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From natural biomaterials to environment-friendly and sustainable nonvolatile memory device

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ABSTRACT

The memory device based on biomaterials is of great value in future applications because the biomaterials are environment-friendly, renewable and pollution-free. In this work, natural biomaterials, which were firstly extracted and processed from orange peel, were used as an active layer for fabricating an environment-friendly and sustainable nonvolatile memory device with Ag/Orange peel/FTO sandwich structure. An obvious memory behavior with reproducible bipolar resistive switching memory performance and large resistive storage window has been observed. This work reveals that the orange peel is a promising material for fabricating an environment-friendly and sustainable memory device in nonvolatile memory applications.

1. Introduction

Facing the worsening of environmental issue, it is highly necessary that we should exploit the advanced electronics with biocompatible, biodegradable, sustainable and environment-friendly [1,2]. Fortunately, the electronic device based on natural bio-materials can meet all of the above advantages [3,4]. In particular, bio-materials are organic, lightweight and stretchable, thus organic-based devices has remarkable advantages for the preparation of flexible electronic devices, which can greatly expand the scope of the application of electronic devices [5,6]. In addition, because of the abundance and self-degradability of many natural biomaterials, the use of natural biomaterials may reduce the cost of electronic devices [7]. Of course, natural biomaterials offer not only an effective solution for environmental degradation, but also natural biomaterials based electronics that can degrade naturally with no impact on the environment [8].

The use of natural biomaterials for the preparation of electronic memory components that can be widely used is indeed a very attractive research topic [3,4]. There are several promising natural bio-materials have been currently exploited for resistive switching memory applications [9–12]. The above research works fully proves that natural biomaterials can expand the prepare raw materials of memory products and can effectively reduce the cost of product preparation. In particular, the electronic devices, which are made by non-toxic biomaterial, have very important applications in biomedicine [13–15].

Here, we choose the orange peel as the active layer of resistive switching devices. The orange peel is an un-useful by-product from oranges. It is nontoxic, pollution-free, renewable, environment-friendly, and naturally decomposed. The orange peel powder was prepared by the physical method for the first time, and then a nonvolatile resistive switching memory was successfully prepared using the orange peel powder. We found that the as-prepared devices have perfect switching reliability and large resistance ratio at room temperature. Finally, we analyze the physical mechanism of memristor effect according to the observed conduction characteristics.

2. Experimental process

In the experimental procedure, as is shown in Fig. 1. The orange peels was washed with distilled water and was cut transversely into much pieces, and dried in a vacuum drying box at 50 °C until it is not hydrated. After grinding and dispersing in alcohol, thus the superfine

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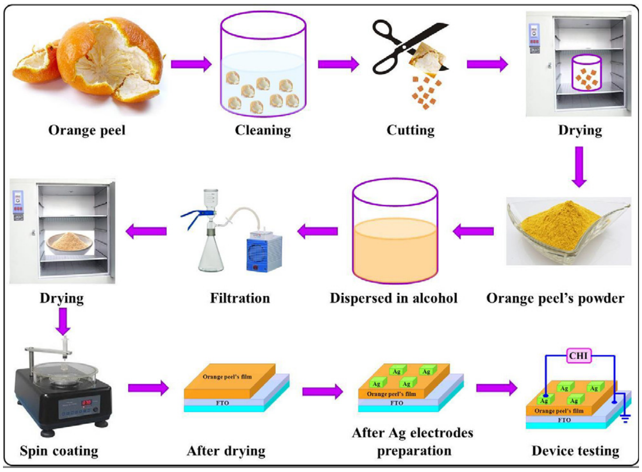

Fig. 1. Extraction of orange peel powder and preparation process of resistive switching devices. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

orange peel powder was obtained by using the vacuum filtration. Next, the memory device with Ag/Orange peel/FTO structure was fabricated. Orange peel film was fabricated onto the cleaned fluorine-doped tin oxide (FTO) substrates by spin coating method. The 200 nm thick layer Ag acting as the top electrodes with the area of approximately 1.2 mm^2 was deposited through a metal mask onto the same side. The chemical element composition of orange peel was characterized by XPS (XPSE-SCALAB250) testing. Finally, we used the electrochemical workstation to test the memory characteristics of the as-fabricated devices in detail.

3. Results and discussion

Fig. 2a shows the XRD pattern of as-prepared orange peel powder. An obvious broad peak around 22° is clearly observed, which have contain many small diffraction peaks without that of oxide or metal material, indicating that as-prepared materials are pure organic nature biomaterials. The more detailed analysis about element constitutes was further studied by XPS, as shown in Fig. 2b. Among these peaks, the three peaks at 284.8, 531.0 eV and 347.0 eV are originated from C 1s, O 1s and Ca 2p respectively from Fig. 2b, and the two peaks at 293 eV and 296 eV are attributed to K 2p. The XPS result is consistent with EDX spectra in the inset of Fig. 2a.

In this work, an evidently hysteretic current–voltage (I–V) cyclic curve of Ag/Orange peel/FTO capacitor was observed (Fig. 3a), the corresponding test circuit diagram is shown in the inset of Fig. 3a. To avoid electrical permanent breakdown [16,17], the compliance current (CC) of 10 mA was set up. In particular, we found that the obtained I–V curve present an obvious asymmetric conduction behavior from the Fig. 3a. These arrows represented in the diagram represent the cyclic scanning direction of the applied voltage. Fig. 3b shows the I–V curve of continuously switching 100 cycles, it can be seen that the switching stability of the device is very perfect nearly without obvious attenuation.

When a voltage from 0.0 V to 1.3 V is applied, a relatively low current is firstly observed, the resistance level corresponding to the difficult conduction is defined as OFF state or high resistance state (HRS). When the scan voltage exceeds 1.3 V (V_{Set}), a sudden current increase occurs, indicating our device is switched to a low resistance state (LRS) from a HRS, which corresponding to a “Set” process, that is to say the device have been beginning to a “writing” process [18]. At the time, the device maintains in the LRS even if the applied voltage continuous increase to 2.0 V. Subsequently, a reverse voltage is swept from 2.0 to 0.0 V. The device still remains relatively stable in the LRS. When the applied voltage is continuously scanned to the negative voltage region about −1.6 V (V_{Reset}), corresponding to the device being switched back to the HRS, the process above could correspond to the “erasing” process of the memory device [18].

Of course, an important parameter is the ON/OFF resistance ratio for the RRAM application based on the resistive switching effect, a high OFF/ON resistance ratio is very pivotal for resistive memory devices, which can effectively avoids the error detection of the memory states in the process of reading and writing [19]. Here, the maintenance performance of resistance values both of the HRS and LRS for the Ag/Orange peel/FTO device were tested, as is shown in Fig. 3c, this value is usually tested at a low bias voltage value (here we set up 0.5 V) to avoid the possible influence of read voltage [20]. For our device the resistance

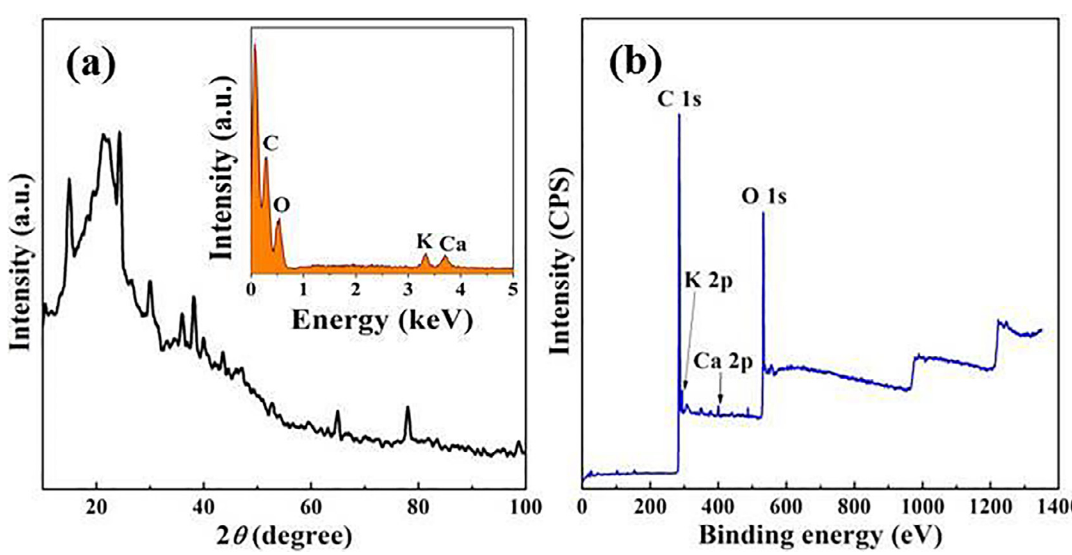

Fig. 2. (a) XRD spectra of as-prepared orange peel powder, the inset shows the EDX spectra. (b) XPS survey spectra of orange peel powder. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)