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Towards Molecular Dynamics Modelling of Mesoscale Bulk Heterojunction Morphologies

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Motivation

The performance of organic photovoltaics (OPVs) based on solution processed polymer:fullerene or polymer:polymer active layers is crucially dependent on the 3D morphology of the mesoscale bulk heterojunction. Here, we use Molecular Dynamics (MD) simulations of single indacenodithiophene-co-benzothiadiazole (IDTBT) polymers in solution to study their persistence lengths, since long persistence lengths are believed to be crucial for high charge mobilities and strong optical absorption. Furthermore, we present initial efforts towards simulating the dynamics of blend microstructure formation at reasonable computational costs by employing coarse-grained (CG) MD models, i.e. describing several atoms in a unified manner. Through this, we hope to aid the interpretation of experimental 3D imaging and refine the current, predominantly phenomenological, hypotheses which are based on indirect experimental probing of 3D morphology.

Persistence length simulations

For an oligomer consisting of $N$ repeat units, its persistence length can be estimated by an angle correlation function quantifying the mean angle $\Theta$ between vectors across different repeat units:

$$C_n(\Theta) = \left\langle \left| \cos \Theta_{i,i+n} \right| \right\rangle_i^n$$

$$= \frac{1}{N-n} \sum_{i=1}^{N-n} \left\langle \left| \mathbf{v}_i \cdot \mathbf{v}_{i+n} \right| \right\rangle_i^n$$

In order to extract a quantitative measure for persistence length, $n_p$ (in units of repeat units), we fit an exponential of type $\gamma$, $2$$

$$C_n(\Theta) \sim e^{-n/n_p}$$

Figure 1: Persistence length simulations of 2-ethylhexyl-IDTBT of different lengths; a 12mer (red) in all-atom (AA) chloroform and a 32mer (black) in coarse-grained (CG) chloroform. Both exponential fits are terminated at $n = 12$.

Coarse-graining the systems

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:

$> 400 \text{ times speed-up}$

We can thus simulate mesoscale bulk heterojunction morphologies in 3D.$^4,5$

Future work

We are presently extending the work on persistence lengths with a broader analysis and comparison to SAXS experiments, while we aim to use coarse-grained MD models in combination with in-situ X-ray analysis of OPV active layers to gain insight into the morphology evolution during solution processed roll-to-rolling printing.$^6$

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Methods

We have used the GROMACS 2016.3 package$^7$ for all MD simulations. The OPLS-AA force field and Ref. 8 formed the basis for the all-atom simulations of IDTBT but with our own parameterizations of e.g. the IDT-BT torsional potential. The coarse-grained simulations were based on the MARTINI force field$^9$ and in part Ref. 5.

References