

Supplementary Information

Fabrication of highly electrical conducting patterns via inkjet printing of mussel-inspired organic nano-material

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1. Polydopamine nanoparticle (PDA-NP) synthesis and size characterization

The PDA- NP was synthesized using the protocol of Yan et al¹. Briefly, PH buffer agent Tris was dissolved in distilled deionized (DI) water at 10mM to form 250 mL solution to which 80 mL of 2-propanol was subsequently added. 125mg dopamine chloride was added to this mixture, and agitated by magnetic stirring at 300 rpm for 72hrs to form the PDA-NP suspension. Purification of the suspension was necessary to remove excess reactants and Tris buffer. This was accomplished by three cycles of centrifugation (3500 rpm for 1hr at 23°C) and re-dispersion of settled particulate matter in distilled DI water via vigorous shaking. The synthesized PDA-NP was dried under a stream of nitrogen. The ink was prepared by mixing the PDA-NP dry powder with distilled DI water followed by 10min ultrasonication. All chemicals were purchased from Sigma Aldrich (USA) and used as received.

The size distribution of PDA-NP was characterized by dynamic light scattering (Zetasizer-nano, Malvern). A representative size distribution of a 1 % wt sample of ink is shown in Fig. S1.

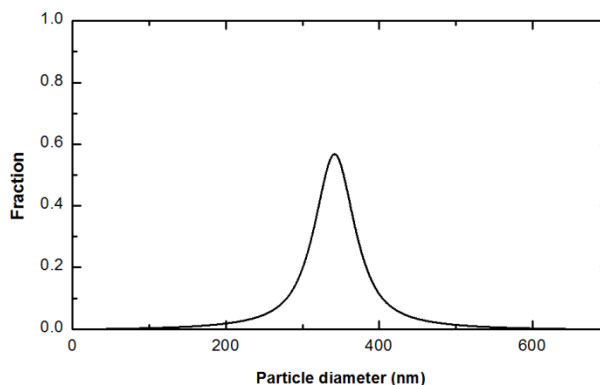


Fig. S1 Dynamic light scattering characterization of the size distribution of synthesized polydopamine nanoparticles

2. Substrate preparation

Glass microscope slides (2947, Corning) were used as substrates and were prepared as follows. All substrates were immersed in a Micro-90 (Cole-Palmer) aqueous solution (~ 1% v) and underwent ultrasonic agitation for 12min. Copious rinsing with distilled DI was followed by drying under a nitrogen stream. The substrate surface was then processed using argon gas plasma treatment (PE200-RIE, PlasmaEtch) to increase surface hydrophilicity. The plasma parameters were controlled at 100 mtorr pressure and 100sccm flow rate argon with 100W radio frequency (13.56 Hz) power for 3min. The substrates were used immediately after plasma treatment.

3. Inkjet printing apparatus

The inkjet printing apparatus utilized in this study is a custom-built system² consisting of a single piezoelectric inkjet nozzle (80µm diameter, Microfab) actuated by a waveform generator (JetDrive III, Microfab) and positioned via a computer-controlled x-y stage (MX80L, Parker). Drop formation was observed along an optical axis perpendicular to the nozzle with a video microscope (Sensicam QE, Cooke Corp.) to maintain drop diameter ($55 \pm 2 \mu\text{m}$), speed ($1 \pm 0.2 \text{ m/s}$), and ensure absence of satellites. Drop frequency was controlled at 100Hz by adjusting the frequency of the waveform generator. The center-to-center spacing between two adjacent printed drops was fixed at $50 \pm 2 \mu\text{m}$ and

controlled by the traverse speed of the inkjet nozzle over the substrate (5 mm s^{-1}). To visualize materials deposition process along with evaporation, a top-view camera (Kodak ES 1.0) and a bottom-view microscope (AxioObserver A1, Zeiss) were equipped.

4. Twin line formation during solvent evaporation

Evaporatively-driven twin line formation dynamics² was recorded during inkjet deposition of the PDA-NP suspension. Figure S2 shows the PDA-NP deposition process during evaporation via bottom-view microscope visualization.

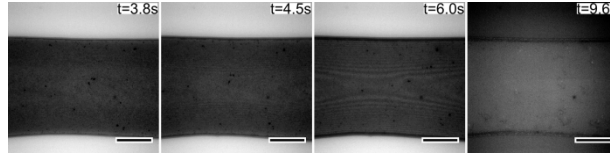


Fig. S2 Typical twin line formation dynamics² during evaporation (observed at the middle of a printed rivulet; the scale bars shown are $200 \mu\text{m}$ and the labels indicate time elapsed after the first ink droplet landed)

5. Electroless plating recipe

The electroless plating process used in this study followed a published report³. An aqueous bath consisted of 3.0mM silver nitrate, 18mM ethylenediamine, 35mM potassium sodium tartarate and 0.04mM 3,5- diiodotyrosine. The bath temperature was maintained at 30°C . Agitation was applied at 100 rpm with mechanical stirring during the entire plating process.

6. Low magnification scanning electron microscopy (SEM) characterization

Figure S3(a,b) show SEM images of printed PDA-NP lines that underwent 120min silver electroless plating process. Continuous silver structures only formed site-selectively on the patterned PDA-NP region. Minimal silver spotting can be observed on the bare glass substrate between the PDA-NP lines. This can be attributed to the silver particles that form and precipitate in the bulk of the plating bath due to the long plating time.

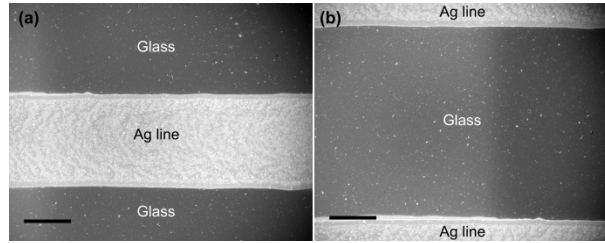


Fig. S3 Typical SEM images of printed PDA-NP lines after 120min silver electroless plating process: (a) a single silver line surrounded by bare glass substrate; (b) bare glass region between two silver lines (the scale bars shown are $200 \mu\text{m}$)

7. Calculation of the resistivity

For electroless plating time $t_{\text{plating}} < 58\text{min}$, only the pair of twin lines is conductive. The measured resistance (R_m) is expressed as:

$$\frac{1}{R_m} = \frac{2}{R_t} = \frac{2}{\rho_t L / (W_t \tau_t)} \quad (1)$$

$$\rho_t = \frac{2R_m W_t \tau_t}{L} \quad \text{for } t_{\text{plating}} < 58\text{min} \quad (2)$$

For $t_{\text{plating}} \geq 58\text{min}$, both twin lines and the interline region are conductive so that the measured resistance is:

$$\frac{1}{R_m} = \frac{2}{R_t} + \frac{1}{R_i} = \frac{2}{\rho_t L / (W_t \tau_t)} + \frac{1}{\rho_i L / (W_i \tau_i)} \quad (3)$$

where ρ_i , W_i and τ_i are the interline region's resistivity, width and thickness, respectively.

The procedure used to measure ρ_i independent of ρ_t is demonstrated as follows. First, the combined resistance R_m was measured, then the twin lines were mechanically sequentially scratched off and the new resistance R_m^* recorded. With the measured width of interline region (W_i^*) and its resistance (R_m^*), the resistivity of the interline region is:

$$\rho_i = \frac{R_m^* W_i^* \tau_i}{L} \quad (4)$$

Substituting (4) into (3), ρ_t can be written as:

$$\rho_t = \frac{2R_m W_t \tau_t}{\rho_i L - W_i R_m \tau_i} \text{ for } t_{\text{plating}} \geq 58 \text{min} \quad (5)$$

In the manuscript, the term W_i is replaced by $W - 2W_i$ where W is the width of the entire line.

References:

1. J. Yan, L. Yang, M.-F. Lin, J. Ma, X. Lu, and P. S. Lee, *Small (Weinheim an der Bergstrasse, Germany)*, 2013, **9**, 596–603.
2. V. Bromberg, S. Ma, and T. J. Singler, *Applied Physics Letters*, 2013, **102**, 214101.
3. G. O. Mallory and J. B. Hajdu, *Electroless plating: fundamentals and applications*, William Andrew, 1st edn., 1991.