Solution-Grown Organic Single-Crystalline p-n Junctions with Ambipolar Charge Transport

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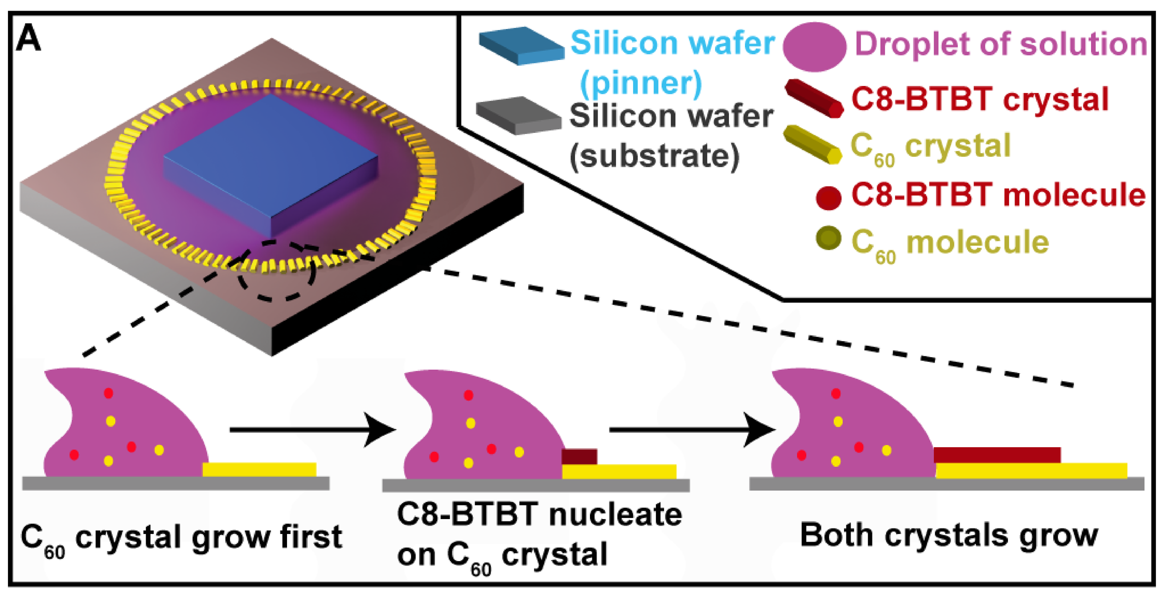
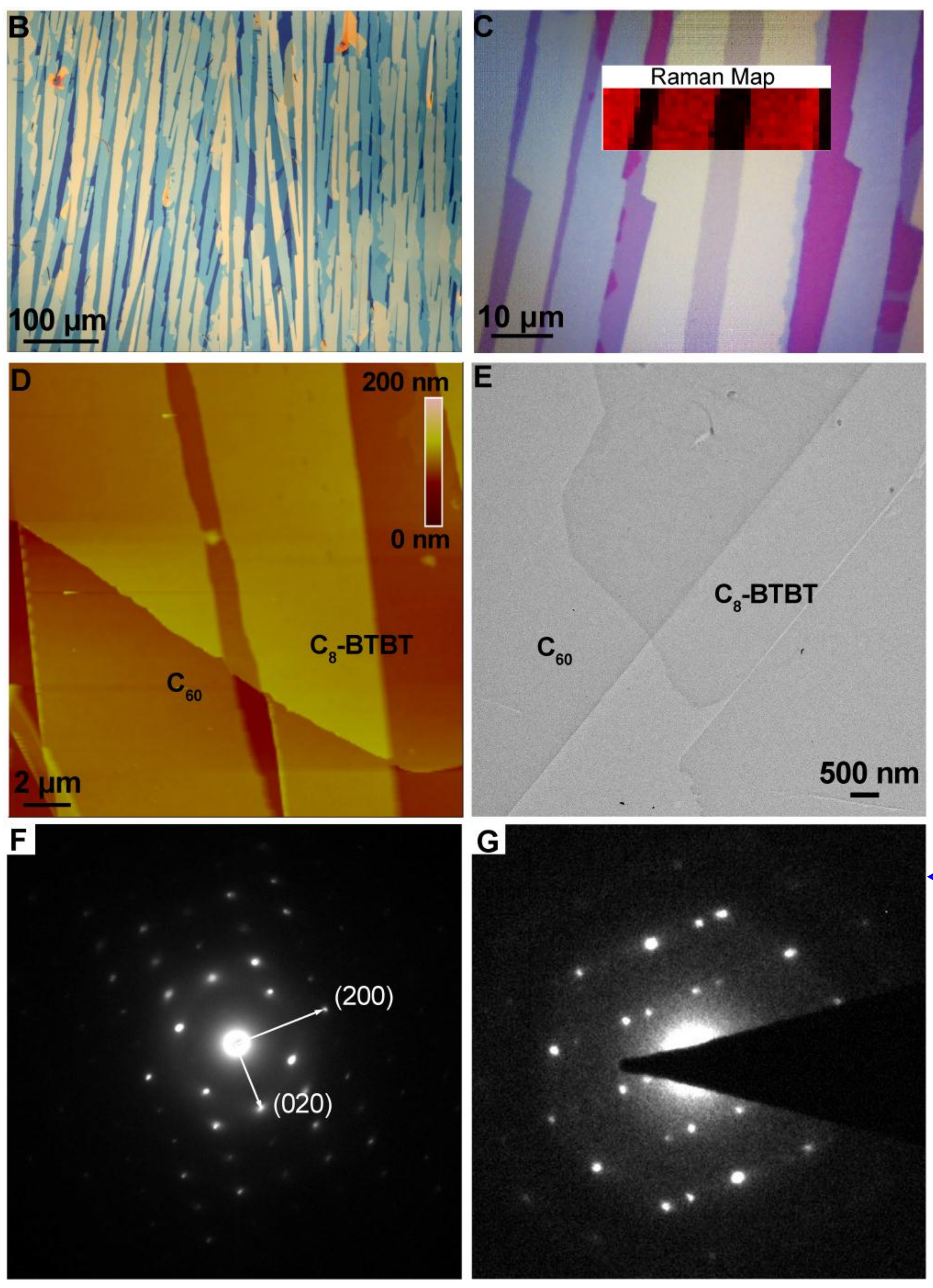
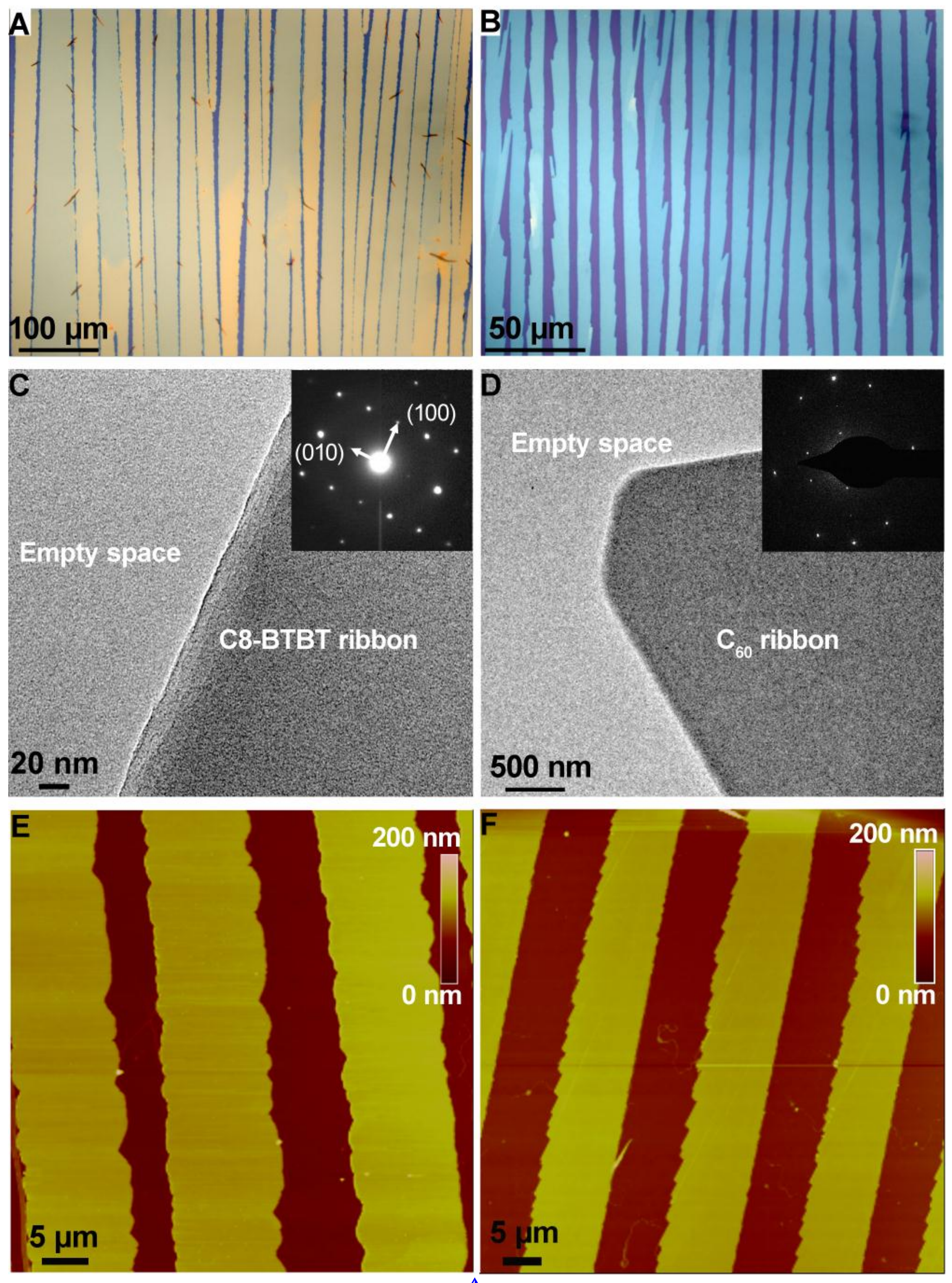
Introduction

Single crystals of organic semiconductors have the potential to show the best charge transport properties among organic materials. Typically, high-performance single-crystal electronic devices consist of one type of crystal, favoring either hole or electron transport. Devices composed of both hole and electron transporting single-crystals, such as single-crystalline p-n junctions, are expected to show ambipolar charge transport that is desirable for complementary circuits, organic light emitting diodes, and organic solar cells. However, it is challenging to prepare organic single-crystalline p-n junctions on which there are only a few reports. Here we demonstrate the growth of single-crystalline p-n junctions in a single step from a mixed solution of 2,7-dioctyl[1]benzothieno[3,2-b][1]benzothiophene (C8-BTBT) (p-type) and C60 (n-type), using the droplet-pinned crystallization (DPC) method previously reported.



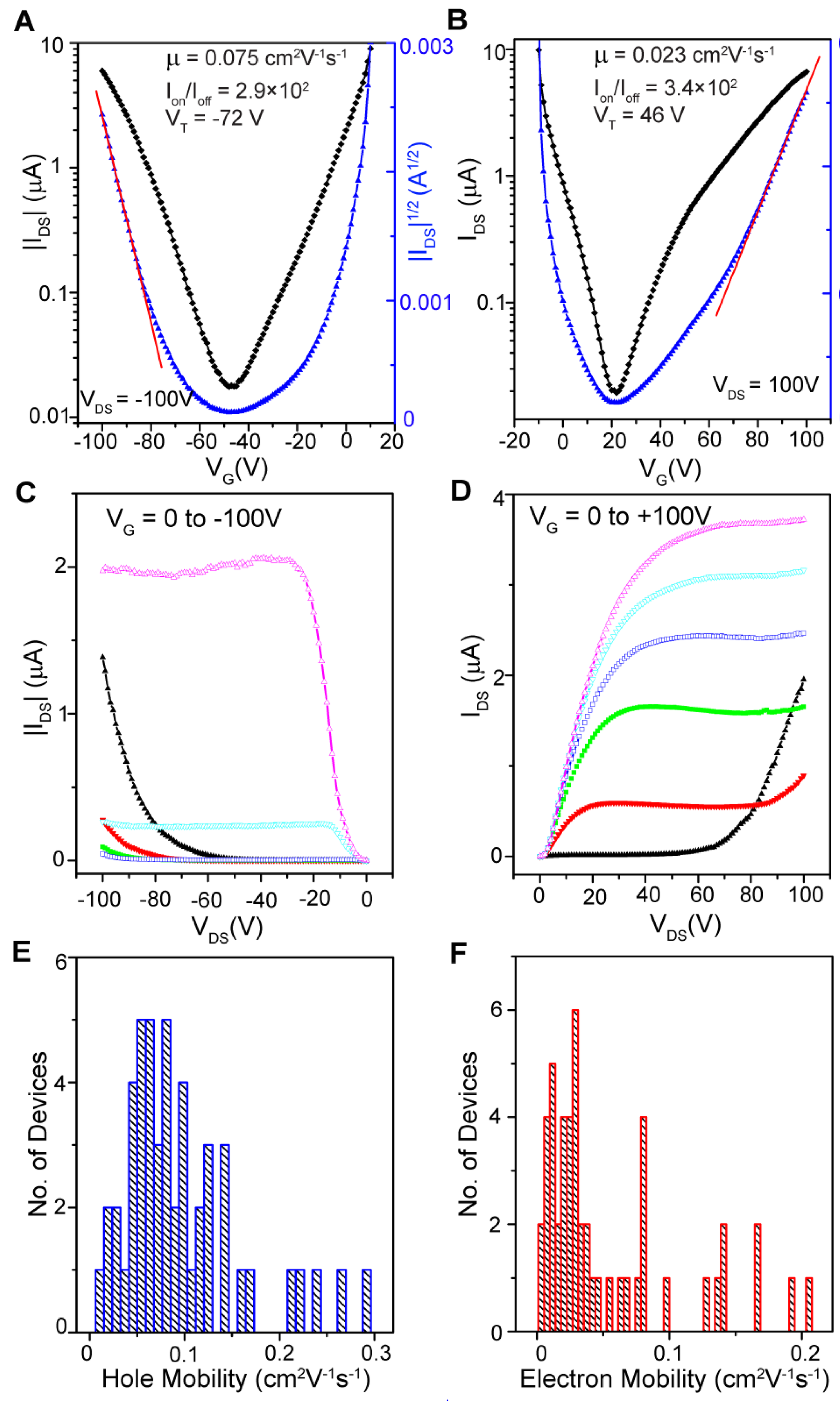
A. Schematic presentations of the DPC method. Typical DPC method to grow well-aligned single-crystals. For growth of p-n junctions, a mixed solution of C8-BTBT and C_{60} is used. C_{60} crystallizes first and C8-BTBT nucleates on it heterogeneously. Subsequently, both crystals grow simultaneously into junctions.





Well-aligned C8-BTBT and C_{60} ribbons were grown using the DPC method. OM, TEM, AFM characterizations are shown above.

B,C. Optical microscope images of p-n junctions. The blue ribbons are C_{60} crystals, while the light yellow ones are C8-BTBT crystals; Inset in C shows a Raman intensity map of the 1355-1509 cm^{-1} region (Raman shift of C_{60}) in an area where three blue ribbons were partly covered by yellow ribbons. **D. An AFM image of the p-n junctions,** showing C8-BTBT ribbon on top of C_{60} ribbon. **E. A TEM image** showing C8-BTBT and C_{60} ribbons stacking together. **F,G. SAED patterns** of individual C8-BTBT ribbon and C_{60} ribbon respectively.



FETs were constructed in bottom-gate, top-contact configuration. Typical transfer (A) and output (C) characteristics in p-channel operation mode under negative drain bias, typical transfer (B) and output (D) characteristics in n-channel operation mode under positive drain bias, histograms of hole (E) and electron (F) mobility calculated from 50 devices were shown above. Among them, the most balanced hole and electron mobility of 0.16 $cm^2V^{-1}s^{-1}$ and 0.17 $cm^2V^{-1}s^{-1}$ were achieved.

Conclusions

Organic single-crystalline p-n junctions were prepared with a solution method and ambipolar charge transport properties characterized. This work provides a new platform to study organic single-crystalline p-n junctions.

References

[1] HY Li et al., *J. Am. Chem. Soc.* **2012**, 5, 2760-2765; [2] YJ Zhang et al., *J. Am. Chem. Soc.* **2010**, 33, 11580-11584; [3] CC Fan et al. *Adv. Mater.* **2013**, 25, 5762–5766