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Ajay Virkar

Investigating the Nucleation, Growth, and Energy Levels of Organic Semiconductors for High Performance Plastic Electronics

Doctoral Thesis accepted by Stanford University
for Chemical Engineering, Stanford, CA, USA

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Preface

Plastic or organic electronics offer several advantages over conventional inorganic technologies. Firstly, the molecular structure of organic semiconductors and conductors can be tuned for various applications using synthetic chemistry. In addition organic thin films are flexible, and can be processed and patterned inexpensively. However, improving the thin film conductivity of organic semiconductors and conductors is necessary for widespread application and adoption. *The overall goal of this thesis is to investigate and control organic small molecule growth at surfaces in order to improve the performance of organic electronic devices.*

In Part I of the thesis, improving the charge carrier mobility of organic thin film transistors (OTFTs), the building block for plastic electronics, is discussed. The nucleation, stability and thin film growth of model organic semiconductors such as pentacene and C₆₀ are described with focus on correlating thin film structure to charge carrier mobility. More specifically, pentacene nucleation and growth on the most common substrate for OTFTs, an octadecylsilane (OTS) monolayer modified silicon oxide surface, is investigated. The role of the density of the OTS was determined to be a critical device parameter that impacts organic semiconductor nucleation and growth, and the charge carrier mobility, as the OTS transitions from an amorphous monolayer into a crystalline one. Dense OTS monolayers were fabricated using the well known ultrathin film Langmuir Blodgett (LB) technique, as well as a new spin-coating technique developed in our lab. The crystalline OTS monolayer serves as an excellent template for promoting desirable organic semiconductor thin film growth leading to high performance transistors. Therefore a crystalline OTS dielectric surface modification layer, which greatly improves organic semiconductor performance, may be important for the future success of OTFTs and organic circuits.

In the Part II of the thesis, lessons learned from studying organic semiconductor nucleation and growth are applied to improving the conductivity of carbon nanotube (CNT) networks for transparent electrode applications. Selective growth

of organic small molecules with low molecular orbital energies was used to greatly reduce the sheet resistance of CNT films by both decreasing junction resistances and stable doping of the semiconducting CNTs. The result is a material which has the highest value (in terms of transparency and sheet conductivity) of any carbon based transparent electrode.

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I was fortunate to work with three great postdocs during my time here. Jason Locklin introduced me to the field of organic electronics and surface chemistry and helped me learn how to think about experiments. His positive attitude and enthusiasm were contagious. I have learned more about thin film growth from Stefan than anyone. He is a very gifted scientist/teacher and a great friend. He also helped me think about the basic molecular processes which were occurring during physical phenomena and taught me to think about energy and interactions when investigating the material science I was interested in. Finally, Melbs is not only a great guy, and about the hardest working guy in lab, but he is also one of my closest friends and the person who I have spent the most stressful and exciting 3 AM lab nights with. Our collaboration on carbon nanotube electronics has been fascinating and rewarding.

I also want to thank my committee for all their help along the way. Curt and Andy met with me several times and helped me refine my thinking and improve the quality of my thesis. Also, Andy helped me a lot on an initial project on liquid crystals and his Polymer Physics course is the best class I took at Stanford. Alberto, is a true expert in organic transistors and he also provided a lot of guidance, helpful ideas and suggestions. I also enjoyed collaborating with members of his group.

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