In-Situ Charging and Charging Map for Characterization of Electronic Materials

Dr. Wen-Shan Zhang[1], Dr. Nikolai Hippchen[1], Prof. Dr. Rasmus R. Schröder[2], Prof. Dr. Uwe H. F. Bunz[1]

[1]Institute of Organic Chemistry, Ruprecht-Karls-University Heidelberg, Im Neuenheimer Feld 270, Heidelberg, Germany, [2]Bioquant, Ruprecht-Karls-University Heidelberg, Im Neuenheimer Feld 267, Heidelberg, Germany

Background incl. aims
Electronic materials have garnered significant interest due to their potential applications in a wide array of important electronic devices, including transistors, sensors, solar cells, and more. Achieving high-performance devices and developing new electronic materials for future technologies relies fundamentally on understanding electronic processes through advanced characterization techniques. Currently, the characterization of the active layer in a device can offer either global functional information, such as with the most current-potential methods, which only demonstrate the impact of defects on performance without detailing the quantity and distribution of defects, or provide localized details, as seen with techniques like atomic force microscopy and conventional scanning electron microscopy (SEM), which may not capture the entirety of the case. Therefore, we present a novel characterization method capable of acquiring both kinds of information from the active layer, which would be highly beneficial for comprehending the structure-morphology-performance relationship.

Methods
The use of Ultra-low voltage (ULV) SEM has become increasingly crucial for investigating beam-sensitive materials, particularly organic molecules and polymers, due to its ability to significantly suppress beam damage. Additionally, the charging behavior under ULV conditions becomes more material-characteristic compared to conventionally used beam energies (e.g., < 500 eV). Fine-tuning the beam energy within the range of 10-200 eV can result in either negative or positive surface charging [ref.1], depending on factors such as beam energy, beam current, charging density, and the conductivity of the materials. This capability allows us to simulate the working state of a p- or n-type transistor by in-situ generating the required charge type. Moreover, the surface potential resulting from charge flow anomalies enables us to visualize morphological defects along the pathways. Through post-imaging processing, we can calculate the real working pathway for charge-carrier transport, subsequently correcting the charge-carrier mobility [ref. 2].
Furthermore, under ULV conditions, we can collect the energy distribution spectrum of emitted electrons, which can be transformed into a surface charging map. The gradient of the charging attenuation provides structural information within (poly)crystalline domains [ref. 3].

Results
Utilizing the first method mentioned above, we successfully corrected 11 organic thin-film transistor devices, resulting in highly reliable mobility values that accurately reflect the material's charge transport capability. With the latter method, we can estimate the charge-carrier mobility from polycrystalline thin films, which align well with the calculated values. Of particular interest is our ability to distinguish between various crystalline domains with different molecular orientations. Furthermore, we can determine molecular orientation by observing the gradient of the charging attenuation, a technique which, to the best of our knowledge, represents the first application of SEM for this purpose.

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Conclusion

By employing in-situ charging and charging maps via ULV-SEM, we can gather information regarding various morphological phenomena. This enables us to directly correlate device performance with the chemical structure of the active material and its morphology, thereby facilitating the design of novel structures and the optimization of the active layer in electronic devices.

Graphic:

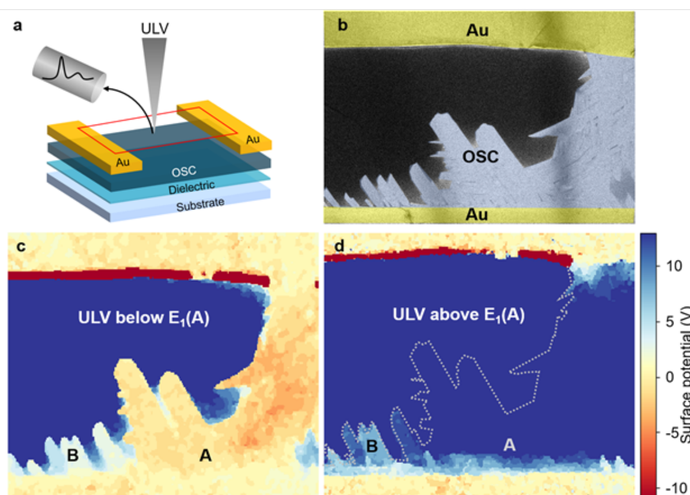

Figure 1. Electron Spectroscopic Characterization of an Organic Thin-Film Transistor Using Ultra-Low Voltage (ULV) Scanning Electron Microscopy (SEM).(a) Working principle (OSC stands for organic semiconductor).(b) False-colored SEM image of a channel section of a transistor.(c) and (d) In-situ charging maps of the channel section as shown in (b). A and B represent two different molecular orientations in the crystalline OSC thin-film.

Keywords:

charging map, molecular orientation, mobility

Reference:

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[3] Manuscript in preparation.