# Continuous Coating of Discrete Areas of a Flexible Web by a Roll-to-Roll Process

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We have shown that wettability contrast may be used to direct a solution into designated areas, so that flexible substrates can be coated with a discrete pattern in a continuous, roll-to-roll manner. The first step is to pattern the substrate with wettable and non-wettable regions. When this substrate is over-coated with the target solution, it withdraws from the non-wettable regions and collects on the wettable target areas. Details of this continuous, discrete, coating method (CDC) along with some of the underlying physics and chemistry can be found in [1]. In this abstract, we outline the method and some of the strategies that may be employed to maximize its potential.

CDC involves the following steps, which are described with reference to Figure 1:

- Creating, on a continuous, lyophilic web of substrate, a lyophobic mask, shown in grey, that defines the non-wettable areas that ultimately will not be coated. The mask is then dried or cured (a).
- Coating the target solution, shown in black, onto the masked support (b).
- Destabilizing the solution layer so that it spontaneously rearranges, withdrawing from the lyophobic regions, to leave the coating on only the lyophilic cells.
- Allowing sufficient time for the target solution to recede from the masked areas and accumulate uniformly in the unmasked cells, and finally drying and/or curing the coated solution (c).

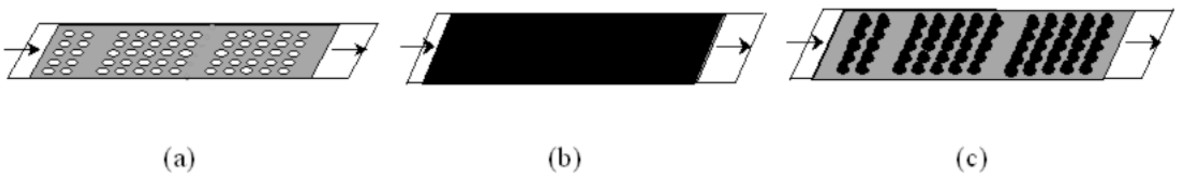

*Figure 1. Schematic illustration of the successive steps involved in CDC. a) Support masked with lyophobic pattern. b) Over-coating of target solution. c) De-wetting of solution into lyophilic regions.*

The material used for the lyophobic mask should be a low surface energy compound, such as a fluoropolymer, that gives a high contact angle with both aqueous and non aqueous coating solutions. Ideally, the method used to deposit the mask will leave a smooth and energetically uniform surface that will dewet both rapidly and cleanly. Flexography provides an effective and potentially in-line method. The substrate and coating solution will be determined by the product application, but will be chosen so that the solution adheres strongly to the substrate, with which it will exhibit a small or zero contact angle (*i.e.* the solution will wet the substrate). Both aqueous and non-aqueous coating solutions can be employed.

To maximize the speed at which the solution dewets the mask, the viscosity of the coating solution should be as low as practicable consistent with product requirements and effective coating. The equation

$$U_{dewet} = k\frac{\gamma_L\left(\theta^0\right)^3}{\eta} \qquad (1)$$

gives an indication of the dewetting speed that may be achieved [2]. Here $\gamma_L$ and $\eta$ are the surface tension and dynamic viscosity of the solution, $\theta^0$ is the equilibrium contact angle of the solution with the mask (in radians) and $k$ is a constant. Our experiments suggest a value of $k \sim 0.007$ for aqueous glycerol solutions on a fluorocarbon mask. The main value of this equation is that it shows the dependency on surface tension and viscosity and the strong influence of the contact angle.

Although a high dewetting speed is beneficial, the overall rate at which CDC may be carried out also depends in a complex way on the geometry of the mask, the distance between the lyophilic cells, the direction of dewetting (*i.e.* its angle with respect to the coating direction) and the number of dewetting fronts. Improvements in both coating uniformity and speed can be achieved by initiating dewetting at multiple points across the coated width using techniques such as pulsed air jets aligned and synchronized with the pattern. By careful design of the mask and suitable destabilization procedures, the overall process speeds can be significantly greater than $U_{dewet}$. In our study, CDC speeds up to 16 m/min were achieved.

Other factors that influence solution coating uniformity follow standard practice, such as the use of surfactants, optimization of solution rheology, and control of setting and drying. Surfactants need to be carefully selected for the application and their use minimized to avoid adverse effects on dewetting speed through the reduction in surface tension. One approach we found effective with aqueous poly(vinyl alcohol)-based coating solutions was to add a volatile solvent such as ethanol together with moderate amounts of surfactant. The sequential improvement in cell uniformity gained by adding first the surfactant and then the ethanol is illustrated in Fig. 2.

(a) (b) (c)

*Figure 6. Rectangular (15mm × 30 mm) cells coated with 150 μm of aqueous PVA solution at 23°C. (a) 5% w/w PVA. (b) 5% w/w PVA with 0.1% w/w surfactant 10G. (c) 5% w/w PVA with 0.1% w/w 10G and 50% w/w ethanol.*

Compared with conventional techniques, CDC enables relatively thick layers to be coated, with all the solution eventually ending up on the target areas. Careful pattern design and the use of scavenger areas allow one to manage any excess. The maximum and minimum wet thickness that can be achieved are largely dependent on the coating method. All methods, such as slide coating, curtain coating, blade or air-knife, gravure, ink-jet and electrospray may be employed. The practical coating thickness also depends upon the resolution demands of the coating pattern. The final thickness depends on the solvent loss during drying.

The spatial resolution of CDC is determined largely by the resolution at which the mask can be applied, but factors such as the thickness of the coated layer and the coating method all play a roll. As a rough guide (for a contact angle of 90˚ on the mask), coating thickness should not exceed half line-width to avoid excess solution spilling over onto the mask. In our work we focused on printing the pattern by flexography and then slide coating the target solution. The ability to coat complex patterns with features as small as 100 μm was demonstrated.

One benefit of CDC is that coatings of subsequent layers with the same pattern are self-aligned with the previous layer, since they are directed by the same wettability pattern. Alternatively, the pattern may be modified between coatings. Simultaneous, multilayer patterned coating is also possible in a single-pass operation. The facility to pattern thick layers of a coating solution is potentially useful for a wide range of applications, such as the creation of micro-lens arrays and large-scale flexible display manufacture, where low to medium resolution features are required. The method may also be used in combination with conventional techniques, such as screen-printing and vapor deposition, to create complex functional structures. Overall, CDC provides a useful addition to the armory of advanced pattern coating methods for new applications.

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[2] C. Redon, F. Brochard-Wyart, F. Rondelez. Dynamics of dewetting. *Phys. Rev. Lett.* **66** (1991), 715-718.