Prof. Aram Amassian's group collaborates with Imperial College scientists to develop faster organic thin-film transistors.

The speed with which your smart phone reacts to your touch as you swipe it is governed by the rate at which electrical charges move through the various display components. Scientists from Imperial College London have collaborated with colleagues at King Abdullah University of Science and Technology (KAUST) to produce organic thin-film transistors (OTFTs) that consistently achieve record-breaking carrier mobility through careful solution-processing of a blend of two organic semiconductors. The OTFTs and their processing methods will be very useful for a host of future electronic applications.

Professor Aram Amassian's group at KAUST teamed with Dr. Thomas Anthopoulos, Department of Physics, Imperial College London, and colleagues Professor Iain McCulloch and Dr. Martin Heeney, Department of Chemistry, to develop and characterize a composite material that enhances the charge transport and enables the fabrication of organic transistors with record-breaking carrier mobility. They described their novel semiconductor blend in a **joint paper published in Advanced Materials**:

In response to the challenge of expensive vacuum deposition processes, synthetic organic chemists have been increasingly successful in synthesizing conjugated small-molecules that are soluble. "While they have a tendency to form large crystals, reproducible formation of high quality, continuous and uniform films remains an issue", remarked Dr. Anthopoulos, lead Imperial investigator. By contrast, polymer semiconductors are often quite soluble and form high-quality continuous films, but, until recently, could not achieve charge carrier mobilities greater than 1 cm2/Vs.

In this collective work, chemists from Imperial, working together with device physicists in the College's **Centre for Plastic Electronics** and material scientists at KAUST combined the advantageous properties of both polymer and small molecules in one composite material, which offers higher performance than do small-molecule and polymer semiconductors alone, while enhancing device-to-device reproducibility and stability.

"A key aspect of this work is that it appears to eliminate the high degree of anisotropy typically observed in polycrystalline films of small-molecule semiconductors," said Professor John Anthony of University of Kentucky, a pioneer in the design and synthesis of high-performance small-molecule semiconductors, who was not directly involved in this research. "This anisotropy leads to significant device-to-device variations in performance, which makes them difficult to use in large-scale commercial applications."

The improved performance is attributed in part to the crystalline texture of the small-molecule component of the blend and to the flatness and smoothness achieved at the top surface of the polycrystalline film. The latter is crucial in top-gate, bottom-contact configuration devices, whereby the top surface of the semiconductor blend forms the semiconductor-dielectric interface when solution-coated by the polymer dielectric.

The smoothness and continuity of the surface and the absence of apparent grain boundaries are uncommon for otherwise highly polycrystalline small molecules in pure form, suggesting that the polymer binder planarizes and may even coat the semiconductor crystals with a nanoscale thin layer. "The performance of the polymer-molecule blend exceeds 5 cm2/Vs, which is very close to the single-crystal mobility previously reported for the molecule itself," noted KAUST co-author Prof. Amassian.

The materials scientists at KAUST addressed the challenging questions about the phase separation, crystallinity, and morphology of the organic semiconductor blend by using a combination of synchrotron-based X-ray scattering at the D1 beam line of the Cornell High Energy Synchrotron Source (CHESS), cross-sectional energy-filtered transmission electron microscopy (EF-TEM), and atomic force microscopy in topographic and phase modes.

"This work is particularly exciting as it shows that by bringing to bear complementary powerful characterization techniques on these complex organic blends, one can learn a lot about how they work. It's a textbook example of a structure-property relationship study highlighting the usefulness of such collaborations." said Professor Alberto Salleo of Stanford University, an expert on advanced structural characterization of polymer semiconductors and not a member of the research team. "A mobility of 5 cm2/Vs is already a spectacular number. The methods described in this manuscript, however, chart the way for researchers to obtain even higher mobilities."

The team is continuing its collaboration in the hopes of designing even better materials and processes by understanding how the material design and solution processing conditions lead to these extraordinary film properties. "The in-situ diagnostics methods developed by the KAUST group will reveal the intricacies of the solution-processing and phase separation of the blend," commented co-author Dr. Martin Heeney. "We look forward to using this insight to improve these devices even further."

"In principle, this simple blend approach could be applied to a range of existing small molecules and polymers, and lead to the development of organic transistors with performing characteristics well beyond the current state-of-the-art," added Dr. Anthopoulos.