white paper

Phase change memory technology

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The basics of phase change memory technology

Phase Change Memory (PCM) is a term used to describe a class of non-volatile memory devices that employ a reversible phase change in materials to store information. Matter can exist in various phases such as solid, liquid, gas, condensate and plasma. PCM exploits differences in the electrical resistivity of a material in different phases. This paper describes the basic technology and capabilities of PCM.

History and background

In the 1950s and 1960s, Dr. Stanford Ovshinsky began researching the properties of a class of amorphous materials. Amorphous materials are those materials that do not exhibit a definite, ordered crystalline structure. By 1968, he reported[1] that certain glasses exhibited a reversible change in resistivity upon a change in phase. In 1969, he also reported a corresponding change in reflectivity that could be induced by laser in an optical storage media. By 1970, the company he and his wife Dr. Iris Ovshinsky founded, Energy Conversion Devices (ECD), published the results of a collaboration with Intel's Gordon Moore. The September 28th, 1970 issue of Electronics[2] featured the world's first Phase Change Memory, a 256 bit semiconductor device.

Nearly 30 years later, ECD formed a new subsidiary, Ovonyx, a joint venture between ECD and Tyler Lowery, the former CTO, COO and Vice-Chairman of Micron Technology. In February 2000, Intel and Ovonyx announced a collaboration and licensing agreement that spawned the modern age of research & development in PCM. In December of 2000, STMicroelectronics ("ST") and Ovonyx also began a collaboration. By 2003, the three companies had joined forces to accelerate progress on the technology by avoiding duplication in basic, pre-competitive R&D and through expanding the research scope. In 2005, ST and Intel agreed to co-develop a 90 nm PCM technology. In 2007, ST and Intel announced their intention to form a new flash company called Numonyx.

In the intervening years since that first work in 1970, much progress has been made in semiconductor manufacturing technology, enabling the practical development of PCM. Also during that time period, phase change materials were perfected for high volume use in rewritable CDs and DVDs. Today, most DVD-RAMs available today use the exact same alloy used in Numonyx PCM development. The PCM technology being developed by Intel uses a class of materials known as chalcogenides ("kal-koj--uh-nyde"). Chalcogenides are alloys that contain an element in the Oxygen/Sulphur family of the Periodic Table (Group 16 in the new style or Group VIa in the old style Periodic Table). Numonyx PCM is using an alloy of Germanium, Antimony and Tellurium (Ge2Sb2Te5), known more commonly as "GST". Most companies performing research and development in PCM today are using GST or closely related alloys.

Theory of operation

Phase change chalcogenides exhibit a reversible phase change phenomenon when changed from the amorphous phase to the crystalline phase. As shown in Figure 1, in the amorphous phase, the material is highly disordered—there is an absence of regular order to the crystalline lattice. In this phase, the material demonstrates high resistivity and high reflectivity. In contrast, in the polycrystalline phase, the material has a regular crystalline structure and exhibits low reflectivity and low resisitivity. As shown in the "Sample" column of Figure 1, these changes in phase are observable.

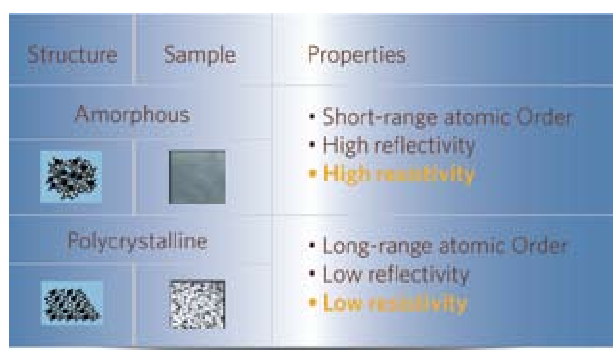

Figure 1. Source: Intel, Ovonyx

1. S.R. Ovshinksy, "Reversible Electrical Switching Phenomenon in Disordered Structures", Physics Review Letters, vol. 21, p1450, 1968.

2. R. G. Neale, D. L. Nelson, G. E. Moore, "Nonvolatile and Reprogramable, the Read-Mostly Memory is Here", Electronics, September, 1970, p56

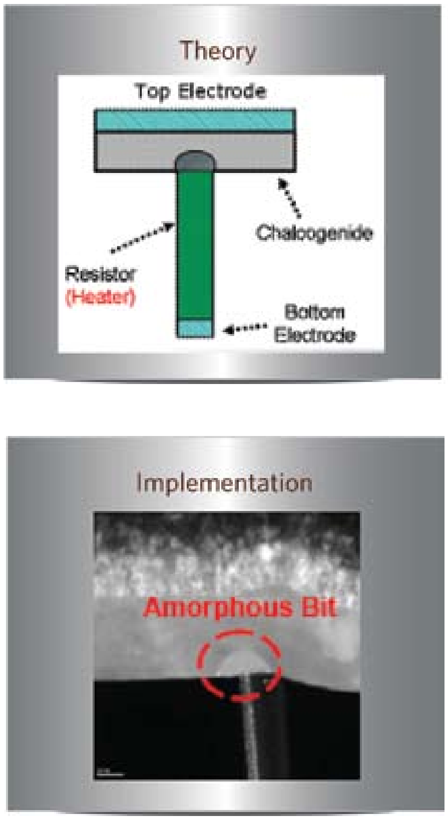

Figure 2. Example phase change storage element

In PCM, we are exploiting the difference in resistivity between the two phases of the material. This phase change is induced in the material through intense localized Joule heating caused by current injection. The end phase of the material is modulated by the magnitude of the injected current, the applied voltage, and the time of the operation.

Figure 2 shows a graphical representation of a basic PCM storage element. As shown on the left, a layer of chalcogenide is sandwiched between a top electrode and a bottom electrode. A resistive heating element extends from the bottom electrode and contacts a layer of the chalcogenide material. Current injected into the junction of the chalco-genide and the heater induces the phase change through Joule heating. At right is the actual implementation of the concept, showing an amorphous bit formed in a layer of polycrystalline chalcogenide. Because of the change in reflectivity, the amorphous bit appears as a mushroom cap shaped structure in the layer of polycrystalline chalcogenide.

PCM attributes and capabilities

Phase Change Memory blends the attributes commonly associated with NOR-type flash, memory NAND-type flash memory, and RAM or EEpROM. These attributes are summarized in the chart in Figure 3.

Figure 3. PCM Attributes: This new class of non-volatile memory brings together the best attributes of NOR, NAND and RAM.

Bit-alterable

Like RAM or EEpROM, PCM is bit alterable. Flash technology requires a separate erase step in order to change information. Information stored in bit-alterable memory can be switched from a one to zero or zero to a one without a separate erase step.

Non-volatile

Like NOR flash and NAND flash, PCM is nonvolatile. RAM, of course, requires a constant power supply, such as a battery backup system, to retain information. DRAM technologies also suffer from susceptibility to so-called “soft errors” or random bit corruption caused by alpha particles or cosmic radiation[1]. Early testing results conducted by Intel on multimegabit PCM arrays for long term data retention show excellent results.

1. R. Baumann, “Soft Errors in Advanced Computer Systems”, IEEE Design and Test of Computers, Volume 22, Issue 3, May-June 2005 Page(s):258 - 266

Read speed

Like RAM and NOR-type flash, the technology features fast random access times. This enables the execution of code directly from the memory, without an intermediate copy to RAM. The read latency of PCM is comparable to single bit per cell NOR flash, while the read bandwidth can match DRAM. In contrast, NAND flash suffers from long random access times on the order of 10s of microseconds that prevent direct code execution.

Write/erase speed

PCM is capable of achieving write speeds like NAND, but with lower latency and with no separate erase step required. NOR flash features moderate write speeds but long erase times. As with RAM, no separate erase step is required with PCM, but the write speed (bandwidth and latency) does not match the capability of RAM today. The capability of PCM is expected, however, however, to improve with each process generation as the PCM cell area decreases.

Scaling

Scaling is the fifth area where PCM will offer a difference. Both NOR and NAND rely on memory structures which are difficult to shrink at small lithos. This is due to gate thickness remaining constant and the need for operation voltage of more than 10V while the operation of CMOS logic has been scaled to 1V or even less. This scaling effect is often referred to as Moore's Law, where memory densities double with each smaller generation. With PCM, as the memory cell shrinks, the volume of GST material shrinks as well, providing a truly scalable solution.

Conclusions

Phase Change Memory is a promising memory technology that has recently experienced a resurgence of interest. PCM employs a reversible phase change phenomenon to store information through a resistance change in different phases of a material. Advances in memory technology and pioneering work conducted by Numonyx has moved the technology to the forefront of the memory industry R&D activity. PCM offers a combination of some of the best attributes of NOR flash, NAND flash, EEpROM and RAM in a single memory device. These capabilities uniquely combined with the potential for lower memory subsystem costs could potentially create new applications and memory architectures in a wide range of systems.

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