Neuron-inspired memory based on plasmon particle network with phase change material

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ABSTRACT

So far we have been studying the modulation of localized surface plasmon resonance (LSPR) of a metal nanoparticle using a GeSbTe (GST) film as an active medium. We demonstrated high-contrast switching of LSPR upon phase change for a Au nanoparticle (AuNP) on a GST thin film and for a AuNP/GST/Au thin film sandwich structure. To go beyond this single particle switching functionality, in this study we discuss the plasmon particle network system with phase change material and explore the possibility of new intelligent memory functionality. It may be possible to build brain-inspired computing devices by incorporating the single particle switch/memory functionality in laterally coupled plasmon particle systems. The network dynamics can be implemented by electromagnetic interaction between plasmon particles. The plasticity and threshold properties of the synapse, which is the memory device in the brain, are reproduced using phase change materials. We demonstrate associative memory through some numerical simulations.

Key words: Localized surface plasmon resonance, GeSbTe, neuron circuit, synapse

All present computers are based on the von Neumann model and have been essentially the same for almost seventy years. Such computers are comprised of memory, arithmetic logic unit, control unit, and input/output devices. So far, these microprocessors, memories, and logic devices have strongly relied on high-speed CMOS technologies. However since the scaling of CMOS technology is approaching to its physical limit, alternative architecture with new device concepts should be investigated to address increasing demands for massively parallel processing with low energy consumption.

For information processing technologies beyond CMOS scaling, brain-inspired computing, in which an electronic circuit simulates a neural network, has been attracting strong attentions. Human brain performs both information storage and processing on the basis of analog memory and digital integrator and comparator. The key device of analog memory is a synapse, in which the information is stored in non-binary fashion, and the brain functionality including learning and association relies on the synaptic plasticity. To date several reports demonstrated electronic devices that emulate synaptic functions using memrisive systems, which can store dynamic history of the system. Among a variety of material candidates and physical mechanisms for the synaptic device, chalcogenide phase change materials (PCMs) are promising because they exhibit reversible switching between crystalline and amorphous states and remarkable threshold behavior in both crystallization and amorphization processes.

Recently active control of the localized surface plasmon resonance (LSPR), which is supported by metal nanoparticles and their complexes, has been intensively investigated to implement dynamic switching and tuning functionality in plasmonic devices. Several schemes for LSPR modulation, including peak position, intensity and bandwidth changes has been explored, typically by embedding metal nanostructures in reversibly switchable media including liquid crystals, photoconducting materials, photochromic molecules, electrochromic conducting polymer, and so on. Plasmonic Fano resonant nanostructures, which arise from the near-field coupling between broad superradiant and narrow subradiant modes, has great potential for active control due to its sharp resonance and sensitivity to a variety of parameters. As an active media for the LSPR control, PCM is advantageous because they exhibit a large contrast in refractive index between crystalline and amorphous phases, which will provide large modulation of LSPR, and also their stable plasticity, which has been demonstrated by the commercial application as rewritable optical recording media for decades.

For active control of LSPR using PCM, we demonstrated single particle spectroscopy of a Au nanosandwich, where a GST thin layer is inserted between interacting AuNRs and a Au film. A stable and repeatable switching with a high contrast was obtained at the hybridized mode between the AuNR and Au film upon phase change of the GST layer. Interestingly, at the initial stage of switching operation, a growth in the modulation contrast was observed, which is a type of “learning” effect in terms of memory device functionality.

In this presentation we discuss the challenge and the possibility for realizing brain-inspired computing devices by incorporating the plasticity and threshold property of PCM in laterally coupled plasmon particle systems. The network dynamics that imitate the neuron circuit with axons and dendrites can be implemented by electromagnetic interaction between plasmon particles without physical connections. We demonstrate that spatial evolution of plasmon-PCM network system can be equivalent to the algorithms based on cell automaton model (Fig. 1) and self-organizing map.

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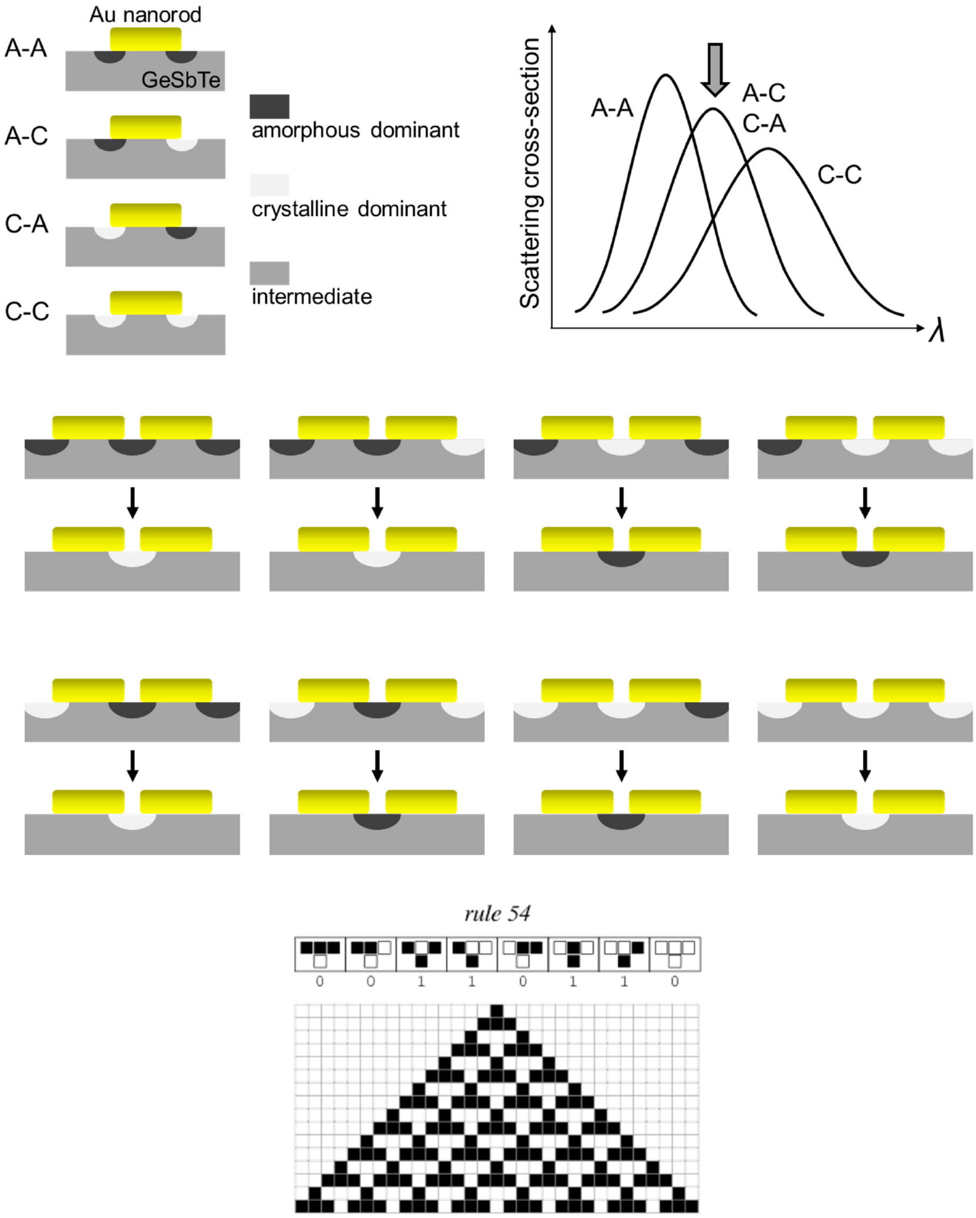

Fig. 1 Implementation of a cellular automaton algorithm in plasmon-PCM network system.