Bio-inspired peptide nanostructures for organic field-effect transistors

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Introction

Peptide-based nanostructures derived from natural amino acids are superior building blocks for biocompatible devices as they can be used in a bottom-up process without the need for expensive lithography. A dense nanostructured network of L,L-diphenylalanine (FF) was synthesized using the solid-vapor phase technique. The formation of the nanostructures and structure-phase relationship were investigated by electron microscopy and Raman scattering. Thin films of L,L-diphenylalanine micro/nanostructures (FF-MNSs) were used as the dielectric layer in pentacene-based field-effect transistors (FETs) and metal-insulator-semiconductor diodes both in bottom-gate and top-gate structures. Bias-stress studies show that FF-MNS based pentacene FETs are more resistant to degradation than pentacene FETs using FF thin film (without any nanostructures) as the dielectric layer when both are subjected to sustained electric fields. Furthermore, it is demonstrated that the FF-MNSs can be functionalized for detection of enzyme-analyte interactions. This work opens up a novel and facile route towards scalable organic electronics using peptide nanostructures as scaffolding and as a platform for biosensing.[1]

Results and Discussion

We have been successful in using FF-MNSs as the dielectric layer both in top-gate and bottom-gate pentacene FETs. The nanostructures of FF-MNSs are obtained by a solid-vapor phase. **Fig. 1** shows a schematic of a pentacene FET with SEM images of the pentacene-PNS (top left) and only PNS film (top right) fabricated in our laboratory.[1] Highly concentrated peptide films yield microstructures, and upon evaporation of pentacene (which is the active organic semiconductor layer), a further promotion of a nanostructuring effect is observed. Using the standard saturation regime FET I-V characteristics [$\mu_{FET} = 2L/WC_0(\partial\sqrt{I_{ds}}/\partial V_g)^2$], where C_0 is the effective capacitance, W the channel width, L the channel length of the transistor, V_g and I_{ds} are the gate voltage and source-drain current, respectively, the charge carrier mobility is extracted. The p-type charge carrier mobilities were ~ 10^{-2}-10^{-3} cm^2/Vs, which is a bit lower compared to pentacene FET with other polymer dielectrics (such as PVP or PMMA).[1] As a comparison, FF peptide (without any nanostructures) was also used as a dielectric film in pentacene FETs. Although the charge carrier mobility was slightly higher in such devices, there was a complete break down under bias-stress (in less than 30 min) indicating that the nano/micro-structuring of the peptides is crucial for stability of FETs.

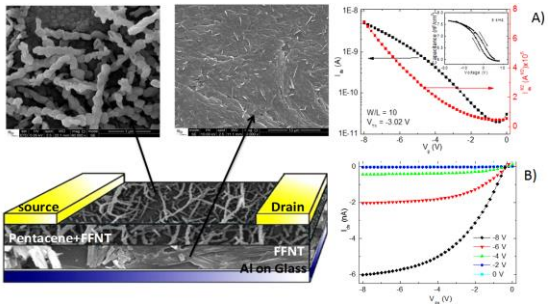

Figure 1. Schematic of a FF-MNS-based pentacene FET. The top left shows a SEM image of pentacene/FF-MNSs and the right image is only from a FF-MNS layer. The transistor output and transfer characteristics of the device are shown on the right panel. Ref. [1].

Using electrochemical methods we demonstrate that functionalized FF-MNSs are very sensitive in protein (Urs) detection. Electrochemical impedance spectroscopy shows that both interfacial capacitance and charge transfer resistance change significantly when the FF-MNS layer is functionalized with pyrenebutanoic acid and upon interaction with Urs. A second method using square wave voltammetry was also used to show the efficacy of FF-MNSs in Urs detection. Functionalized FF-MNSs in top-gate OFETs are thus a viable platform for future applications in protein-analyte detection.

Conclusion

Our work reports for the first time the use of diphenylalanine peptide nanostructures as the gate dielectric in OFETs. We show that for OFETs to withstand a bias-stress effect, the nanostructured morphology of the peptide layer is essential. FF-MNSs further allow a simple fabrication of top-gate pentacene OFETs, which could pave the way for enzyme–analyte sensing applications in the future.

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