2D cognitive optical data processing with phase change materials

Q. Wang[1,2], J. Maddock[1], E. T. F. Rogers[1], T. Roy[1], C. Craig[1], K. F. Macdonald[1], D. W. Hewak[1] and N. I. Zheludev[1,3]
[1]*Optoelectronics Research Centre and Centre for Photonic Metamaterials, University of Southampton, Highfield, Southampton, SO17 1BJ, UK*
[2]*Institute of Materials Research and Engineering, 3 Research Link, Singapore 117602, Singapore*
[3]*Centre for Disruptive Photonic Technologies, Nanyang Technological University, Singapore 637371, Singapore.*
qw1v12@soton.ac.uk

Abstract: We demonstrate high-density, multi-level crystallization of a $Ge_2Sb_2Te_5$ thin film using tightly focused femtosecond laser pulses. The optical reflectivity in each distinct phase states level is characterized for applications in ultra-fast cognitive parallel data processing.

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The conventional computing paradigm is based on binary digital logic for data processing. With the goal of achieving low power, highly parallel cognitive computing system; the research in biologically inspired computing is an emerging filed [1, 2]. In order to emulate synaptic behavior, the material/device should possess some kind of memory and also have a mechanism that can be modulated by the stimulus it receives. Ovonic optical phase-change memory (PCM) as one of kinds of suitable candidates has advantages such as high scalability, good endurance and good technological maturity [3]. In this work, we focus on the use of the optical properties in PCM for two-dimensional (2D) cognitive data processing in synaptic applications.

Chalcogenide glass, $Ge_2Sb_2Te_5$ (GST) is one kind of mature PCM, widely used in rewritable optical discs. It exhibits large changes of optical reflectivity, electronic conductivity and thermal conductivity between amorphous and crystalline phases, and is easily changed between these states using optical, electrical or thermal energy [4]. Recent studies demonstrated the cumulative switching of GST films induced by ultrafast lasers [3, 5, 6]. The repeatable energy dose and rapid heat diffusion allow continuous change of its optical reflectivity, which can be used to emulate biologically inspired synaptic functions. In this work, we demonstrate high-density, multi-state crystallization of a $Ge_2Sb_2Te_5$ thin film using tightly focused femtosecond laser pulses. The partial crystallization of GST allows multi-level optical data storage for cognitive parallel data processing application.

In our experiments, the 3-layer stacks were sputter deposited on 0.17 µm glass substrates at room temperature, where the amorphous GST film of 50 nm thickness was sandwiched by a 50nm ZnS:SiO2 film on the substrate for thermal diffusion and a 50 nm layer of ZnS:SiO2 on the top to prevent degradation in the air. We locally heat the GST film using focused femtosecond laser pulses, but we control the pulse energy so that we bring heat the film to around crystallization temperature T_c; hence it only partially crystallise. The degree of crystallization is probed by measuring the optical reflectivity of the submicron switched area.

In our setup, a Ti-Sapphire femtosecond laser (Coherent Chameleon Vision S) generated pulse trains of 730 nm wavelength and 85 fs duration. After that, an electronic optical modulator (EOM) pulse picker (Conoptics Corp.) was used to select single pulses eventually incident on the sample surface. Optical measurement of the change in reflectivity of GST film were conducted by using an LED array illumination on the samples surface, and at the same time by imaging with a 50× objective lens (NA 0.7), tube lens and a CCD camera. In the GST film, the data were written by using accurately controlled low energy pulses trains to trigger off the nucleation and crystal growth. The number of pulses is varied to achieve different reflectivity levels. After each pulse shot, one image was acquired immediately to record the relative change of reflectivity related to the number of pulses used.

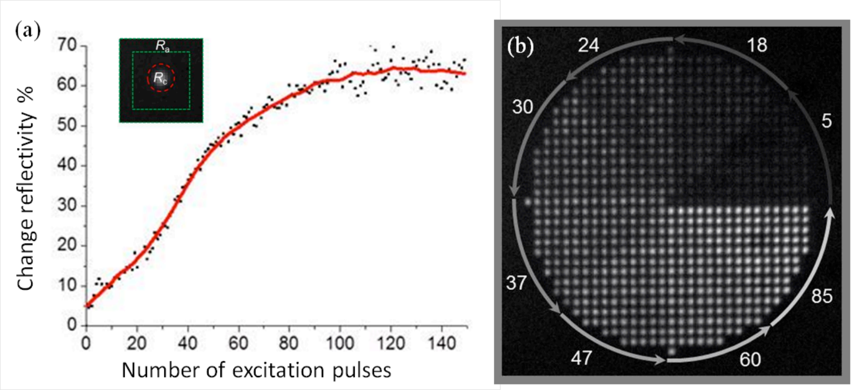

Figure 1 (a) An experimentally measured change in optical reflectivity ((Rc-Ra)/Ra) of the Ge2Sb2Te5 sample as a function of the pulse number of 85 fs femtosecond duration with 0.36nJ pulse energy applied. Solid lines are smoothed curves (Savitzky-Golay method) of the according experimental data, and the insert demonstrates the Ra and Rc area for calculation. (b) A spiral plate pattern of showing 8 levels of gray-scale (total diameter 34 μm). Arrows show the direction of the increasing number (from 5 to 85) of pulses incident on the GST film.

Figure 1 (a) shows the typical characteristic curves illustrating the change in optical reflectivity of the partial crystallization GST mark as a function of the pulse number. With the increased number of pulse shot, the GST film undergoes the process from the nucleation growth to quick crystallization growth process. The enormous reflectivity variation offers an opportunity to utilize multiple reflectivity levels between two phase states, to store and calculate multiple bits in each phase-switched domain. Furthermore, the results show clearly the energy accumulation property of GST materials, which can be used to realize synaptic behavior, complementing inspired computing. With an input of series of phase mask into SLM to control the focus pulse scanning on the sample surface, it then can produce multi-level gray scale image. As shown in the Fig 1 (b), an 8-level spiral plate pattern was written on the GST film by successive excitation of femtosecond pulse trains, where each level involves specific amount of pulses according to the nonlinear curve in the Fig 1 (a).

In conclusion, we have demonstrated multi-level data storage and gray-scale image writing in a thin GST film using femtosecond laser. Our results have the potential to dramatically increase the optical data storage density in phase-change materials. Additionally, the cumulative effects in controllable phase transition of GST films give the interesting prospect of realizing cognitive parallel image processing in synaptic applications.

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