

Memory, Memristors, and Atomristors

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Memory in computer systems is now arguably the most important device for advancing energy-efficient computing architecture and capability.¹ It is also a major driver for improving storage in mobile systems, and it directly influences the product price. There are all sorts of memory (see Figure 1), which, broadly speaking, can be classified into volatile and non-volatile devices. Both types store information as binary numbers. The former type requires a hold voltage to maintain the memory state, while the latter type does not. Dynamic and static random access memory (DRAM and SRAM) are the most common kinds of volatile memory, while non-volatile memory includes flash, disk drives, and emerging devices such as phase-change memory (PCM) and resistance-change random access memory (RRAM). In general, modern computing systems consist of both types of memory at different levels of the architecture to balance requirements of speed, energy consumption, memory density, and so on.¹

In an ideal computer, a single non-volatile device with a small size, fast switching, long retention, and an unlimited number of cycles would satisfy all computing requirements; hence, this could be called a universal memory, much like the field-effect transistor (FET) virtually fulfills all logic applications. While the odds are that a universal non-volatile memory device is a mirage, there is significant global research on emerging memories such as RRAM regarding their potential as worthy candidates.² RRAM, as the name implies, stores information in the resistance states of the device. In recent years, the term “memristor” has emerged as an alternate name for RRAM devices. While there is a subtle difference in the smoothness of the current-voltage curves of most metal-oxide RRAM and the original memristor concept,³ many contemporary researchers use the two terms interchangeably because both describe hysteresis in the electrical response, which produces a non-volatile resistance state.

Memristors or RRAM are pleasantly very simple structures composed of a metal-insulator-metal sandwich, with the insulator being the active layer; however, the physics are rather complex. The insulator is often (but not always) a metal oxide. As is always the case in engineering, there is a strong desire for ever-increasing levels of performance and reliability. Particularly for the former, much effort has gone into decreasing the insulator thickness to reduce the switching voltage, time, and energy, while hopefully increasing the memory density. Unfortunately, it has been found that most insulating oxides don't work well as memory below a thickness of a few nanometers—owing to excessive current leakage caused by defects in the amorphous material. Recently, it was discovered that by using insulating metal sulfides that are one-atom thin, RRAM-like memory devices could be made with an active layer of less than 1 nm. These surprising results—found using a graphene-like material named MoS₂—have now led to a new class of memory devices named atomristors, which produce a memristor effect in atomically thin insulating materials.⁴

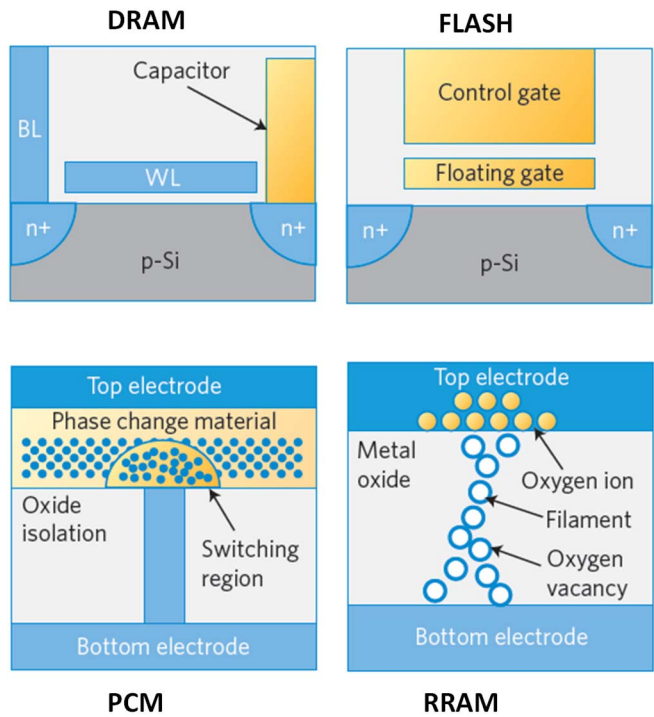


Figure 1. Schematics of different kinds of memory devices such as DRAM, flash, PCM, and RRAM (RRAM is also called memristor in contemporary jargon). The schematics are adapted from Wong and Salahuddin.¹

Atomistors are the thinnest memory devices (see Figure 2) and show potential towards a universal memory effect in non-conducting, atom-thin layers. They provide a new class of materials to consider for memory storage, though significant research is needed to understand the detailed physical mechanism and improve yield and reliability. By replacing the metal electrodes with graphene, a fully 2D memory sandwich that is less than 2-nm thin is possible, which leads to the idea of dense memory fabrics that can be layered to form 3D networks. Such networks are highly desired for brain-inspired (neuromorphic) computing. Beyond information storage and neuromorphic systems, atomistors are also proving suitable for the new application of non-volatile switches used in radio-frequency communication systems, becoming the first RRAM-like device for this growing application.

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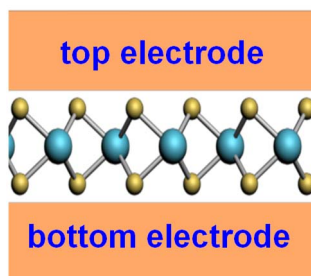


Figure 2. Atomistor memory device consisting of an atomic layer of the 2D material MoS₂. Atomistors are the thinnest memory devices.

CONCLUSION

Though it is too early to predict the future, the growing research in solid-state memory devices holds great promise for future energy-efficient computing systems where logic and memory coexist in optimized architectures. While the device names such as RRAM, memristors, and atomristors may change like fashion, the underlying memory effects remain an intriguing revelation of nature that is bound to benefit electronic technology.

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