Abstract

The data storage requirement in the digital world is increasing day by day with the advancement of the Internet of Things (IoT). The current generation of silicon-based memory technology is facing serious problems in terms of performance, data storage density, power consumption, data processing time, cost-effectiveness, and so on. Conventional flash memory is one type of non-volatile memory that relay on tunneling through the oxide layer, consumes high power, and response time is high. The hard disk drive (HDD) is a widely used memory in the current era, but the main disadvantage is finding the particular magnetic domain where the data is saved, which leads the memory response time to a few milliseconds. The limitations of conventional memories can be tackled by next-generation memories. Ferroelectric random access memory (FERAM), Phase change memory (PCM), Magnetic random access memory (MRAM) and Resistive random access memory (RRAM) are considered as next-generation memory and have the potential to solve the problem. Among the other memories, non-volatile RRAM is an option that provides high-density and low power data storage capabilities. The information is stored in terms of resistance, where the high resistance state (HRS) is 0 bit, and the low resistance state (LRS) is 1 bit. The computers are based on von Neumann architecture, where processor units are separated from the memory unit and connected via a data bus. This causes a delay in response time and cannot go beyond a certain size limit, called von Neumann bottleneck. The current resistive memory has the capability to solve the von Neumann bottleneck, where the memory can simultaneously process and store data similar to the biological brain.

The small molecule-based RRAM device is a point of interest because of its capability to be used in high-density data storage devices. A small organic molecule 5-Mercapto-1-methyl tetrazole (MMT) has been used with a polymer poly (4-vinyl pyridine) (PVP) matrix for the active layer of RRAM device. The MMT molecule with a different weight ratio in PVP was studied for RRAM application which reveals the invariant RRAM property. The maximum on−off current ratio for all the devices is 10^5, suggesting that the MMT molecule does not show any change in its characteristic properties when surrounded by an insulating material. When the device was fabricated without the polymer matrix, the surface morphology of the device completely changed as it was filled with large holes. These holes provide short-circuited pathways for the current by forming the direct metal contact between the top and bottom electrodes.

Size miniaturization of the electronic device can be done using organic small molecules as well as inorganic nanoparticle QDs. The synthesis of CdS QDs and the study of RRAM properties has been studied. Al/CdS+PVP/ITO like MIM structured device was fabricated which shows extremely good switching properties. The data retention capability of 60000 seconds and 300 endurance cycles were studied. The charge-trapping mechanism is associated with the RS property.

With the development of artificial intelligence and ultra-high speed computing the solution of von Neumann bottleneck is needed. In this regards, resistive memory can provide solution as RRAM has the capability to act as biological synapse that can store, process and transfer data. This attracts researchers to study resistive memory devices. Here fabrication of a small organic molecule Trimesic acid (TMA) and PVP composite-based resistive memory device. It shows excellent resistive switching with a high on–off ratio, excellent stability and data storage capability. Pulse transient measurements on the device demonstrated the capability of neuromorphic computation. The gradual set and reset process and change of conductance with an applied pulse confirmed the neuromorphic application. Paired pulse facilitation shows that the device can behave like the human brain. The redox active molecule and its change in conformation are the reasons for the switching behaviour of the device that led to the neuromorphic application of the device.

For an important application like RRAM, it is crucial to understand the mechanism in nanoscale and control the Resistive switching (RS) by various means. Different models have been proposed to explain the RS behaviour of the material. First, the electrode effect on the switching, which includes contact type, and charge trapping/de-trapping near the electrode-material interface. The other mechanisms are conducting filament formation, electrochemical metallization, ionic diffusion, and oxidation-reduction of the materials. So, there are many disagreements on the proposed models of RS, and it requires understanding using different experimental techniques. STM is one of the best tools for understanding the surface property, as well as studying the local density of states (LDOS) of the material. So, using the scanning tunnelling microscopy (STM) technique to understand the RS in materials in the nanoscale range would be very helpful. The RS properties and capabilities of neuromorphic computing of single AgInS2 quantum dot with the help of STM and scanning tunnelling spectroscopy (STS) have been studied in this chapter. The bandgap of the material and its temperature dependency has been studied and it suggests a nonlinear and linear variation at lower and higher temperature than the Debye temperature respectively. The STS shows the change of conducting states after applying localized pulses. The devices made from the quantum dots replicate these properties as well. The neuromorphic application of the device was tested by using the pulse transient measurement that mimics the learning and forgetting of information through the gradual set and reset process. The localized ionic transport is involved in the RS mechanism.