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Molecular Dynamics Supported In Situ X-Ray Scattering on Organic Solar Cell Layers

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Motivation

Organic solar cells are presently only used for niche applications due to their semi-transparency, flexibility, low weight, and possibilities of custom designs in terms of colours and shapes, but with their low-cost solution processing and projected energy payback times of only fractions of those of silicon modules, the technology has a great potential to reach commercial viability within few years. However, upsampling the manufacture of organic photovoltaics (OPVs) from laboratory-scale devices to large-scale modules without compromising the device efficiency demands an understanding of the microstructure formation during post-deposition drying of the active layer. By combining the strengths of molecular dynamics (MD) modelling and in situ X-ray scattering, we aim to identify the processing parameters that are key to overcome this lab-to-fab challenge and move towards cheap, large-scale, and non-toxic solar cells with record efficiencies.

Simulating post-deposition drying

The efficiency of solution processed OPVs is crucially dependent on the 3D mesoscale thin-film morphology, which in turn is greatly influenced by solvent properties and evaporation rate. In order to reliably simulate active layer morphologies from MD simulations, we have scripted a range of evaporation schemes incorporating e.g. potential walls mimicking substrate–air interfaces as well as including a suspended solvent vapour above the film from which solvent molecules are continuously removed.

Approaching experimental time-scales

Using the MARTINI force field\(^2\) to coarse-grain our systems, the time- and length-scales relevant for morphology evolution are within reach of MD simulations.\(^3\)\(^4\) ~1000 times speed-up

Overcoming the lab-to-fab challenge

The knowledge gained from these studies can be used to pin-point the optimal processing conditions for large-scale manufacturing of organic solar cells.

Figure 1: Solvent evaporation simulation and examples of corresponding grazing incidence small-angle X-ray scattering (GISAXS) signals recorded at cSAXS, SLS.

Figure 2: All-atom and MARTINI coarse-grained models for chloroform (CF), PCBM\(^*\), and a dimer of C\(_{24}\)IDTBT.

Figure 3: Schematic of the roll-to-roll slot-die coating setup used for in situ GISAXS experiments at the cSAXS beamline, SLS (adopted from Ref. 2).

Figure 4: Fully roll-to-roll printed flexible OPV module.

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Methodology

We have used the GROMACS 2016.3 package for all MD simulations. The OPLS-AA force field\(^1\) formed the basis for the all atom simulations with our own parameterisations of e.g. most angles and in particular the intramonomer torsional potentials and sidechain couplings – these were based on quantum chemical DFT calculations. The coarse-grained simulations were based on the MARTINI force field\(^2\) and in part Ref. 4.

References

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