

Fabrication of thin-film organic memory elements

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A flexible organic memory unit will be a key element when manufacturing future RFID circuits on flexible substrates. Although the research of memory devices using organic materials dates back almost 40 years, the performance of these devices has remained low when compared to their inorganic counterparts. However, in the last few years there has been considerable progress, even leading to commercial applications. This has largely been due to a greater understanding of the physical mechanisms involved and development of new materials and device preparation methods.

The main problem limiting the application of these devices is that their operation tends to degrade in air and under stress of successive read-write cycles. Furthermore, the physical phenomena affecting their stability are many times unclear. In this study many different aspects related to the sample preparation were studied in order to identify which of them had an influence on the performance and stability of the devices. The test device structure consisted of two metal electrodes and an organic layer between them. As the organic film different polymer materials including block polymers, poly(3-hexyl thiophene) (P3HT), and polystyrenes were tested in various compositions. The film thickness varied from a few tens of nanometres to ~200 nm. During the work, different electrode materials, interface effects, film thickness, device area, substrate materials, impurity effects, and curing parameters etc. were studied.

Results from the electrical characterisation showed that electrical switching took place in all of the tested materials but not in all fabrication parameter combinations. One of the most important aspects in the sample preparation affecting the device performance was the purity of processing environment. The importance of the dust particles in constituting conducting paths to charge carriers and thereby enabling electrical conductivity was identified. Thus, samples processed in a clean room environment showed quite different results compared to samples processed in less dust-free environment. Furthermore, samples with small dimensions inhibited electrical switching behaviour, probably due small amount of dust particles in the device area. In addition to the purity of the processing environment the interface effects played a major role in the operation of the devices. In our samples, the filamentary conduction through the Al_2O_3 layer formed on top of Al electrode was observed to be the main origin of the electrical switching behaviour. Thus, samples with Au electrodes showed decreased switching compared to the Al electrode samples. These results and their interpretation are compared to the behaviour of similar devices using an organic nanocomposite material as the active layer, reported elsewhere.

Best performance as a memory device was observed in P3HT samples, which showed reversible switching when an external voltage was applied. The switching was achieved in the voltage region, where negative differential resistance (NDR) was detected (approximately 3 to 7 V). In this region, the device could be programmed to two states, to a high conducting or low conducting state. The different states could be read by measuring the current through the device at lower voltage (typically 1 V). The current density difference between the two states was approximately two orders of magnitude. The states were non-volatile without applying a constant voltage, which is particularly important in the RFID applications. In addition, different ways to utilise the NDR characteristics in memory devices were tested. These included the use of two memory elements in a serial configuration, thus comprising a structure well-known in the case of resonant tunnelling diodes.