Epitaxial Chalcogenide Deposition for Optical Phase Change Devices

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ABSTRACT

Because of their low power requirement and fast switching, Van der Waals layered chalcogenide superlattices have performed well in dynamic resistive memories in what is known as interfacial phase change memory devices.

Electromagnetic manipulation is a focus area for research in APL's Research and Exploratory Development Department. The ability to dynamically reconfigure the properties of optical materials is of immense importance to this area. Optical memory storage, namely compact disks (CDs) and digital video disks (DVDs), is just one of the wide range of applications of chalcogenide phase change materials (PCMs).

Typically, a chalcogenide PCM has two or more discrete states (phases). When the PCM transitions between these states, it undergoes significant changes in the optical, electronic, or other material properties. Since it is possible to reversibly switch the material's phase via laser or electrical pulses of controlled intensity and duration, chalcogenide PCMs can be used to store digital information. In the case of optical memory storage, the discrete states consist of an amorphous, low reflective state and a crystalline, high reflective state.

Examples of chalcogenide PCMs include germanium telluride (GeTe), antimony telluride (Sb_2Te_3), alloys such as germanium antimony telluride ($Ge_2Sb_2Te_5$ or GST), and other compounds alloyed with bismuth and selenium. Depending on the application of interest, the alloy composition can be varied to achieve the desired switching properties. For example, GeTe lends itself to microwave switching because of its resistive state, whereas $Ge_2Sb_2Te_5$ is the material of choice for memory devices because of its high stability.

Traditionally, PCMs are grown in thin film form; however, the APL team is studying a new class of related materials known as interfacial PCMs (iPCMs). iPCMs

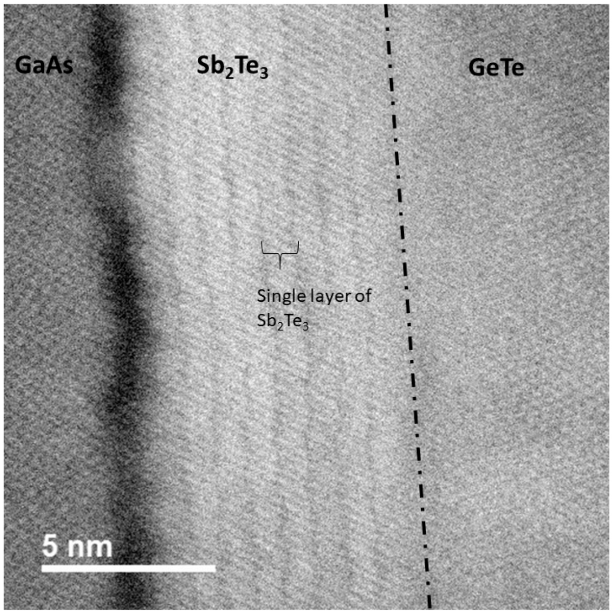

Figure 1. An APL-grown superlattice structure. Superlattice of 10 nm Sb_2Te_3 and GeTe grown on gallium arsenide (GaAs) (100) observed via transmission electron microscopy. Atomic makeup of the layers is visible, as are the single layers of Sb_2Te_3.

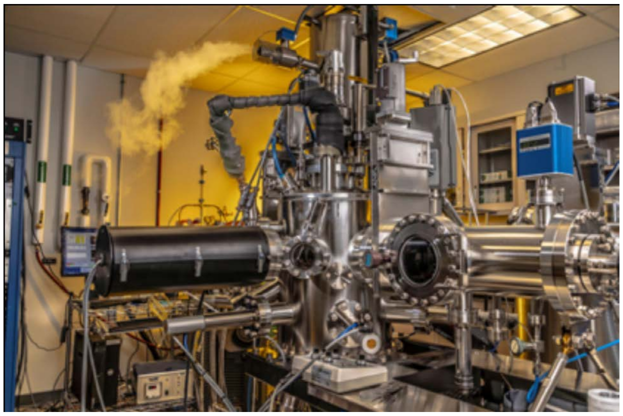

Figure 2. Molecular beam epitaxy (MBE) deposition chamber at APL. An APL team used MBE to create superlattice structures.

are composed of stacks of nanometer-thick chalcogenide PCMs referred to as superlattices. An example of an APL-grown superlattice structure is shown in Figure 1, illustrating the extremely thin layers and atomically abrupt interfaces. iPCM superlattices behave similarly to traditional PCMs. Rather than undergoing an amorphous-crystalline phase transition, however, these materials undergo an interfacial reorientation in the bond alignment at the nanometer-scale interfaces. The amount of energy and time required to undergo this interfacial transition decreases significantly relative to the amorphous-crystalline phase transition, thereby allowing for faster switching with less energy use as compared to traditional PCMs.

The key method the team used to create these superlattice structures is molecular beam epitaxy (MBE) growth. MBE allows for atomic level deposition of elements. The technique uses ultra-high vacuum, controlled evaporation, cryogenically cooled walls, and substrate heating to control defect density, thickness, and atomic stoichiometry of grown films with great precision. The available deposition materials—tellurium, bismuth, antimony, germanium, and selenium—allow for the growth of a wide range of potential compounds and alloys.

Currently, APL investigators are studying the phase change transition in iPCM superlattices consisting of alternating thin layers of GeTe and Sb_2Te_3. This includes research on the integration of novel iPCMs into novel optoelectronic devices capable of transitioning the iPCM and thereby acting as a reconfigurable optical/electronic switch. These novel iPCMs will enable new capabilities and device technologies that operate in the infrared spectrum. Possible applications for these devices include covert optical communication (such as tagging, tracking, and locating), spectral sensing, sensor protection, and thermal management. This novel capability may help advance research into the growth of topological insulator materials and thermoelectrics with applications in quantum information and sensing as well as power and energy, respectively. To date, the team's work has resulted in two peer-reviewed publications, with more experimentation underway.[1,2]

REFERENCES

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