Abstract and Keywords

In this dissertation, we have reported the fabrication and characterization of phototransistors based on nanomaterials, designed for various advanced electronic applications. The devices are fabricated using nanostructures, including 2D materials and lanthanide nanocrystals. We developed a stimulus-gated neuromorphic watermarking strategy for hardware security using a flexible array of low-voltage UV-triggered synaptic phototransistors based on 2D siloxene nanosheets and organic semiconductor pentacene. By emulating biological synaptic behavior, a dynamic watermark is designed that can be unlocked only via application of UV light pulses possessing precisely defined parameters of intensity, pulse duration, and pulse interval, thereby providing multi-layered activation-dependent security. Such activation-dependent control renders the watermark inherently resistant to reverse engineering, safeguarding IP while simultaneously deterring counterfeiting. A deterministic EPSC stimulus model is derived that quantitatively links the optical input to synaptic current evolution, enabling reproducible logic-state transitions. In addition, we developed a low-voltage UV-responsive synaptic phototransistor based on WS_2 nanosheets and the organic semiconductor pentacene. A flexible neuromorphic UV vision array is designed, possessing multifunctional capabilities such as image recognition, memory, erasure, and noise reduction under UV exposure. This work demonstrates the potential of synaptic phototransistors for artificial UV vision technologies. Furthermore, we designed a short-wave infrared phototransistor using 2D black phosphorus flakes, operating at a wavelength of 2200 nm. This phototransistor achieved a high responsivity of 126 AW^{-1}, at a low effective incident optical power of 2 nW and a low drain-source bias of -0.8 V. A detectivity of 1.2×10^9 Jones was also obtained under similar conditions. By modulation of the gate voltage, the responsivity and detectivity can be tuned. Also, the temperature-dependent photoresponse has been studied over a broad range from room temperature to 10 K. Additionally, we developed a multistate, low-voltage, flexible, nonvolatile memory (NVM) organic phototransistor (OPT) based on $LaPO_4:Tb^{3+}$ lanthanide nanocrystals. The device exhibits four stable current states with a pronounced I_{ON}/I_{OFF} ratio of 10^5 and resilience to mechanical bending. By exploiting the device's multilevel storage, secure data encryption is implemented on a flexible transistor array through current-to-binary state mapping, yielding a dual-layer security scheme that couples encryption mapping with voltage-dependent decryption to strengthen data protection. We further introduced a base-4 algorithm for binary-to-decimal/hex/octal conversion using 2-bit symbol mapping. This leverages the 2-bit transistor architecture to enhance cell-level density while simplifying converter logic, yielding a compounded transistor count reduction.

Keywords: phototransistors, 2D materials, lanthanide nanocrystals, artificial synaptic transistors, nonvolatile memory, neuromorphic watermarking, organic field-effect transistors (OFETs), low-voltage operation, flexibility, short-wave infrared phototransistor, information encryption, hardware reduction, neuromorphic UV vision