ChemistrySelect

Research Article
doi.org/10.1002/slct.202300026

Chemistry Europe
European Chemical Societies Publishing

www.chemistryselect.org

Tetraphenylethene Carbothioamide-Based Organic Stimuli-Responsive Mechanochromic Memristive Devices with Non-Volatile Memory and Synaptic Learning Functionalities

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A tetraphenylethene-based organic material (TC) was synthesized to demonstrate mechanochromic memristive properties. The synthesized material shows aggregation-induced emission and mechanochromic properties. The solvent optimization study reveals that the ethyl acetate-based TC switching layer shows good resistive switching (RS) properties. To get the mechanochromic memristive properties, different external stresses (ground, heat, and fume) were applied to the TC materials, and these materials were used for the fabrication of switching layers. The results asserted that ethyl acetate and grinding-based TC devices show good digital-type RS effects and non-volatile memory properties. On the other hand, heating and fuming-based TC devices show analog and quasi-digital type RS effects, respectively, and mimic various biological synaptic properties such as potentiation-depression, excitatory postsynaptic current, and paired-pulse facilitation index. The present investigation is important to fabricate stimuli-responsive memory and artificial synaptic devices for futuristic non-volatile memory and neuromorphic computing applications.

Introduction

Conventional silicon-based electronic devices are facing a serious bottleneck in terms of memory, processing, heat, and power consumption.[1] These bottlenecks can be resolved by either designing a new kind of computing architecture or utilizing the functional materials for the fabrication of novel memory and computing devices. The latter approach is convenient because of the availability of functional organic and inorganic nanomaterials. These functional nanomaterials can be engineered to meet the end demand of electronic devices. Owing to this fact, researchers are synthesizing high-performance materials for the fabrication of non-volatile memory and artificial synaptic devices.[2] Among different physical effects, resistive switching (RS) has gained popularity in industry and academia.

In recent years, the RS memory effect is utilized for the fabrication of both memory and brain-inspired computing devices.[3,4] In this effect, the device can show either digital or analog current-voltage (I-V) properties based on the intrinsic characteristics of the active switching layer, top electrode, and bottom electrode. The device with a digital RS effect is useful for non-volatile memory applications, whereas, biological synaptic properties can be mimicked by using the analog RS effect.[5] In recent years, a variety of materials such as organic, oxide, perovskite, 2D materials, biomaterials, etc. are being used to demonstrate the RS effect.[6–10] Among different materials, organic materials are a promising candidate to fabricate an active switching layer of non-volatile memory and artificial synaptic devices. Organic memory devices are low-cost, efficient, mechanically robust, and biocompatible as compared to traditional high-k dielectric-based devices.[11] Therefore, different organic materials have been synthesized and demonstrated their non-volatile memory and synaptic learning properties.

The tunable RS effect plays an important role when a single device can be used for both memory and neuromorphic computing applications. The tunable RS effect can be achieved by modulating the external bias, properly engineering the interface between electrodes and the switching layer,[12] utilizing different top electrodes,[13] controlling the thickness of the switching layer,[14] etc. The literature suggested that aggregation-induced emission and mechanochromic organic materials are not reported for RS applications. Typical mechanochromic organic materials change their color under the influence of external stresses such as grinding, heating, fuming,

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Supporting information for this article is available on the WWW under https://doi.org/10.1002/slct.202300026