

Optimising Organic Bilayer Heterojunction Sensors through Device Geometry and Operating Bias

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Summary:

Organic bilayer heterojunctions (BLHs) are promising chemical sensor devices owing to interfacial charge transport. Here, $\text{CuF}_{16}\text{Pc}/\text{LuPc}_2$ devices are studied for ammonia detection with varied CuF_{16}Pc sublayer thickness, humidity (RH) and applied bias. The response and calibration characteristics show that both geometry and operating conditions strongly affect the device sensitivity. These results provide practical guidelines for tuning organic heterojunction sensor performance.

Keywords: organic semiconductors, bilayer heterojunction (BLH), ammonia sensing, phthalocyanines, sensitivity tuning

Background, Motivation and Objective

Organic bilayer heterojunctions (BLHs) have emerged as promising platforms for chemical sensing because their electrical response is strongly governed by interfacial charge transport between two molecular semiconductors. In such devices, the contact between materials of opposite majority-carrier polarity can lead to charge accumulation at the interface, resulting in enhanced conductivity and improved sensing characteristics [1,2]. Phthalocyanine-based BLHs are particularly attractive for gas sensing because their electronic properties can be modulated by interactions with electron-donating or electron-withdrawing analytes, including ammonia [3].

In $\text{CuF}_{16}\text{Pc}/\text{LuPc}_2$ BLH devices, the highly resistive CuF_{16}Pc sublayer and the more conductive LuPc_2 top layer form an interfacial transport pathway, as illustrated in Fig. 1. The nonlinear current–voltage characteristics of these devices indicate the presence of an effective transport barrier, which separates low-bias and high-bias operating regimes. This behaviour suggests that sensor performance may depend not only on the chemical nature of the active layers, but also on the position of the operating point along the I–V curve.

The objective of this work is therefore twofold. First, we investigate whether the effective transport barrier can be tuned by changing the thickness of the CuF_{16}Pc sublayer. Second, we examine how the applied bias voltage can be

used as an operating parameter to enhance the relative response and sensitivity of the BLH ammonia sensor.

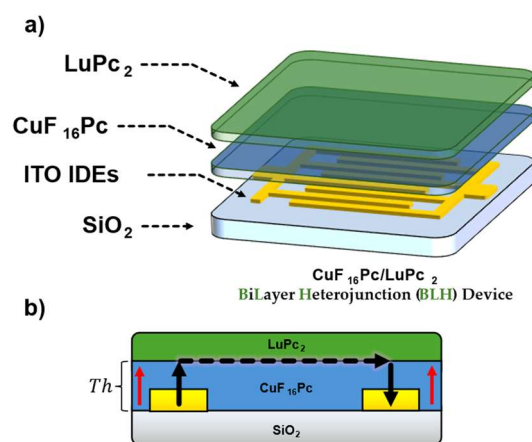


Fig. 1. Bilayer Heterojunction (BLH) sensor device. **a)** Architecture of the heterojunction consisting of highly resistive bottom CuF_{16}Pc sublayer and conductive LuPc_2 top layer. **b)** Sketch BLH cross-section with the indication of current pathway through the junction.

Description of the New Method or System

The investigated devices consist of $\text{CuF}_{16}\text{Pc}/\text{LuPc}_2$ bilayer heterojunctions, in which the CuF_{16}Pc sublayer thickness was systematically varied (≈ 50 , 75 and 100 nm) while the LuPc_2 top layer thickness was kept constant (50 nm). This approach enables the influence of the bottom resistive layer on charge transport and sensing behaviour to be isolated. To the best of our knowledge, this is the first systematic

investigation of the role of CuF₁₆Pc sublayer thickness in tuning the operating regime and sensitivity of this BLH sensor system.

In addition, the ammonia response was investigated under different applied bias voltages within a single automated measurement protocol. The measurements were performed using a Keithley 6517 electrometer controlled by in-house software developed in NI LabVIEW. This setup enabled programmed gas exposure cycles combined with controlled changes in the applied voltage bias, allowing the sensor response, recovery and calibration behaviour to be evaluated as a function of the electrical working point.

This methodology provides a direct way to correlate device geometry, nonlinear electrical transport and gas-sensing performance in organic BLH.

Building on preliminary results presented previously [4], the present work provides a systematic investigation of CuF₁₆Pc sublayer thickness and applied bias voltage as coupled parameters for tuning the sensitivity of CuF₁₆Pc/LuPc₂ BLH ammonia sensors.

Results

Original Fig. 2. shows the I–V characteristics of the prepared CuF₁₆Pc/LuPc₂ BLH devices with CuF₁₆Pc sublayer thicknesses of 50, 75 and 100 nm, while the LuPc₂ top layer thickness was fixed at 50 nm. The curves clearly show that increasing the CuF₁₆Pc sublayer thickness shifts the nonlinear transport regime towards higher voltages. This behaviour indicates that the effective transport barrier of the BLH device can be tuned through the geometry of the heterostructure.

The shift of the transport barrier has a direct influence on the sensing characteristics. When the devices are operated at the same applied voltage, thicker CuF₁₆Pc sublayers exhibit higher baseline resistance. This leads to a larger relative response upon ammonia exposure and, consequently, to a higher calibration sensitivity. The observed trend demonstrates that sublayer thickness is not merely a fabrication parameter, but an active design variable for controlling the operating regime of the sensor.

Following this observation, the applied bias voltage was further investigated as a second tuning parameter. By shifting the working point of the device towards lower voltages, closer to the high-resistance nonlinear regime, the ammonia response was enhanced. This resulted in improved sensitivity of the BLH device. These findings show that the performance of organic heterojunction sensors can be optimised not only by modifying the device architecture, but also by selecting an appropriate electrical operating point.

More generally, this behaviour may be relevant to other chemical sensors exhibiting nonlinear I–V characteristics. The present work therefore provides an in-depth study of how interfacial transport, device geometry and operating bias jointly determine the performance of organic BLH ammonia sensors.

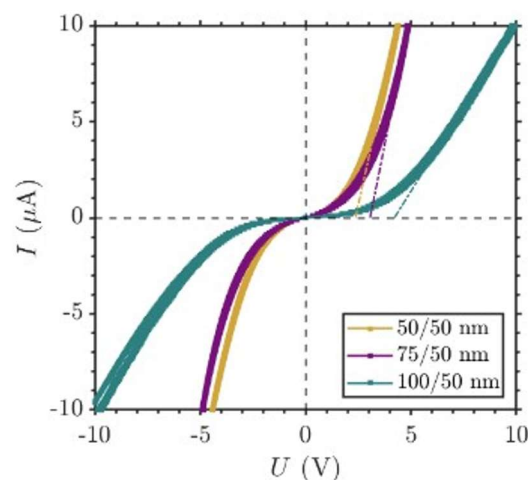


Fig. 2. I–V Characteristics of the prepared BLH devices with the indication of the shifting energy barriers.

References

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