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A Low Voltage Memory (~2V) Based on Polystyrene for Printable Electronics

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1. Introduction

The fabrication and characterization of two-terminal nonvolatile memory devices using organic semiconductors and polymers have drawn great interests in the past few years [1-2]. These devices can switch between a high- and a low-impedance state upon application of an electric field. Different active materials and device architectures have been suggested for this purpose. The devices switch to an ON state under a certain bias and retained the state even after the bias was switched off. That can be used as a write once and read many times memory (WORM). Small molecules and conjugated polymers such as polystyrene (PS) has been demonstrated the bistable property [3–4]. Besides memory effect, PS also has advantages including low cost, low Tg point and easy to process in solution. As a result, PS is a good candidate for organic electronic devices. However, the operating conditions of WORM type memory with PS nanoscale thin film operating at low voltage are still not yet reported.

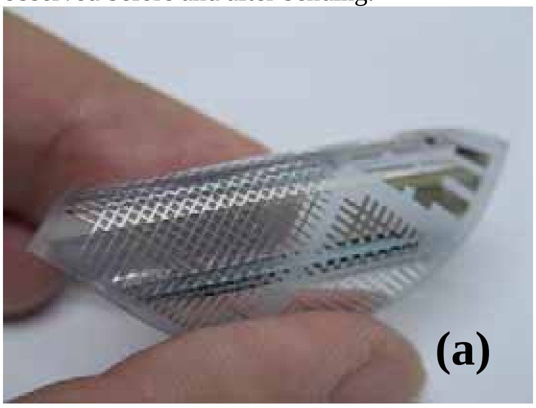
In this letter, we demonstrate a low voltage (~2V) operated memory by using single PS layer sandwiched between two metal electrodes. Besides low voltage, the operating voltage is quite uniform and stable. The standard deviation for over 15 devices is only 0.1V. This inexpensive solution processes make PS memory a good candidate for roll-to-roll print manufacturing of low cost electronics.

2. Experiments

The PS for memory application was prepared by 1.2wt% dissolve in 1,2-dichlorobenzene. The device has a simple structure with an organic film sandwiched between two aluminum electrodes. First, bottom Al electrodes were thermally deposited onto glass or PEN substrates in vacuum about $2x10^{-6}$ Torr. The organic solution was then spun on the electrodes at different spin speed: 1500, 2000 and 3000 rpm and baked to dry in nitrogen atmosphere. Finally, top Al electrodes were deposited perpendicular to the bottom electrodes with shadow mask. The device area is 0.2 x 0.2 mm^2.

3. Results and discussion

The organic PS memory on flexible PEN substrate with PS was shown in Fig. 1(a). The crossbar structure was also shown in Fig. 1(b). The same bistable electric properties were observed before and after bending.



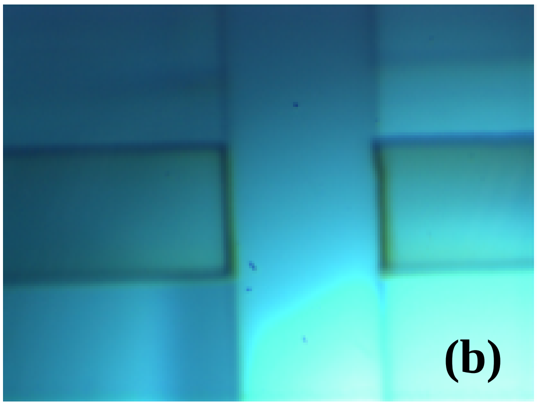


FIG. 1 The flexible bistable device made from PS. (a) PS memory on PEN substrate and (b) the cross-bar structure

Fig. 2 showed the electric properties of PS. The device started from a high-impedance state “off” and went to a low-impedance, high conducting “on” state when voltage was increased to +2 V. The “on” state is retained during the following voltage scan from 0 V to 3 V. This is a write once read many (WORM) memory. The on-off ratio and switching voltage from different spin speed at 1.2wt% PS were also observed. The current ratio was about 3 orders of magnitude and the switching voltage was about 2~2.5V. We found that as the speed increased the switching voltage or called turn-on voltage and the on/off ratio decreased. It suggested that the film thickness affected the device performance. The thicker film required a larger turn-on voltage to change the conductivity and formed a smaller on-off ratio.

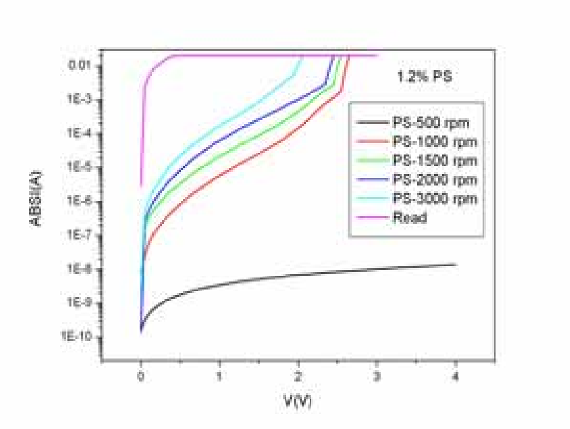


FIG. 2 The current-voltage bistable characteristics of PS memory from different spin speed at 1.2wt%.

Organic film thickness was controlled by the spin speed which could also affect the switching voltage. Fig. 3 showed the turn-on voltage deviation of different spin condition. 15 devices were selected to measure in each spinning condition. We observed a uniform turn-on voltage about 2.5V under spin speed of 1500~2000rpm and the film thickness was less than 90nm. The thickness related to the electric properties was also reported in other organic device [5]. The stable and uniform turn-on voltage suggests this thickness is a optimum value. If it too thick, the transport is not easy, cause smaller on/off ratio and unstable. Too thin, the carriers are much easily tunneling through PS that cause higher off current therefore the on/off ratio decreased.

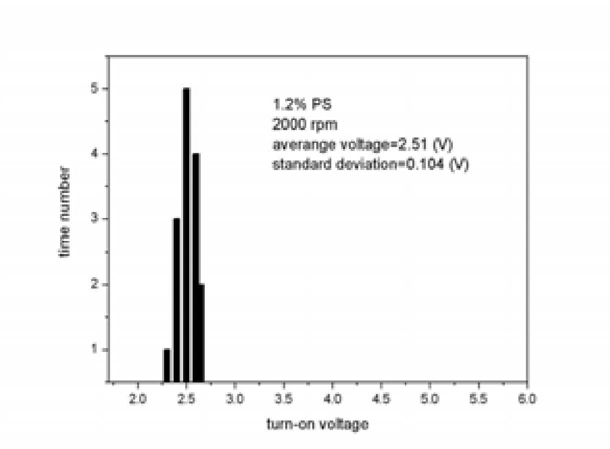


FIG. 3 the turn-on voltage deviation is about 2.5V at the spinning speed of 2krpm.

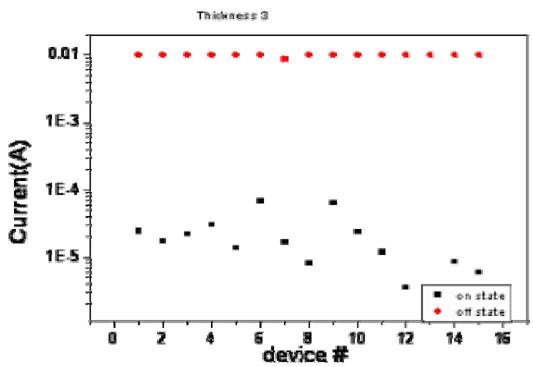


FIG. 4 the uniform on/off ratio at the spinning speed of 2krpm.

Fig. 4 showed the on/off ratio deviation of the same spin condition. The ratio was kept about 3 orders of magnitude during the 15 devices. For the memory mechanism, there are three possible reasons. First it might have one or many filaments path in the PS film. Second, ion doping might form a high conductive way. And the third, structure defect could be a tunneling center and then connect as a low resistance way that allowing electron transportation. The dominated mechanism is still under investigation.

4. Conclusion

We have reported the operation condition of the WORM memory fabricated by polystyrene. The thickness from 1.5~2krpm spinning speed has the best and uniform performance of the memory device. The uniform on/off ratio was about 3 orders and the turn-on voltage was about 2.5V. Polystyrene was a promising material for roll-to-roll printing and manufacturing for low cost printed electronics.

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