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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, upscaling the fabrication 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– and 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.\(^3,4\)

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 fabrication of organic solar cells.

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Methodology
We have used the GROMACS 2016.5 package for all MD simulations. The OPLS-AA force field\(^5\) formed the basis for the all atom simulations with our own parameterizations of e.g. most angles and in particular the inter-monomer torsional potentials and sidechain couplings – these were based on quantum chemical DFT calculations. The coarse-grained simulations were based on the MARTINI force field\(^6\) and in perf Ref. 4.

References
6. W. L. Jorgensen Group, Yale University, Department of Chemistry.

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

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

Figure 3: All-atom and MARTINI coarse-grained models for chloroform (CF), PCBM,\(^4\) and a dimer of C\(_6\)IDBT.

Figure 4: Scalably deposited, flexible OPVs (A. S. Gertsen et al., in peer review, Energy Environ. Sci.).

Simulation time

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