fig. 5(a). A magnified view of the coating bead

revealed that there is a clear correlation between streak formation and downstream contact line position on the downstream die lip, as shown in Fig. 5(b). The thickness variation fitted well to the forms of the downstream contact line. The results show that if contact line could be pinned to the edge of die lip, the streaks should decrease and the uniformity of the coating, improved.

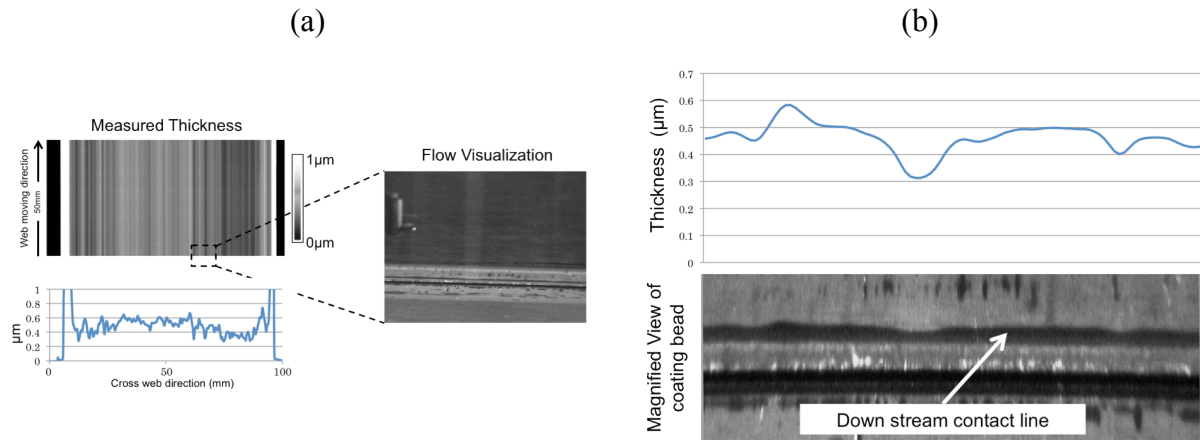


Figure 5: Results of thickness measurement and coating bead visualization (a) and their magnified view (b)

CONCLUSION

A simple thickness measurement method that consists of LED light source and digital camera was developed. The measurement system is powerful tool to analyze coating defects such as streaks. It was observed that the thickness variation and the forms of the downstream contact line is proportional relation. It suggests that pinning the contact line to the edge of die lip is important to improve the coating uniformity.

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