Exploring Unipolar Inverters Based on Organic Electrochemical Transistors

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The first Organic Electrochemical Transistor (OECT) was reported in the early 80s. Since then, they have garnered attention from a broad scientific community due to their good ion-to-electron transduction. Lately, advances in material engineering and an improved understanding of physical chemistry have enabled these devices to achieve high current density, low operating voltage, open-air stability, and good switching speed. These characteristics have led to the application of OECTs in complex devices, including biosensors, artificial neurons, logical computing to name a few. One of the simplest OECT-based circuit is the unipolar inverter, where the voltage-controlled switching characteristic of the transistor is used to invert electrical signals and perform binary operations. Unipolar inverters are constructed either by associating a transistor with a resistor or by using two transistors of the same polarity. As the name suggests, they invert a high/low input signal into a low/high output signal, being the building blocks for digital processors and modern electronics. In this study, we investigated the fundamental characteristics of inverters based on PEDOT:PSS and P3HT organic semiconductors with aqueous electrolytes. We explored the circuit arrangements for both materials and their relationship with electrical characteristics. Additionally, by sweeping the load resistance (R_{ld}), we examined the relationship between this parameter and maximum gain, switching speed, and the stability of the logic levels. We observed a deviation from the ideal values for the logic levels in both materials. Through circuit analysis, we were able to model this deviation by considering the OECT channel resistance. Our results indicate that there is an optimal load resistance to achieve logic levels as close as possible to the ideal values, which is related to the product of the off and on-channel resistances. For PEDOT:PSS devices, the gain exhibits a parabolic shape with respect to R_{ld}, while for P3HT, it scales linearly with R_{ld}. For both cases, the optimal load resistance deviates from the point of maximum gain, indicating that a trade-off exists between achieving maximum gain and other performance parameters such as stability of the logic levels. Therefore, it is necessary to carefully consider and prioritize which inverter parameter is most critical for the specific application or desired performance characteristics Our research has allowed us to establish guidelines for experimental setups for different channel materials and to challenge findings from published studies. Additionally, our results form the basis for electrochemical modeling of unipolar inverters, representing an unprecedented contribution to the field.

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