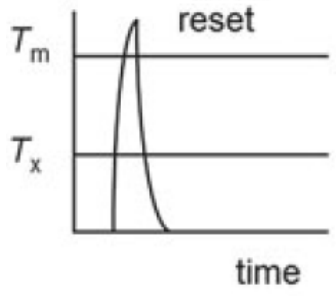
MIT 3.071
Amorphous Materials

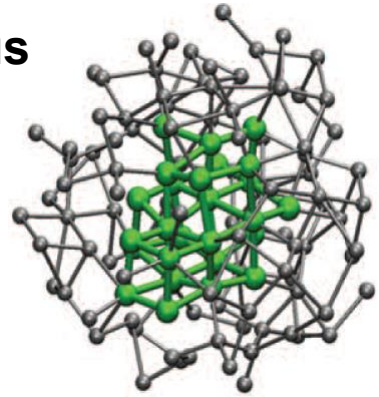
4: Phase Change Data Storage

Juejun (JJ) Hu

Phase change materials

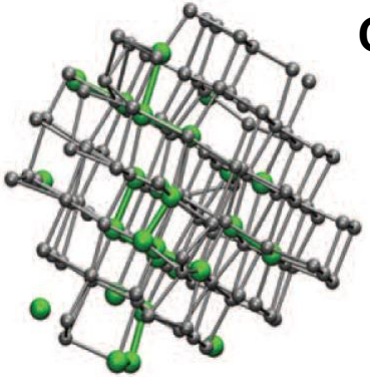


Amorphous

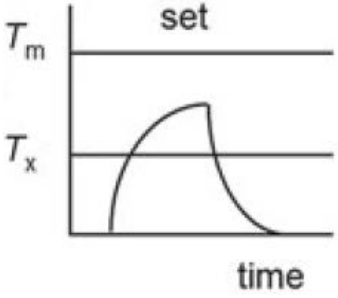


Reset

Set



Crystalline



High electrical resistivity

Low optical reflectance

Low electrical resistivity

High optical reflectance

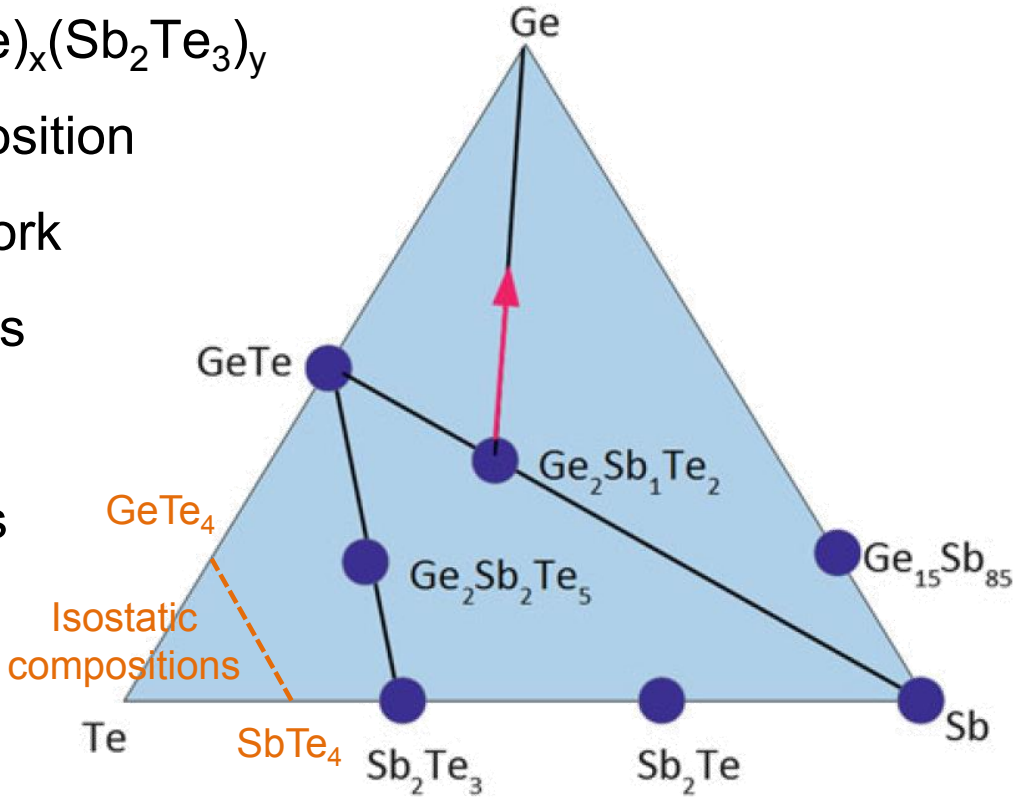
Key performance metrics

- Data retention
  - Good glass stability
- Programming speed
  - Fast crystallization

- Recording density
  - Size dependence of material properties, driver size
- Endurance (cycle lifetime)
  - Phase and interface stability
- Power consumption
  - Enthalpy of melting, heat capacity $Q = \Delta H_m + \int_{RT}^{T_m} C_V dT$
  - Low thermal conductivity

Ge-Sb-Te (GST) phase change alloy

- Pseudo-binary alloy: $(GeTe)_x(Sb_2Te_3)_y$
  - Main commercial composition
  - Stressed rigid 3-D network
- Fast switching compositions
  - $Ge_{15}Sb_{85}$, Sb_2Te
- High thermal stability alloys
  - $(Ge_2Sb_1Te_2)_x(Ge)_y$
- Amorphous: covalent
- Crystal: resonant bonding



Phys. Rev. B **81**, 174206 (2010);
Solid-State Electron. **111**, 27 (2015).

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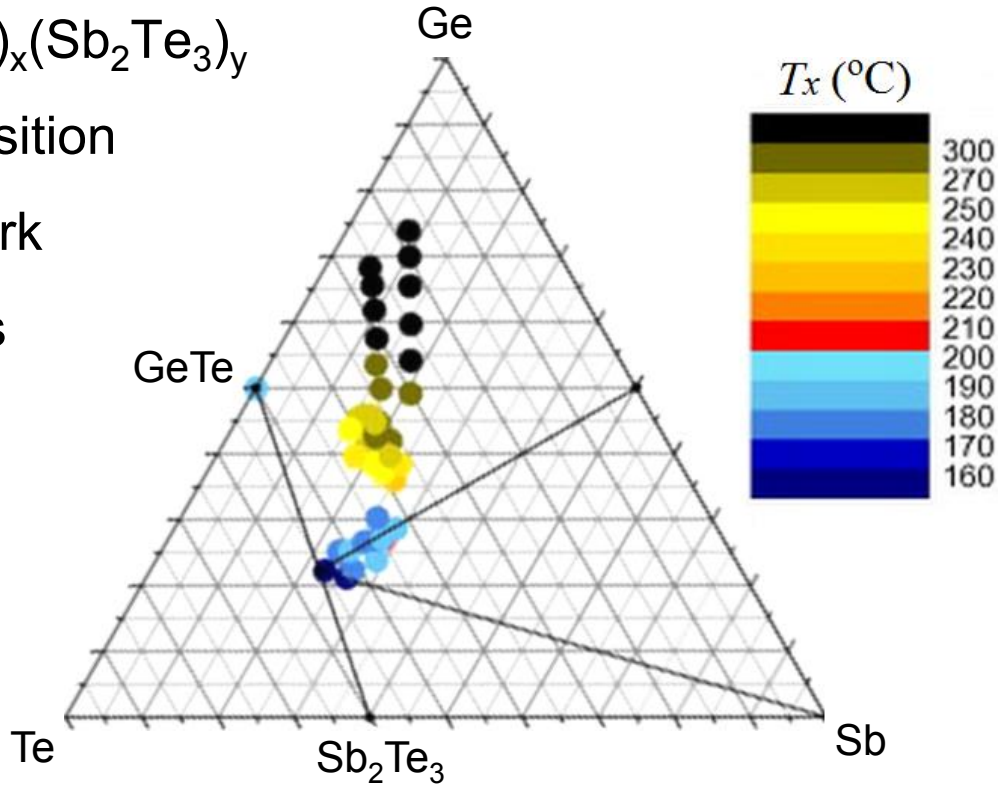
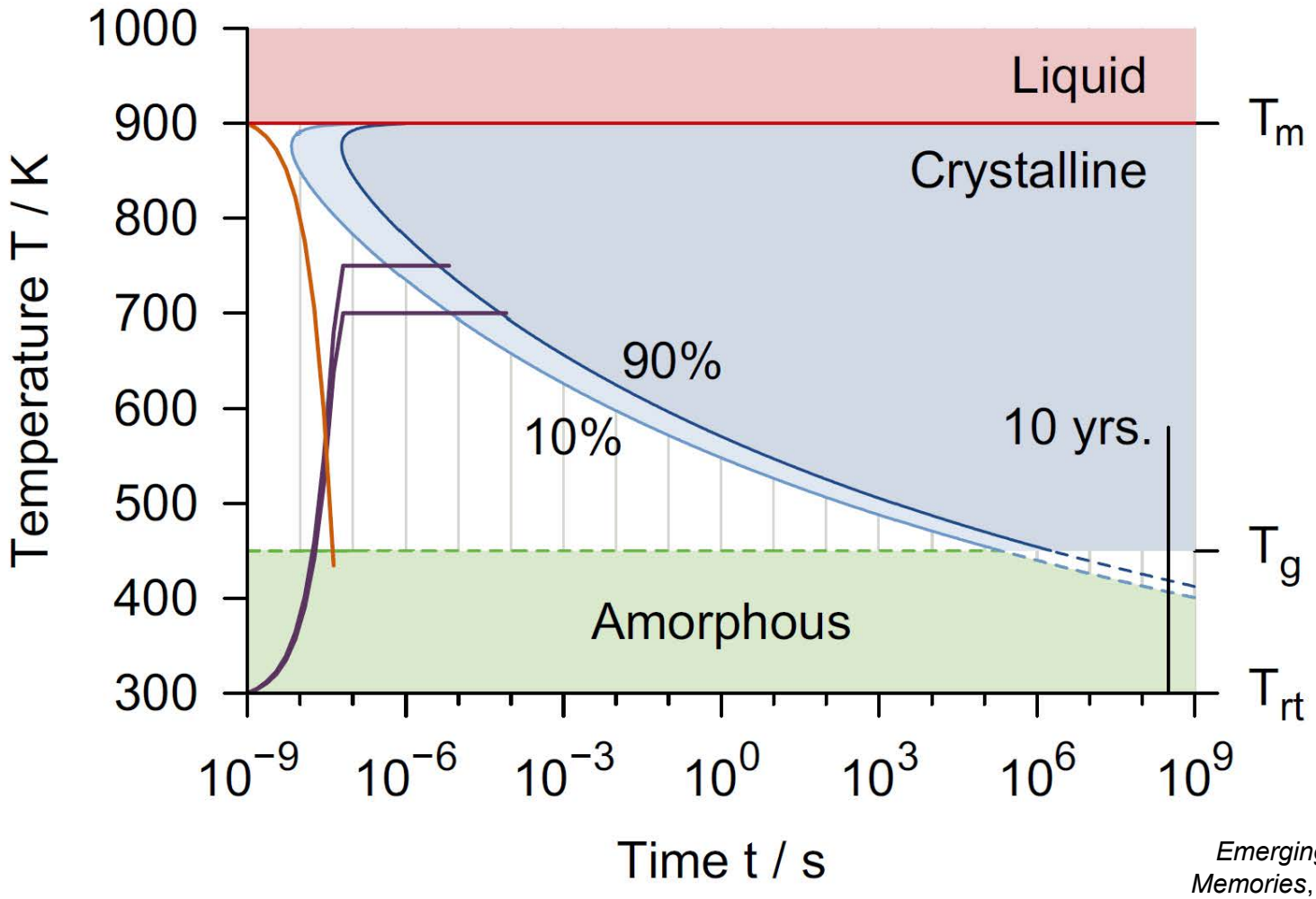


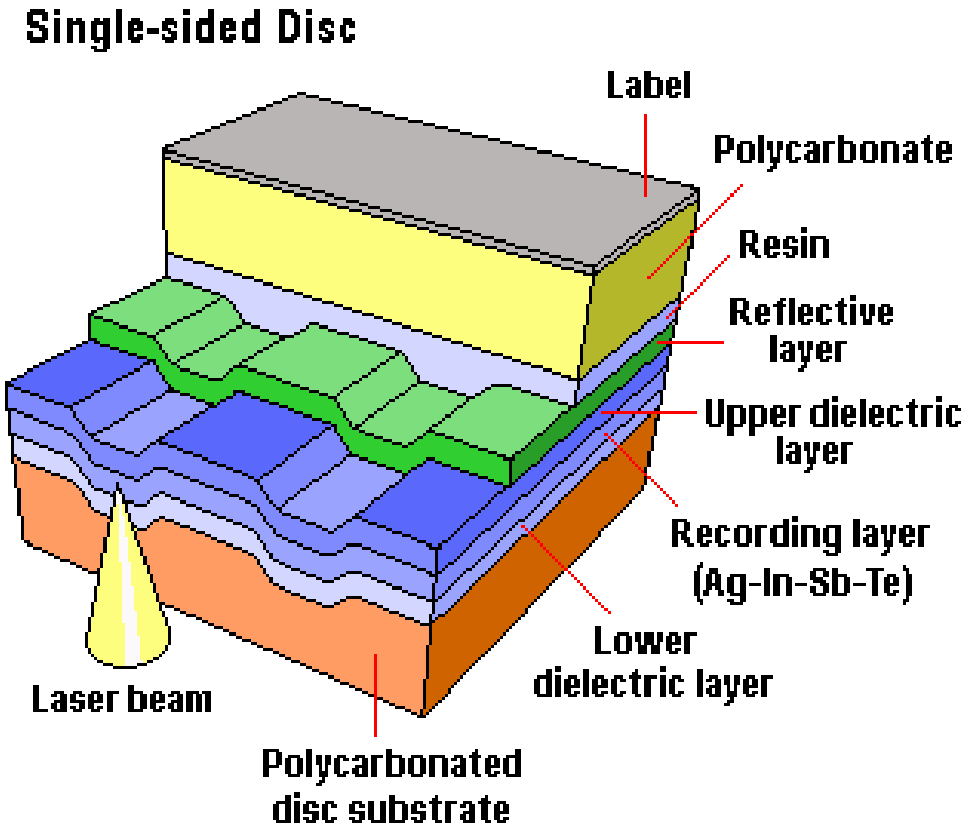
Phys. Rev. B **81**, 174206 (2010);
Solid-State Electron. **111**, 27 (2015).

T-T-T diagram of GST phase change alloys



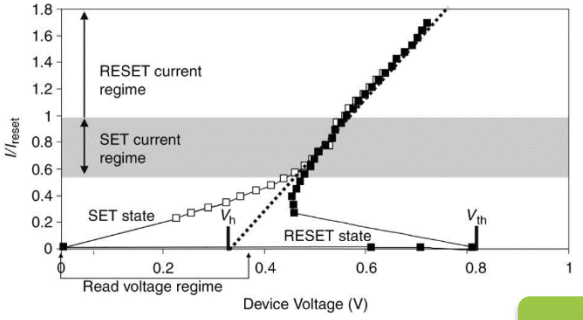
Emerging Non-Volatile Memories, Springer (2014)

Re-writable CDs and DVDs



Modulation of optical reflectance via laser-induced phase change

Phase change memory (PCM)



Discovery of threshold switching in chalcogenides

1968 Ovshinsky

1970 Gordon Moore

256-bit phase change memory demo

Discovery of rapid switching pseudo-binary GST material

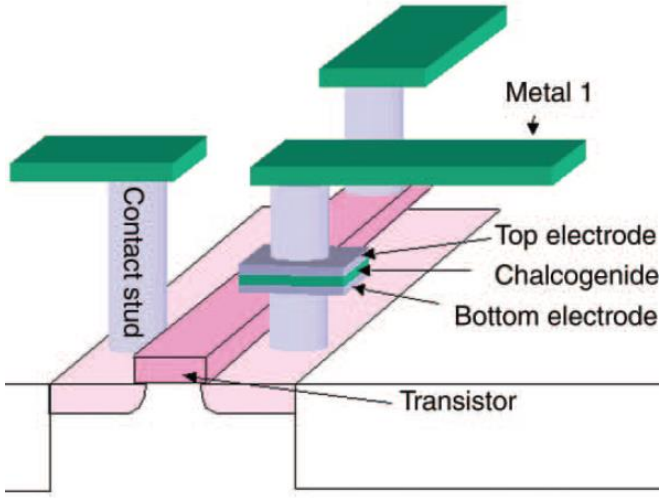
1987 Yamada *et al.*

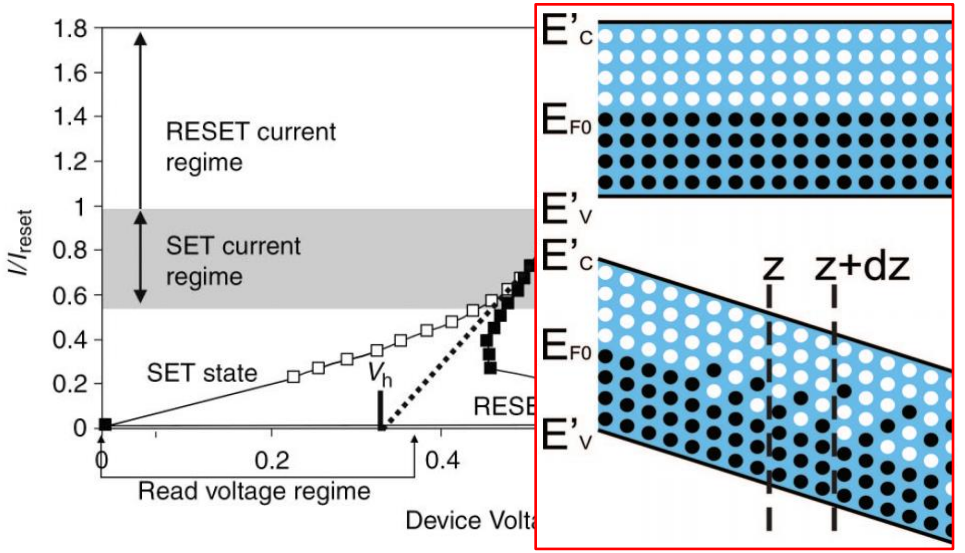
IBM, Micron, Samsung, …

Non-volatile phase change memory module commercialized

Phase change memory (PCM)

- Electrodes used for both programming and read-out





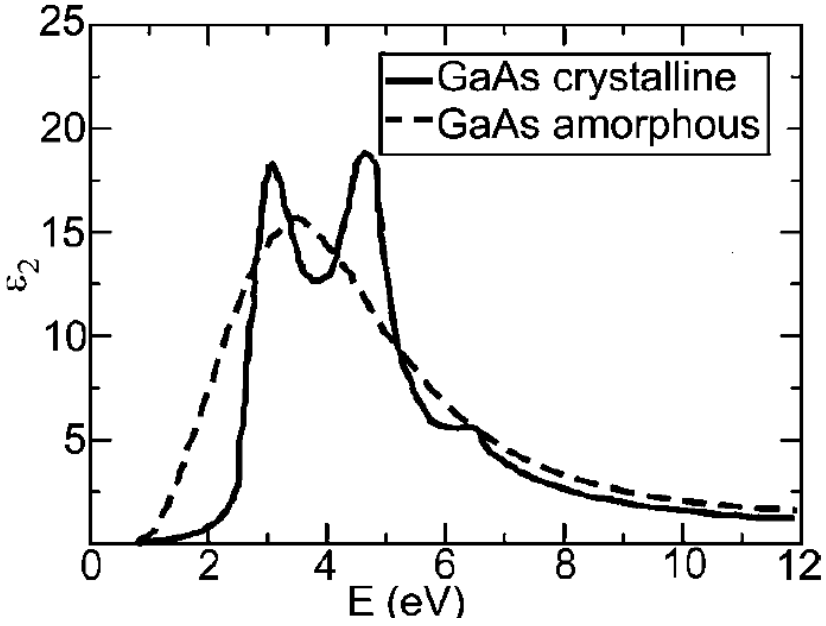
- Threshold switching: electric field driven bistability
  - Transient behavior: electronic in nature, no structural change
  - Contributes to reduced SET voltage

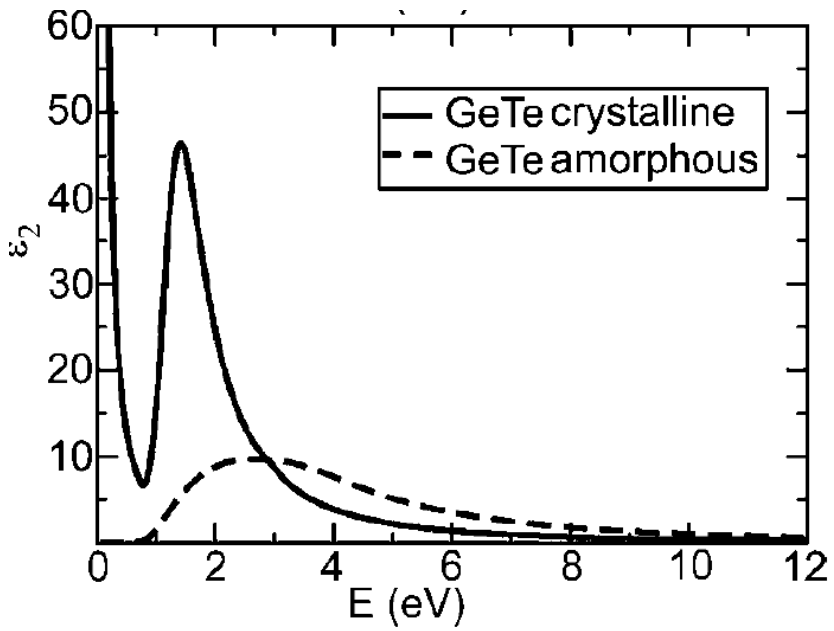
S. Hudgens and B. Johnson, *MRS Bull.* (2004); *Phys. Rev. B* **78**, 035308 (2008).

Where does PCM stand against competitors?

	Memristor	PCM	STT-RAM	DRAM	Flash	HD
Chip area per bit (F^2)	4	8–16	14–64	6–8	4–8	n/a
Energy per bit (pJ)[2]	0.1–3	2–100	0.1–1	2–4	10^1–10^4	10^6–10^7
Read time (ns)	<10	20–70	10–30	10–50	25,000	5–8x10^6
Write time (ns)	20–30	50–500	13–95	10–50	200,000	5–8x10^6
Retention	>10 years	<10 years	Weeks	<Second	~10 years	~10 years
Endurance (cycles)	~10^{12}	10^7–10^8	10^{15}	>10^{17}	10^3–10^6	10^{15} ?
3D capability	Yes	No	No	No	Yes	n/a

Applications beyond data storage: optics

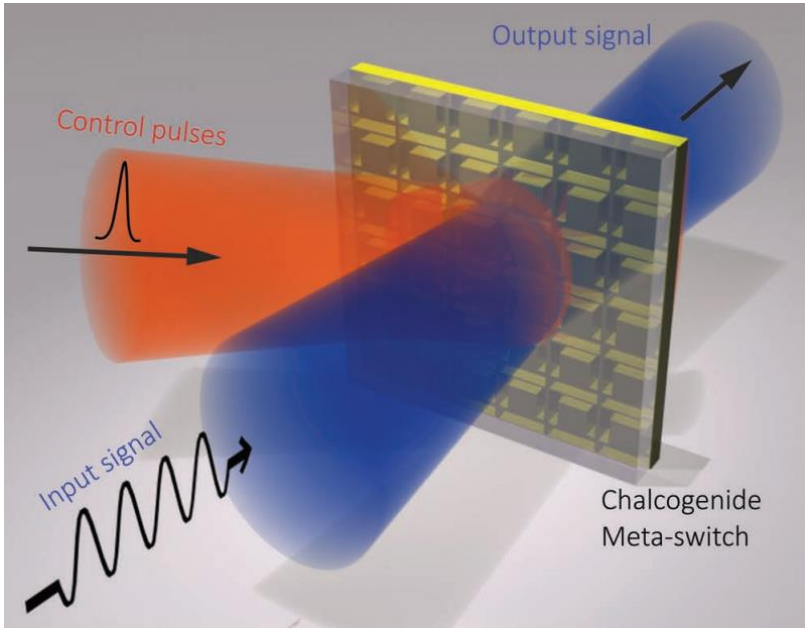




Large optical property contrast in GeTe due to change of bonding type from crystalline (resonance) to amorphous (covalent) phase

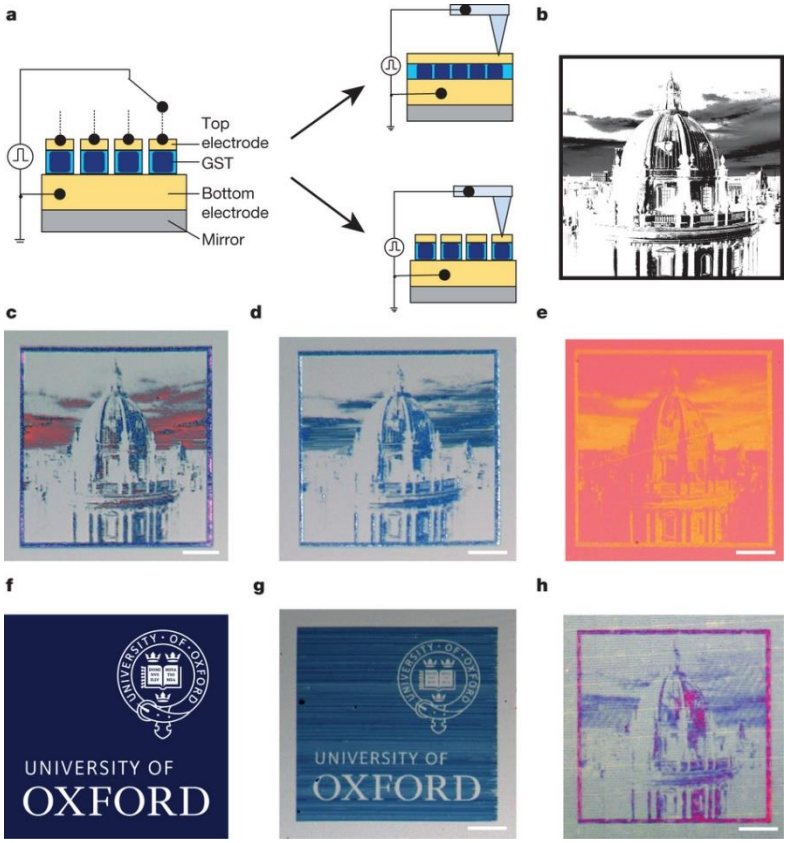
Chem. Rev. **110**, 240-267 (2010).

Applications beyond data storage: optics



Optical switch

? Applications involving bistable states



Electronic paper display

Nature **511**, 206 (2014); *Adv. Mater.* **25**, 3050 (2013).

Further readings

- *Phase Change Materials: Science and Application*, Springer (2009).
- *Emerging Non-Volatile Memories*, Springer (2014).
- "Chalcogenide Phase-Change Materials: Past and Future," *Int. J. Appl. Glass Sci.* **1**, 15 (2015).

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