A new trend of wet coating technology from mass production to ubiquitous applications

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Wet precision coating has been widely used in the industry for decades. However, the coating technology is mainly still remaining only in the factories equipped with giant and heavy coating machines for mass production. The surge needs of additive manufacturing (AM) technology have demonstrated that there's still plenty of room in the labs, offices and even homes for the development of wet precision coating if there exists a smart, inexpensive and easy-controllable compact coating machine.

Coating is a complex multi-disciplinary technology that comprises different science and engineering aspects [1]. The new surge needs has brought a challenge for us to consider whether to select an extendable coating technology from those existing methods or to develop a totally new one for our future use. In this work, we have taken the slot coating method, one of the most representative methods in the wet coating technology, and precision capillary coating method, one of the most commonly used methods in the coating history, as two examples to show their modernization possibilities by using the newly available manufacturing methods and widely available materials in the 21st century.

The slot coating is a pre-metering coating methods in which the film thickness (h) of the coating film is predetermined by the given feed flow rate (Q), the coating width in the cross-web direction (W) and the substrate speed (V) and is independent of rheological properties of the coating fluid. From the mass conservation, the coated film thickness is written as

$$h = \frac{Q}{W \times V}. \qquad (1)$$

The pressure drop across the meniscus of the coating bead (ΔP_b), which is determined by Laplace pressure caused by the radius of curvature of the meniscus at the air-liquid interface [2], can be derived as:

$$\Delta P_b = 1.34 \frac{\mu^{2/3} V^{2/3} \sigma^{1/3}}{h}, \qquad (2)$$

where μ is the viscosity of the coating fluid, and σ is the surface tension across the air-liquid interface. Furthermore, by assuming that the coating liquid is flowing between two parallel plates, the pressure drop in the slot (ΔP_s) can be expressed as:

$$\Delta P_s = 12 \frac{\mu Q L}{W t^3}, \qquad (3)$$

where L and t are the length from the cavity to the slot exit and height of the slot, respectively. Combing Equation (1)-(3), the ratio of the pressure drops along the slot to the one across the coating bead can thus be written as:

$$\frac{\Delta P_b}{\Delta P_s} = 0.112 \frac{t^3 \sigma^{1/3}}{\mu^{1/3} L h^2 V^{1/3}}. \qquad (4)$$

By suitable choosing design of shim and coating die geometry (t and L), various coating fluids (characterized by σ and μ) for different expected conditions (h and V) can then be satisfactorily coated in different applications.

Based on a series of systematic analyses of the coating design, modern manufacturing technology and the application needs, we have taken the commercially available standard silicon wafer/glass plate as the working material of coating die (to save the tedious and costly precision machining processes for making the flat plane of traditional slot die), and applied the standard integrated circuit manufacturing process, or named as precision micromachining technology (sometimes also called as MEMS technique), to build the connecting channel geometry in the new coating head [3]. A super thin coater with only about 1 mm die thickness can be easily generated. Furthermore, the weight, manufacturing cost, delivery time of a coating head and also the size of whole coating machine can be significantly reduced; furthermore, the design flexibility has been dramatically increased. Fig. 1 shows (a) the fabrication process and (b) a schematic example of the new coating head of a slot die coater.

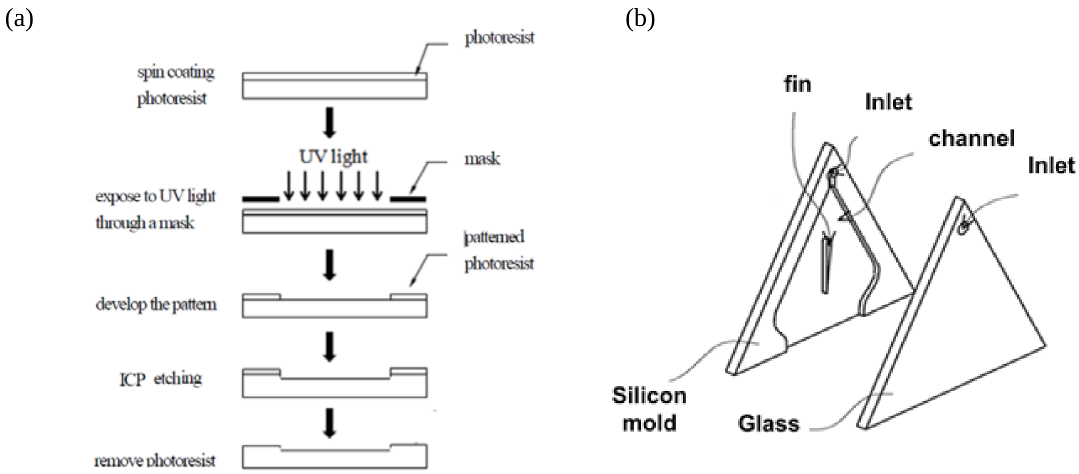

Fig.1 (a) fabrication process and (b) the assembly of a new slot coater [3]

To reveal one of the brand-new applications by using this new slot coater, a Thin-Film Direct Coating Western Blotting (TDC WB in short thereafter) method has been developed and tested for biomedical detection recently [4]. It demonstrated that the overall material cost savings by TDC WB can be as high as 3/4, and 2/3 antibody reaction time can be also saved in comparison with that of traditional WB. It has already shown a good potential for spreading of the wet coating technology into common laboratories with significant benefits in the near future.

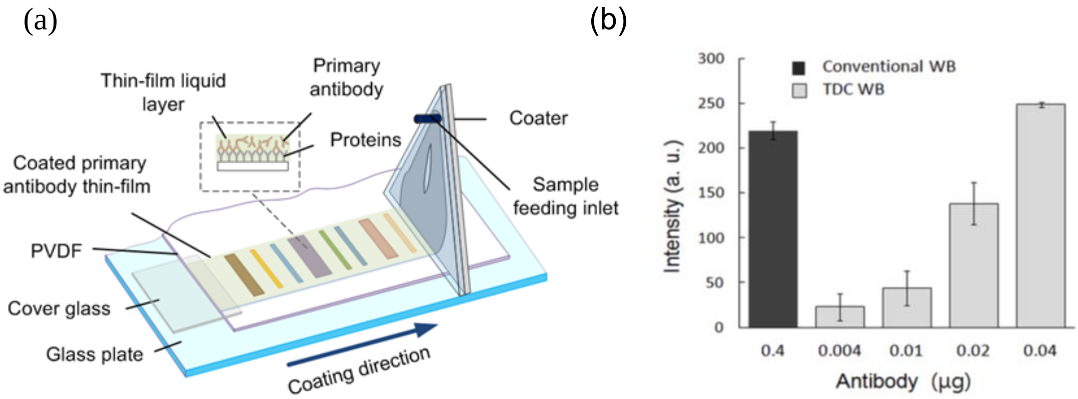

Fig. 2 (a) The sketch of the TDC WB (b) Comparison of results of conventional WB and TDC WB [4]

For limited or expensive coating materials in biomedical and industrial applications, the capillary coating method [5] combining with automatic traversing system is especially suitable for such applications. DNA microarray was a typical application case that was famous for its parallel processing efficiency, which has dramatically accelerated the Human Genome Project at the end of 20th century. This coating technology has been also enhanced in precision and applied to the OLED fabrication process. We coated PEDOT:PSS as hole injection layer (HIL) on the ITO glass as shown in Fig. 3 and resulted in some tens nm-thickness (dry film) with satisfactory coefficient of variation. More other applications will be demonstrated in the presentation.

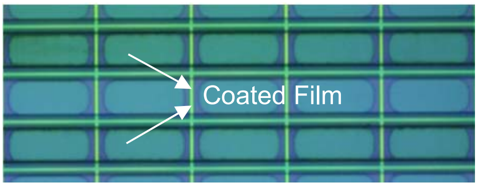

Fig. 3 HIL coating on OLED display [7]

By using the similar method combining the two-phase flow controlling technique, a novel high-speed pattern-coating technology, i.e., the “Air-Bubble Coating” (as shown in Fig. 4) have been developed with high potential for different industry applications [6-8].

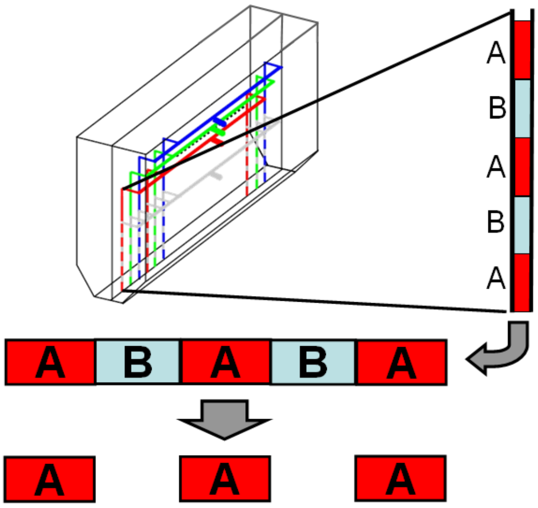

Figure 4 Schematic diagram of the “Air-Bubble Coating” for producing color filter. In each coating channel, the coating fluids are separated by air bubbles. During coating process, the fluids flow out of the channels sequentially and the air bubbles (B) are sacrificed to leave the liquid films (A) on the substrate [8].

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