

Phase Change Memory Alloys: An Alternative for Data Storage

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The search and development of the ideal memory device is ongoing. Researchers have envisioned a perfect memory device, “unified memory,” which can simultaneously maintain high speed, memory density, and nonvolatility¹. Truly nonvolatile memory is capable of retaining data without power for extended periods of time. Currently, unified memory has not been commercially achieved and devices often compensate with volatile RAM, which has much faster read and write delays.

Flash memory is now the state-of-the-art method of data storage in non-volatile memory. The technology relies on charge-based storage to record and erase desired data. While the current memory density can certainly be improved, the cost of high-capacity flash memory materials and the increasingly apparent slow read and write speeds have encouraged developers to seek alternatives².

Phase change memory (PCM) materials have arisen as an ideal memory replacement. PCM materials are capable of changing between distinct phases via thermal excitation, usually through electrical or optical pulses, and store data by exhibiting different properties in each of the two states. Most often, these materials will exhibit storage via changes in electronic resistance. Ideal PCM materials should have phases with highly contrasted properties, possess high stability while in a working phase, and be capable of rapid transitions between phases³. The mechanism is described in figure 1. Additionally, immediately applicable PCM material should also have a low thermal conductivity to ensure phase switching occurs at low energy, and a relative softness to maintain order at crystalline-amorphous phase boundaries³.

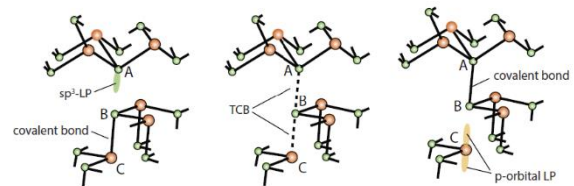


Fig 1. The proposed mechanism of phase switching in GeTe PCM material³.

GeTe has become the most widely used PCM material because it carries many of these desirable properties. Much of its low energy switching can be attributed to its chalcogen content. Chalcogenide glasses carry an inherently specific concentration of lone pair electrons which do not participate in standard covalent bonds^{3,4}. In GeTe’s amorphous state, lone pairs are theorized to exist in Ge sp^3 hybridized orbitals. Given a sufficient thermal stimulus, the lone pair will align with a Ge-Te bond and form an

equidistant Ge-Ge-Te triple-centered bond. Following the bond formation, the Te atom bond length increases until it is no longer considered covalently bound³. A correlation between Te atoms and vacancy locations has been observed and has been suggested to promote phase segregation—a driving force in GST phase transitions⁵.

From a bonding perspective, Dembovsky's equation $\psi = (NVE - CN)/NVE$, where NVE is the number of valence electrons and CN is the subject's coordination number, is often used to gauge a material's efficacy as a PCM material⁴. Values between 0.5—0.66 are attributed to the most useful species. Materials with a high ψ term are typically amorphous while low ψ materials are more ordered.

Notably, GeTe, has a value of $\psi = 4$ and is a poor glass former⁵. GeTe can be alloyed with metalloids of similar bond character to its desirable properties. The Ge-Sb-Te (GST) system, seen in figure 2⁶, and its pseudobinary line are the most commonly used tool in altering phase change dynamics, crystallization temperature, and activation energy⁷. Sb is a useful dopant in GeTe samples because of its similarity in p-orbital character. A variety of other dopants including carbon and transition metals have been used⁸.

It is worth mentioning that the fabrication of GST alloys is integral to the material because minor changes in structure can drastically effect the resultant properties. Sputtering and pulse laser deposition are preferred techniques to preserve the stoichiometry of the product⁹. In application where conformality is not necessary, evaporation is the preferred fabrication method⁷.

GST alloys can perform SET and RESET operations much faster than flash, they are disadvantaged in their RESET power. The reset operation power is needed to convert GST alloys from crystalline to amorphous states. Currently, dopants are being added to GST alloys to increase ψ , pushing GST into more amorphous states, while conserving GST's other important properties⁸.

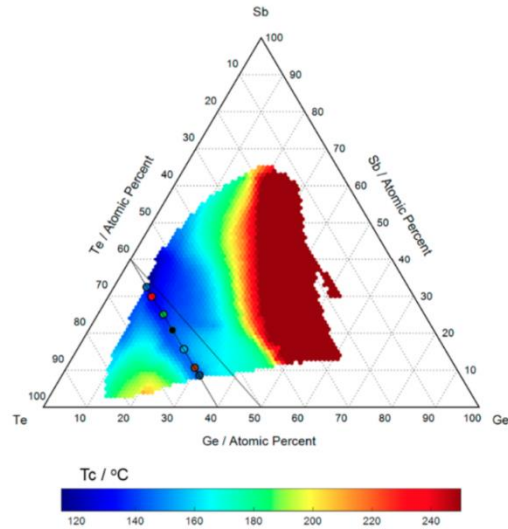


Fig. 2. The transition temperature of $\text{Ge}_x\text{Sb}_{1-x}\text{Te}$ compounds as a function of atomic percentage and temperature⁶.

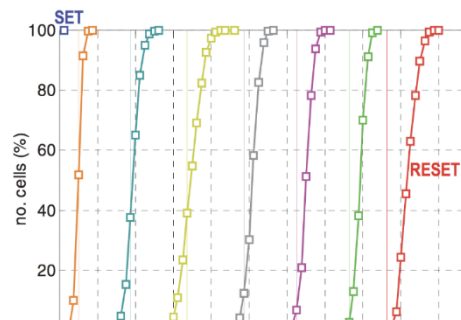


Fig. 3. Intermediary states that can be observed between SET and RESET in an MLC¹⁰.

Perhaps most interestingly, GST alloys may be manipulated to store more than one bit per cell. New multi-level cells (MLCs) can be made by partially degrading the material until it exhibits intermediary properties. In this manner, MLCs can increase the storage density in memory devices by $b = \log_2(n)^{10}$. As the number of states increases, however, the possibility of error scales as well. The necessity for highly differentiated phases is heightened when designing GST MLCs so that the intermediate phases are sufficiently distinguishable.

References

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