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# A simple droplet pinning method for polymer film deposition for measuring charge transport in a thin film transistor

Hanying Li [a,b,*,1], Jianguo Mei [a,1], Alexander L. Ayzner [a,c], Michael F. Toney [c], Jeffrey B.-H. Tok [a], Zhenan Bao [a,*]

[a] Department of Chemical Engineering, Stanford University, Stanford, CA 94305, USA
[b] Department of Polymer Science and Engineering, Zhejiang University, Hangzhou 310027, PR China
[c] Stanford Synchrotron Radiation Lightsource, SLAC National Accelerator Laboratory, Menlo Park, CA 94025, USA

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Thin-film field-effect transistors (FETs) are widely used to evaluate charge transport properties of semiconducting polymers. Discovery of high performance materials require design and synthesis of new polymers. However, most polymers require multi-step synthesis and are difficult to be obtained in a large scale for comprehensive device evaluations. Here, we report a simple method to cast semiconducting polymer films from solutions with polymer concentration as low as 0.5 mg/mL, which is substantially less than typical values (~10 mg/mL) used in conventional spin coating method. Here, we demonstrate that using this method, our cast films of a previously-reported polymer (PDPP-TT2T) exhibited field-effect mobility ($\mu_{hole}$ = 0.89 ± 0.13 cm$^2$ V$^{-1}$ s$^{-1}$, $\mu_e$ = 0.025 ± 0.005 cm$^2$ V$^{-1}$ s$^{-1}$), which is comparable to the reported values using the same device geometry. Furthermore, we extend this method to examine cast films of a pair of polymers (PDPP-3T-Ref, PDPP-3T-Si) to study the effect of siloxane substitution in the side chains on the molecular packing and their subsequent FET performance. We observed that shorter $\pi$-stacking distance (3.61 Å) for the siloxane-terminated polymer, when compared to that for the reference polymer (3.73 Å), resulted in improved FET performance (e.g., $\mu_{hole}$ = 0.63 ± 0.046 cm$^2$ V$^{-1}$ s$^{-1}$ for PDPP-3T-Si vs $\mu_{hole}$ = 0.17 ± 0.062 cm$^2$ V$^{-1}$ s$^{-1}$ for PDPP-3T-Ref). Taken together, this work presents an efficient alternative film-casting approach to produce polymer FETs that consumes much less material for their fabrication, lending viability for evaluation of various polymeric materials.



## 1. Introduction

Semiconducting polymers are promising for cost-effective, light-weight, and flexible electronic and optoelectronic applications such as solar cells [1–3], light emitting diodes [4], and complimentary circuits [5–7]. Field-effect transistors (FETs) are widely used to evaluate transport properties of semiconducting polymers. In recent years, high-performance polymer-based FETs have widely been reported. For examples, hole mobility >1 cm$^2$ V$^{-1}$ s$^{-1}$ (to as high as 5.5 cm$^2$ V$^{-1}$ s$^{-1}$) [8–16], electron mobility about 1 cm$^2$ V$^{-1}$ s$^{-1}$ [5], and ambipolar polymers [17–19] with balanced hole and electron mobility both exceeding 1 cm$^2$ V$^{-1}$ s$^{-1}$ have been described, indicating a bright future for polymer electronics. In addition, studies on polymer-based FETs have better elucidated the relationships between polymer structures and charge transport properties [20–23], enabling a better understanding of the design criteria for better polymer electronic devices. It was determined that conjugated building block, side chains, molecular weight, and crystalline grain size and texture

* Corresponding authors. Address: Department of Chemical Engineering, Stanford University, Stanford, CA 94305, USA. Tel.: +1 650 723 2419; fax: +1 650 723 9780 (H.Y. Li).

*E-mail addresses:* Hanying_li@zju.edu.cn (H.Y. Li), zbao@stanford.edu (Z. Bao).

[1] These authors contributed equally.

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have all collectively played key roles in determining FET performance [9,13,16,24–37].

Polymer semiconductor thin films for FETs are usually fabricated via spin-coating from solutions. Although this approach provides uniform films, it typically requires solubility of the polymer in the order of several mg/mL to deposit a continuous film with required thicknesses of >40 nm. Inevitably, this results in excessive wasting of materials because most of the polymer solution is subsequently spun off. As such, the spin-coating technique is unsuitable for low solubility polymers, and is especially not cost-effective since laborious synthetic efforts are required to prepare sufficient material quantity.

In contrast, the drop casting approach, which is a relatively slow drying process, consumes much less materials since an entire solution droplet evaporates to the final polymer film. However, the disadvantage of drop-cast films is that they are not as uniform in thickness as those achieved from the spin-cast approach (Fig. 1A). Here, we demonstrate a modified drop casting method (Fig. 1B) to achieve uniform polymer films and high-mobility FETs, with an added advantage that it uses diluted polymer solutions and thus, greatly reducing polymer consumption.

## 2. Results and discussion

We first used a previously-reported [14,17,28] polymer, PDPP-TT2T (structure, Fig. 1D) as a model system to demonstrate that our film-casing method, namely droplet-pinned casting, has advantages over both spin coating and drop casting approaches. Specifically, we seek to demonstrate that our method is able to deposit polymer films with comparable high charge carrier mobility as spin coating while consuming much less material. Second, as

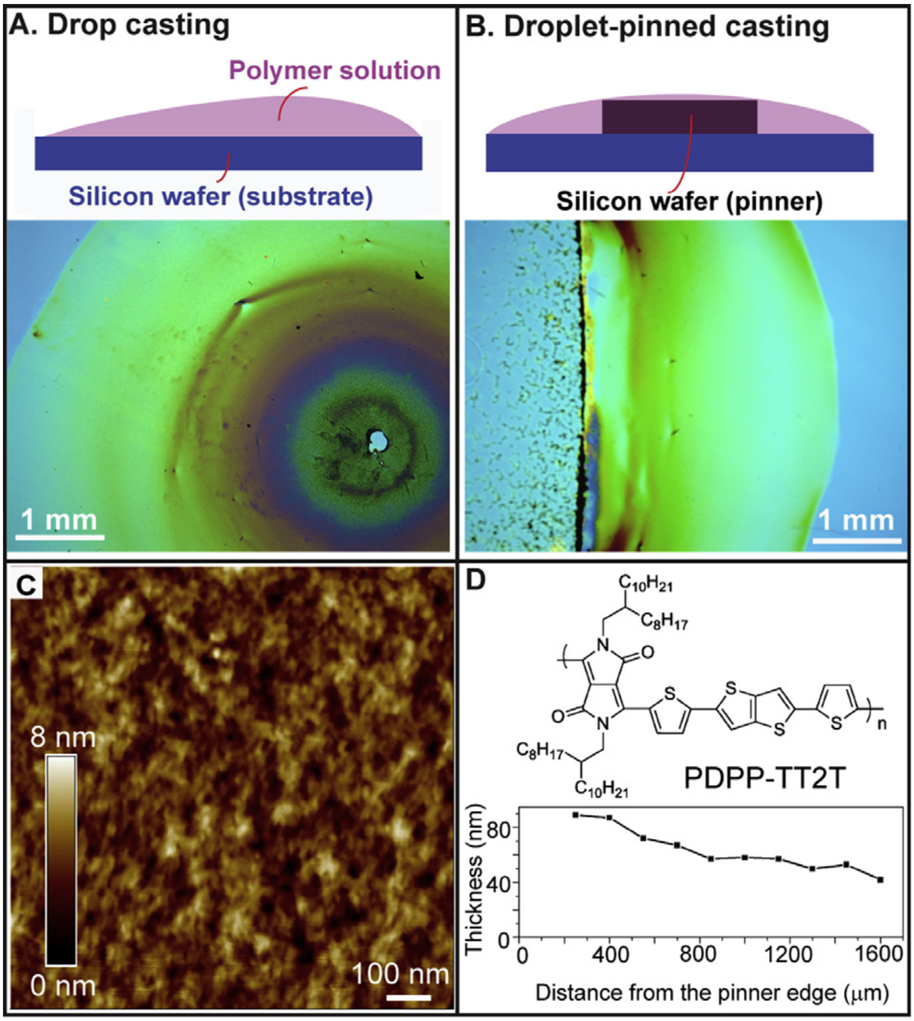


**Fig. 1.** Schematic illustration and images of PDPP-TT2T films prepared by the droplet-pinned casting method. (A) Schematic illustration of the drop casting process and optical microscopy (OM) image of a drop-cast film. The OM image shows that the film is non-uniform especially near the center. (B) Schematic illustration of the droplet-pinned casting process and OM image of a film prepared by it. The small piece of Si pinner immobilizes the droplet and provides a more steady drying condition, leading to more uniform films than drop casting shown in A. (C) An AFM image of a film prepared by droplet-pinned casting, showing smooth surface with a root mean square (rms) roughness of ∼1 nm. (D) AFM-measured film thickness as a function of the distance from the pinner edge. *Inset:* the molecular structure of PDPP-TT2T.