UNIVERSITY OF EXETER

EPSRC Centre for Doctoral Training in Metamaterials

On-chip All-Photonic Phase-Change Memories

Emanuele Gemo[1], C.David Wright[1], Anna Baldycheva[1], Harish Bhaskaran[2]

1. Department of Engineering, University of Exeter, Exeter EX4 4QF, United Kingdom

2. Department of Materials, University of Oxford, Parks Road, Oxford OX1 3PH, United Kingdom

Abstract Chip-scale memory devices consisting of a thin *phase-change material* (pcm) layer deposited on top of an integrated waveguide are investigated. The $Ge_2Sb_2Te_5$ pcm alloy provides a suitable platform at TC wavelengths, modulating a low power beam transmission as a function of the pcm phase distribution. Writing is performed via tailored high-power pulses. Novel waveguide designs drawing concepts from metamaterials and plasmonics will be analysed, in order to enhance memory density, power efficiency, reliability and throughput.

Scope

The incorporation of a phase-switchable cell of GST with integrated waveguide structures has been experimentally demonstrated to be capable of providing the write, erase and read operations required for a non-volatile memory in a photonic integrated circuit (PIC) architecture[1,2]. Device and concepts are illustrated in Fig.1. Fast write operations (sub-nanosecond Reset), long data retention and multi-bit per cell storage have been demonstrated[2]. Despite these desirable features, devices developed to date have large footprint and relatively high power consumption. This work focus on the simulation of this class of devices, for the future aim to design and fabricate new phase-change based PIC memory architectures, in order to reduce size, power requirement and operations time, maintaining the optimal signal modulation.

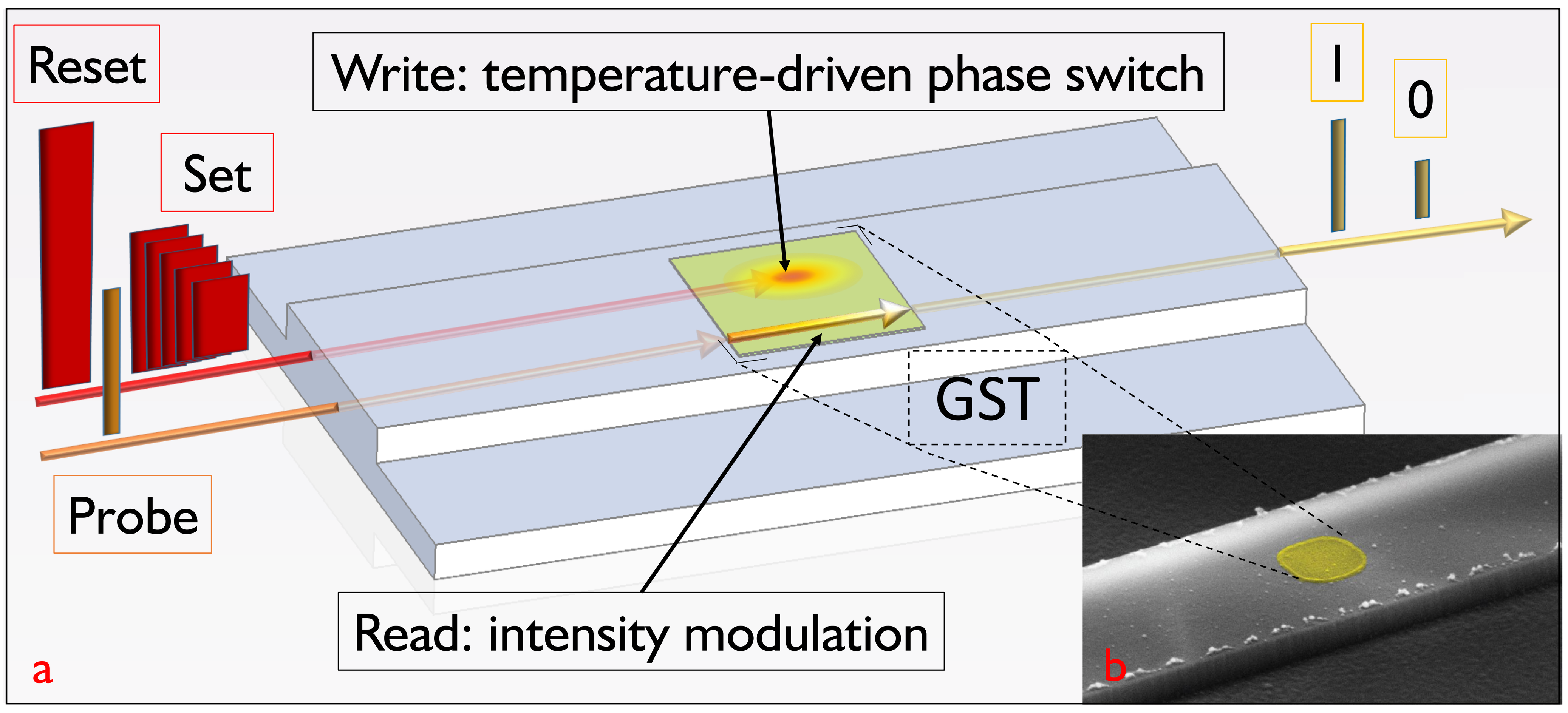

Figure 1. **a)** Device structure and optical memory operative principles. i) A GST layer (green) is deposited on top of a Si_3N_4 rib waveguide (grey). The absorption of the evanescent component of the field by the GST layer modulates the waveguide transmission for the low power read operation and provides the heat source with high power pulses write operations. **b)** Inset: Scanning electron microscope image of a device with a footprint of 0.4 × 0.4 μm^2 [2]

Experimental results

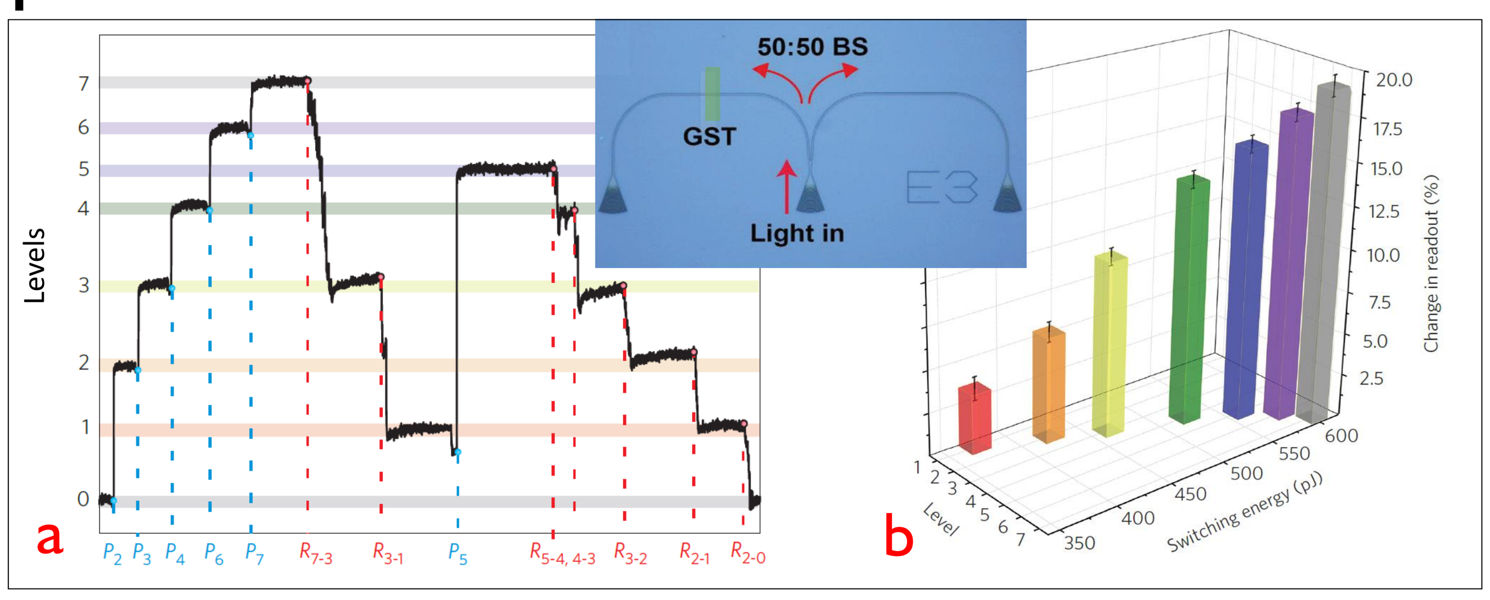

Figure 2. **a)** Non-volatile multi-level switching of a typical photonic phase-change memory (inset) using a single optical pulse. **b)** Relation between used pulse energy, addressed level and corresponding change in readout, for write operations used in a). Ref. [2]

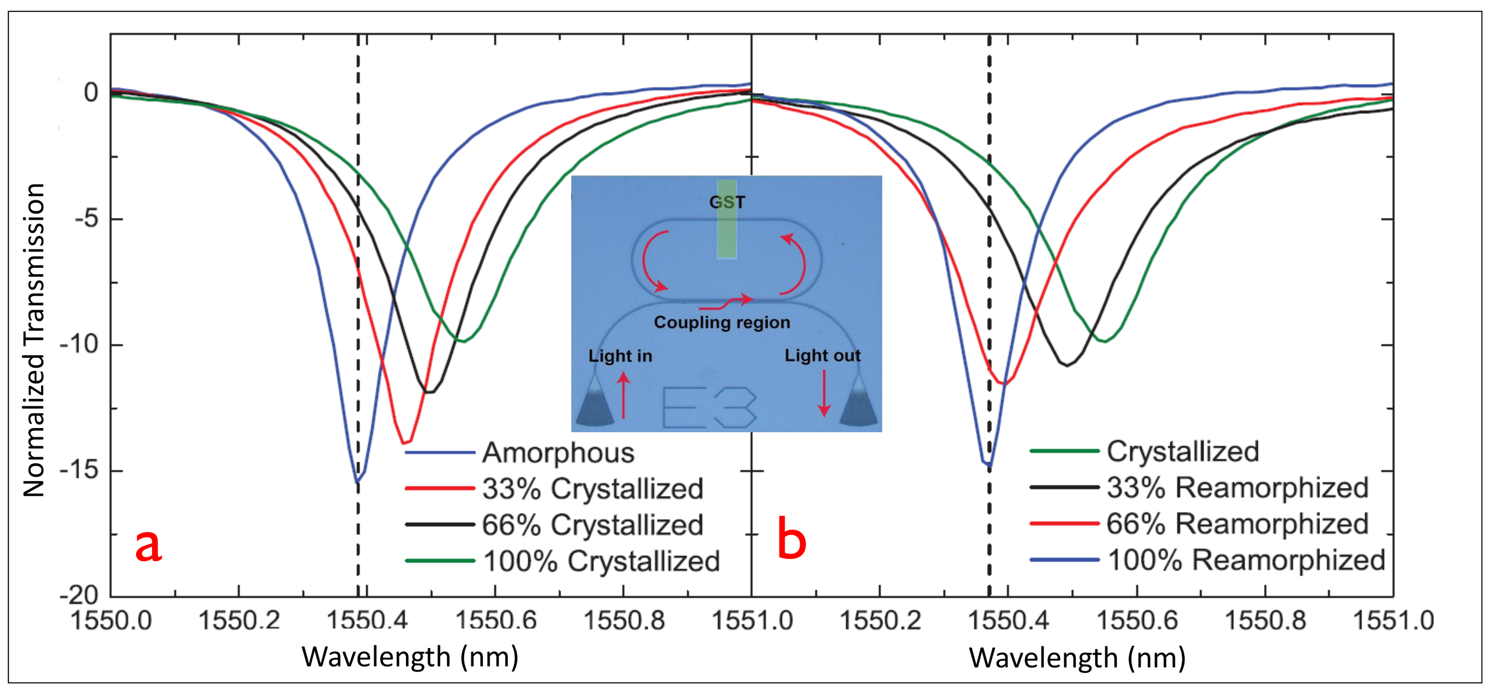

Figure 3. Transmitted spectrum of a waveguide coupled with a nanoring resonator (inset), used as a demultiplexer, during crystallization **a)** and reamorphization **b)** of the 1.5x3 um^2 GST area. Ref. [3]

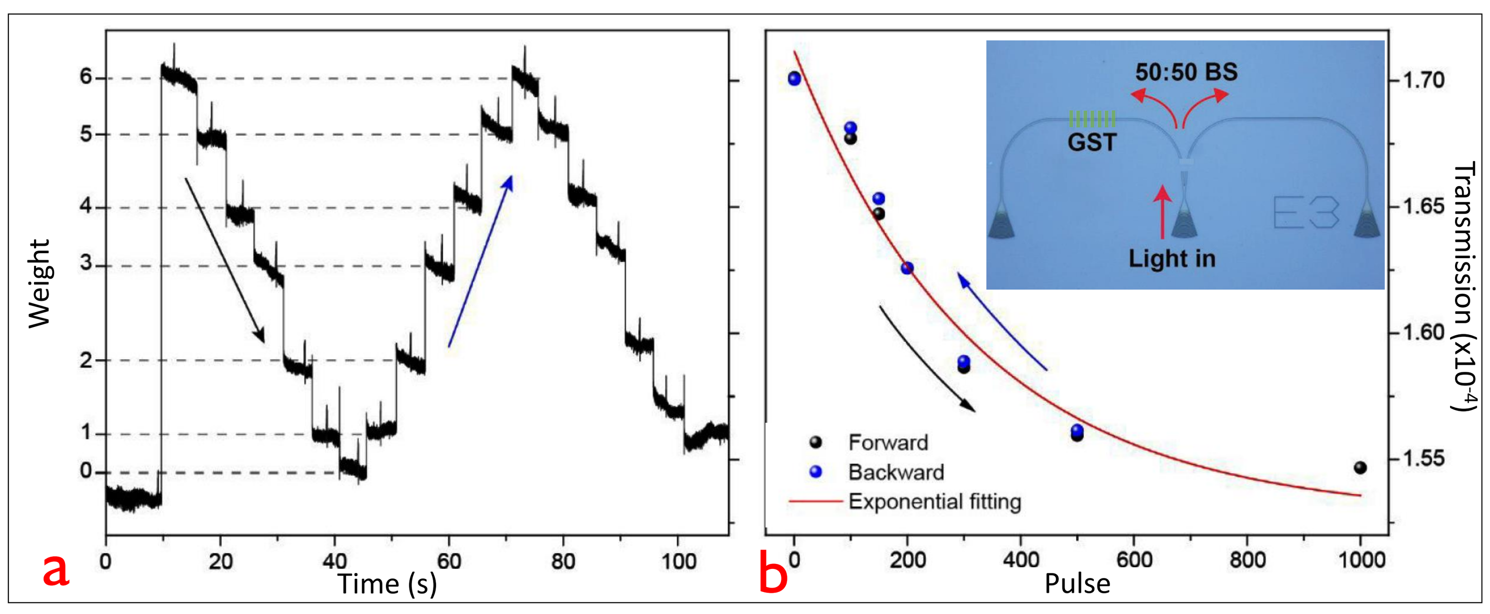

Figure 4. Optical phase-change synapse structure (inset). **a)** Demonstration of differential synaptic weighting during switching between crystalline and amorphous states of GST islands. **b)** Measured transmission as a function of the pulse number, for forward and backward switching. Ref. [4]

Simulation results

The time-dependent propagating field, temperature and phase distributions have been calculated successfully reproducing previously published experimental data[2], as briefly described in Fig 5. The adopted phase-change model is classical nucleation and growth, with the inclusion of an exponential equation mimicking the melting process. Future work will focus on the refinement of this simulation framework, particularly over TBRs, material thermal properties, e.m. loss. We will also develop a 3D Gillespie-Cellular Automaton model capable to simulate larger volume and multiple phases.

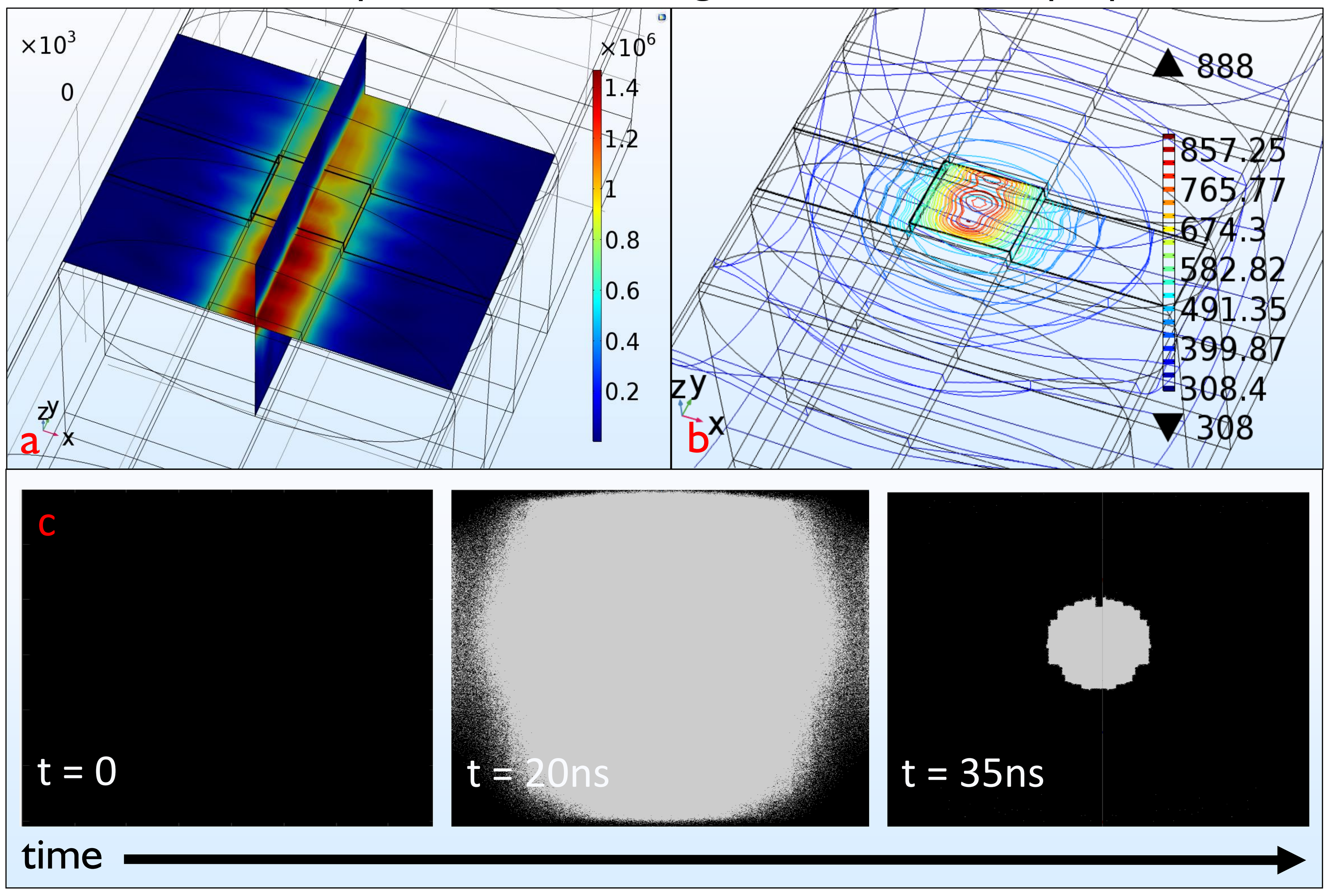

Figure 5. Simulations results of Si_3N_4/silica 1300x335nm rib waveguide – 1.3x1um^2 crGST cell, 1550nm wavelength, 300pJ/20ns pulse. **a)** Wave propagation, norm of the E. field plot [V/m]; **b)** Heat diffusion, temperature isotherms [K] at t = 1ns. **c)** Top view of the GST layer, time dependent evolution of the crystallinity (black: crystalline, grey: amorphous/liquid). After 35ns, only a minor fraction of the amorphized phase is retained below T_m, leading to the experimentally measured change in readout (ref. [2]).

References

[1] Pernice, W.H. and Bhaskaran, H., 2012. Photonic non-volatile memories using phase change materials. *Applied Physics Letters, 101*(17), p.171101.

[2] C. Rios, et al., 'Integrated all-photonic non-volatile multi-level memory', Nat.Phot. 9, 725–732 (2015)

[3] Rudé, et al., 2013. Optical switching at 1.55 μ m in silicon racetrack resonators using phase change materials. *Applied Physics Letters*, *103*(14), p.141119.

[4] Cheng, Z., Ríos, C., Pernice, W.H., Wright, C.D. and Bhaskaran, H., 2017. On-chip photonic synapse. *Science Advances*, *3*(9), p.e1700160.

eg402@exeter.ac.uk

http://ex.ac.uk/eg402

www.exeter.ac.uk/metamaterials

EPSRC

Pioneering research and skills