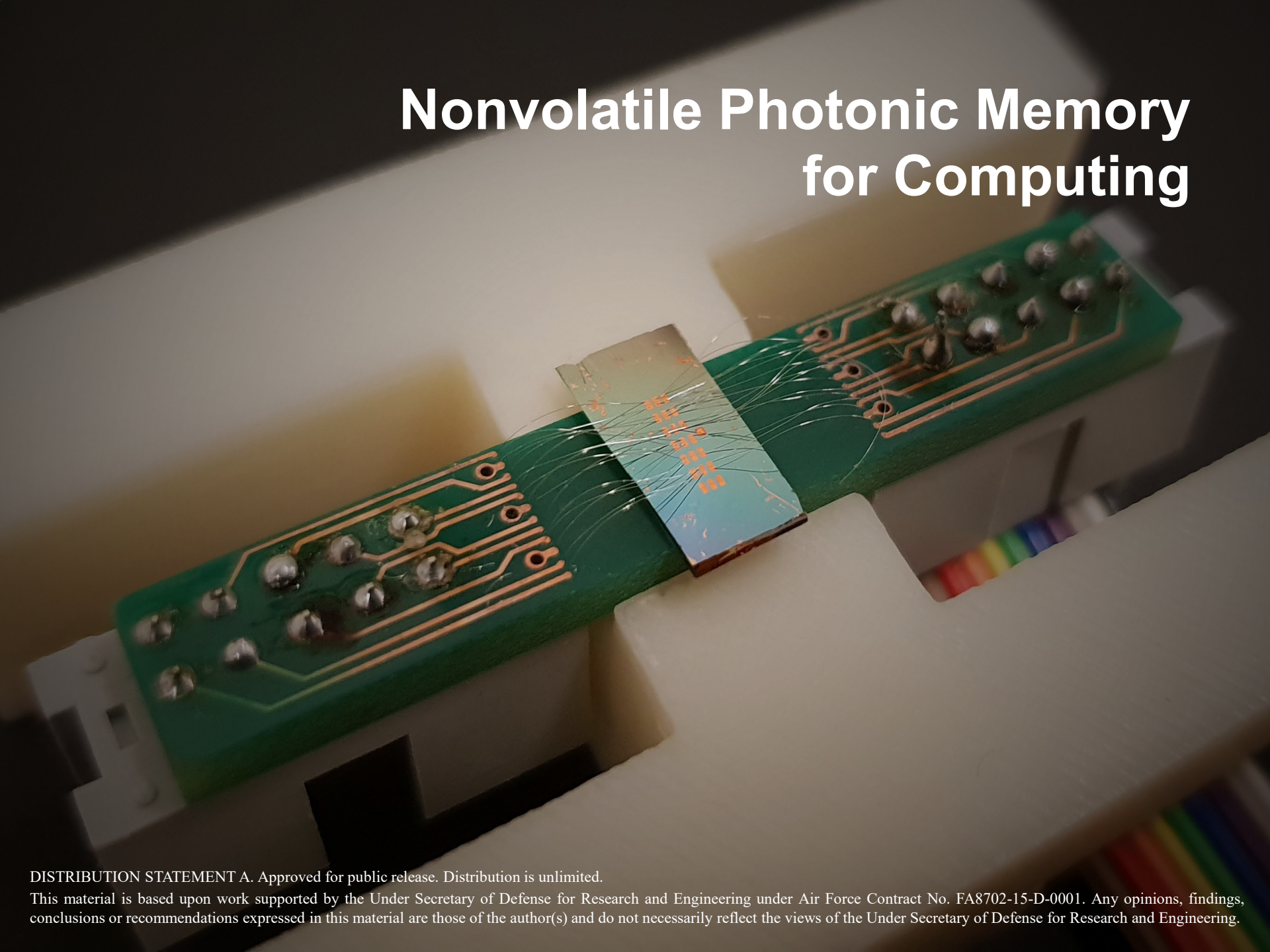
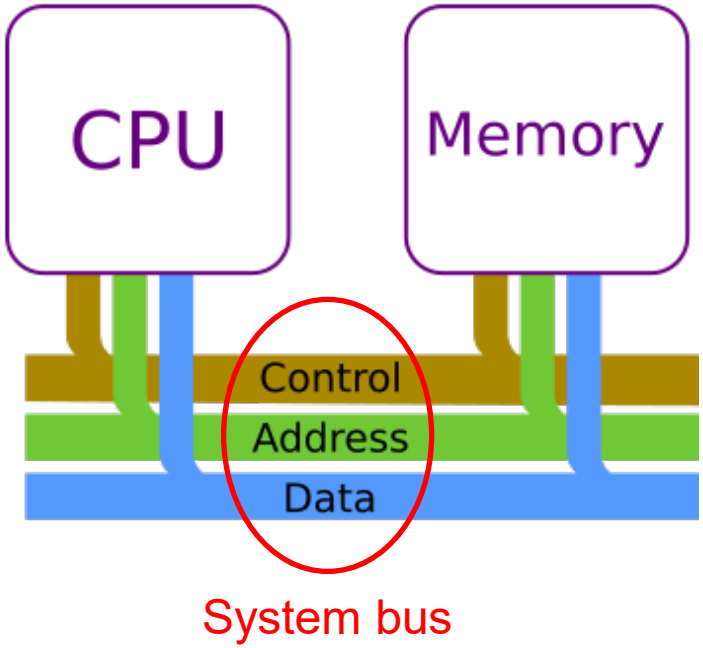
Nonvolatile Photonic Memory for Computing

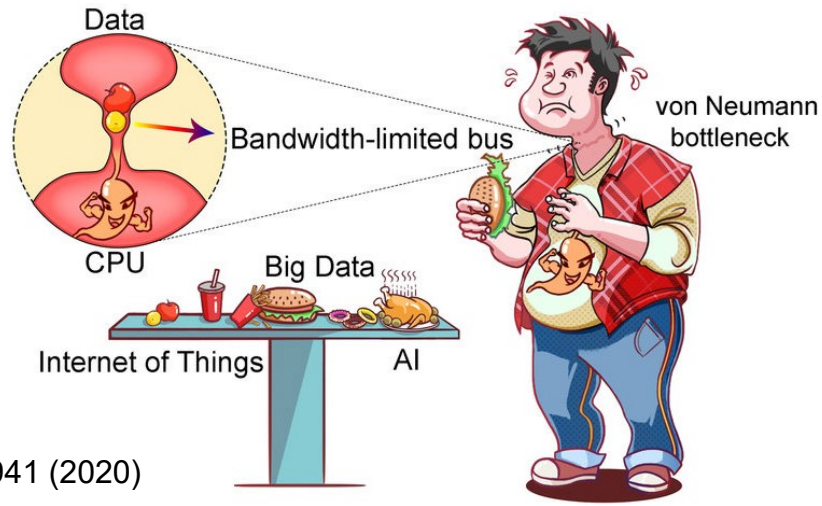


This material is based upon work supported by the Under Secretary of Defense for Research and Engineering under Air Force Contract No. FA8702-15-D-0001. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Under Secretary of Defense for Research and Engineering.

The von Neumann bottleneck



Communications between CPU and memory limits computing speed and energy efficiency



Chem. Rev. **120**, 3941 (2020)

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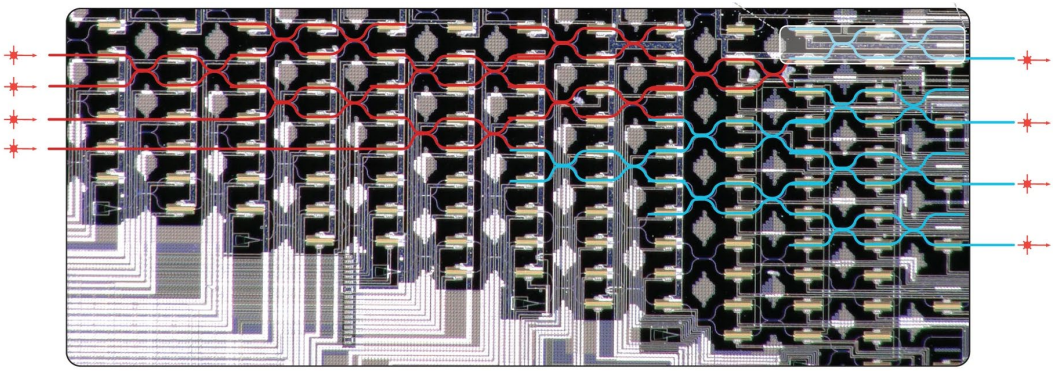
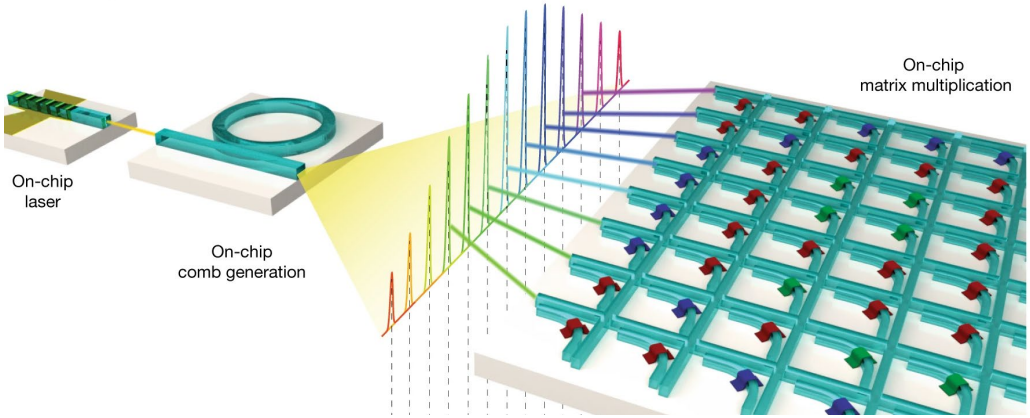
Photons coming to rescue: analog optical computing



Optical matrix-vector multiplication and accumulation (MAC)

Nat. Photonics **11**, 441 (2017);
Nature **589**, 52 (2021)



A **nonvolatile** optical memory for storing matrix elements is needed

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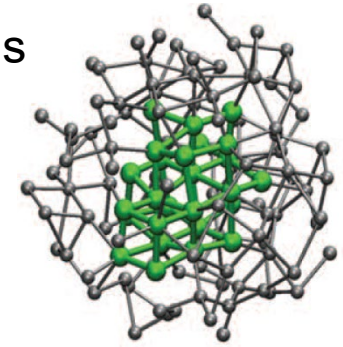
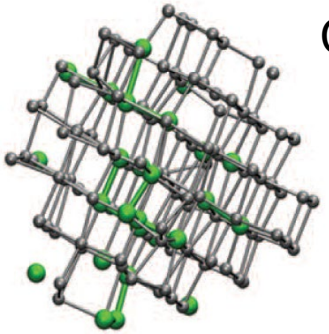
Phase change materials (PCMs)

Amorphous



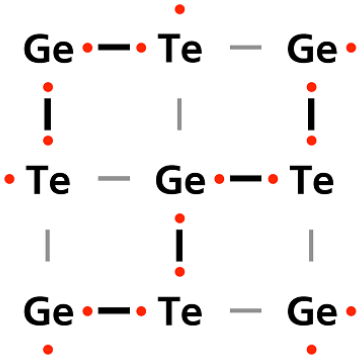
Quench

Anneal

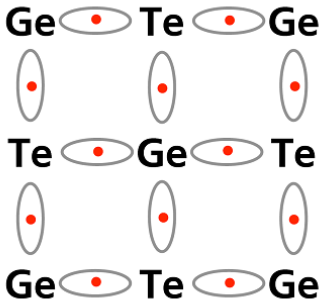


Crystalline

Covalent bonding



Large electrical & optical contrasts



Metavalent bonding

Adv. Mater. **31**, 1806280 (2019)

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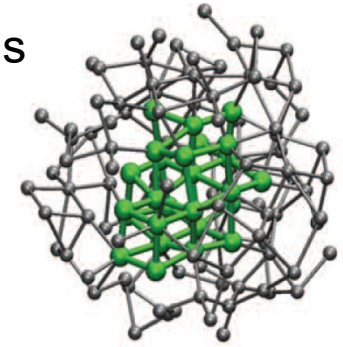
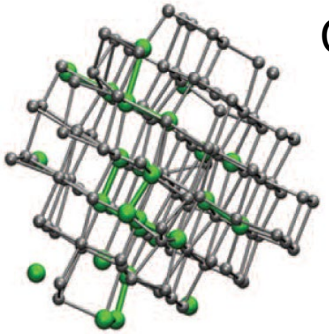
Phase change materials (PCMs)

Amorphous



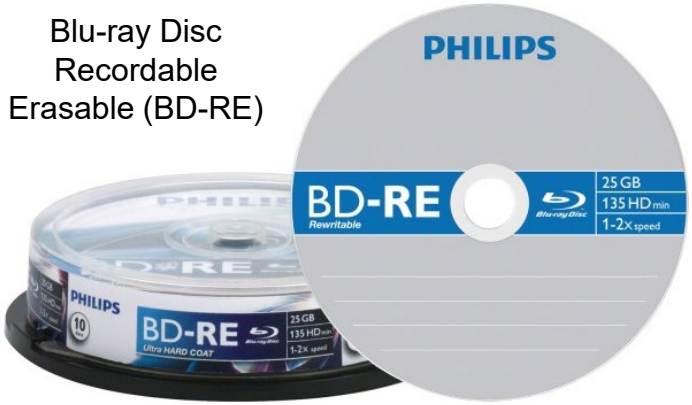
Quench

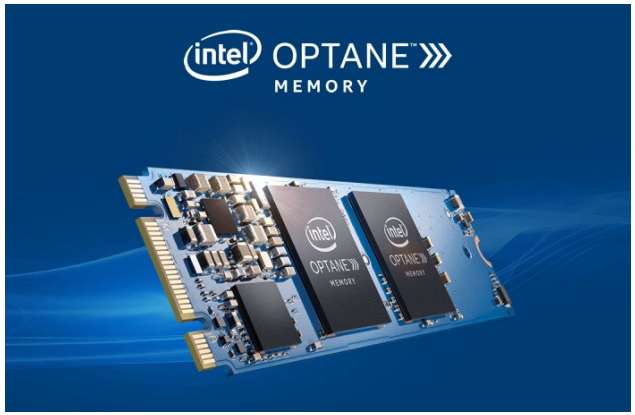
Anneal



Crystalline

Blu-ray Disc
Recordable
Erasable (BD-RE)





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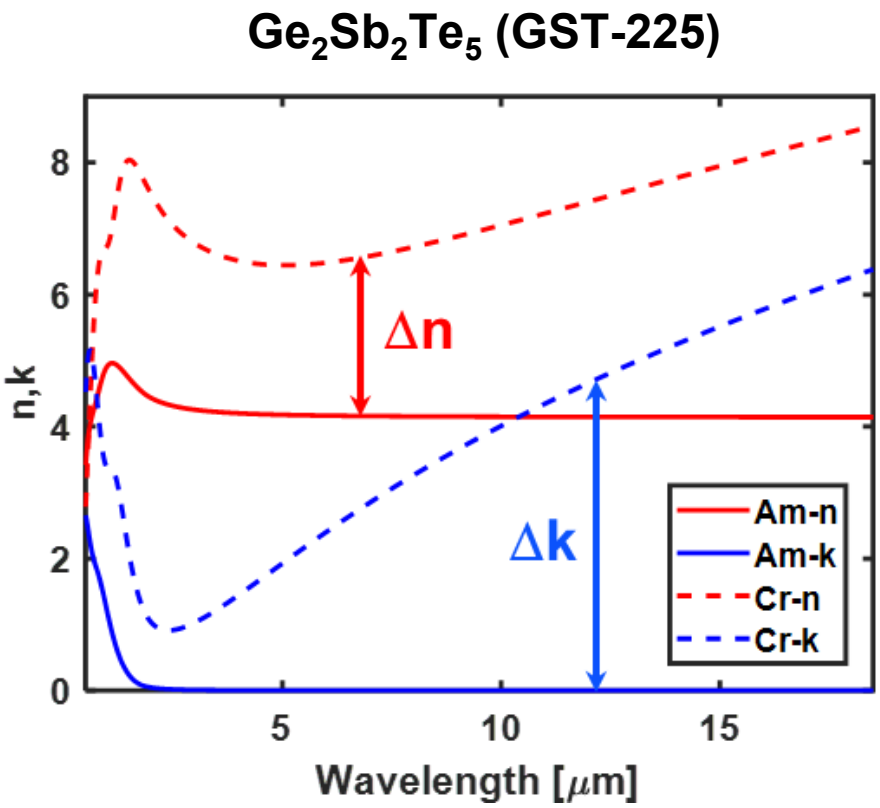
Optical properties of the classical PCM



- ✓ Giant index contrast
- ✓ Nonvolatile switching
- ✓ Intermediate states
- × Large optical loss

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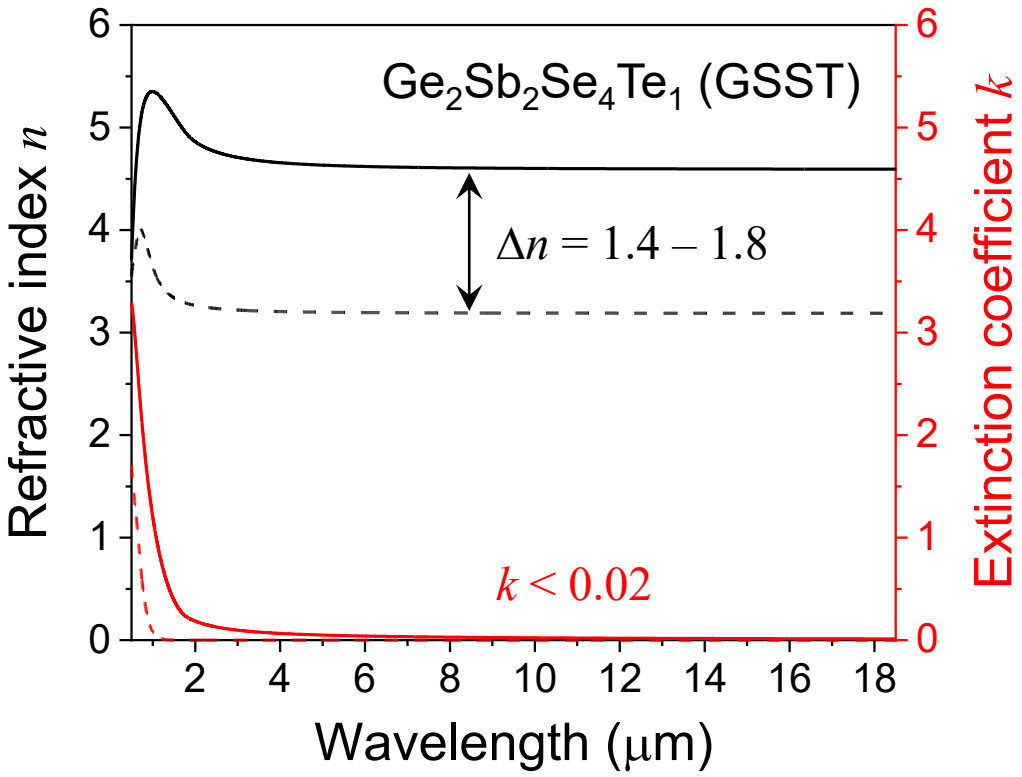
GSST: the first broadband transparent phase change alloy



- ✓ Index change: Δn = 1.4 – 1.8
- ✓ Loss: k < 0.02

  1 – 18.5 μm (a)
  5 – 18.5 μm (c)

FOM **100x** higher than GST-225

Opt. Lett. **43**, 94 (2018);
Nat. Commun. **10**, 4279 (2019)

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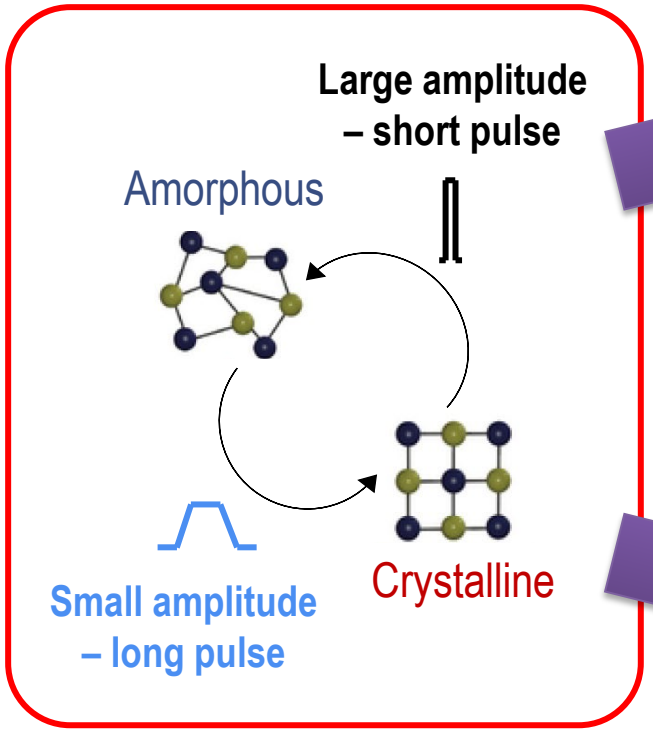
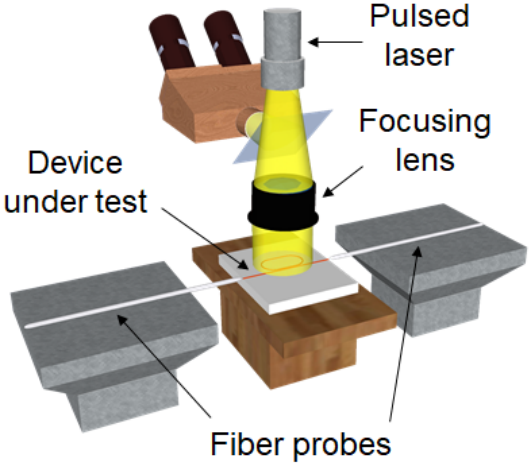
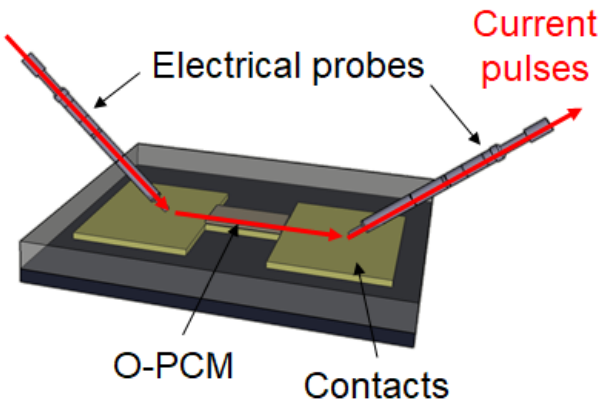
Optical and electrical switching of PCMs





Optical (laser) switching

Electro-thermal switching



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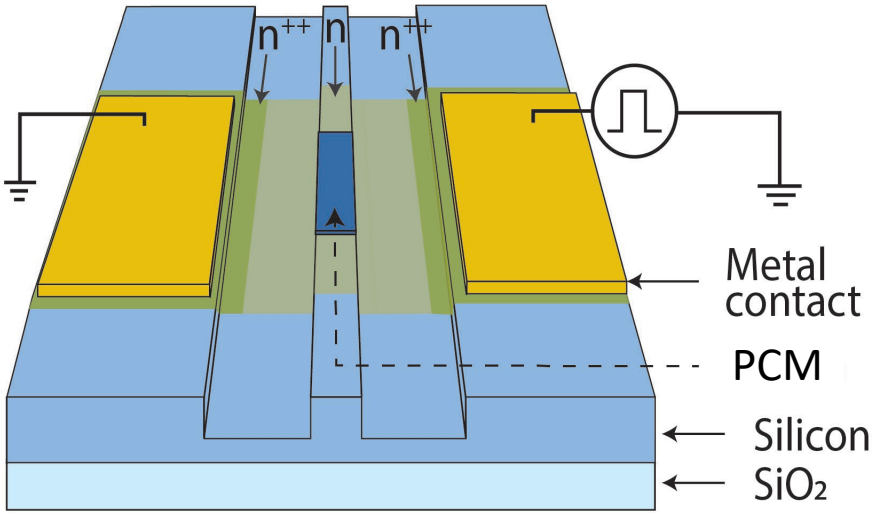
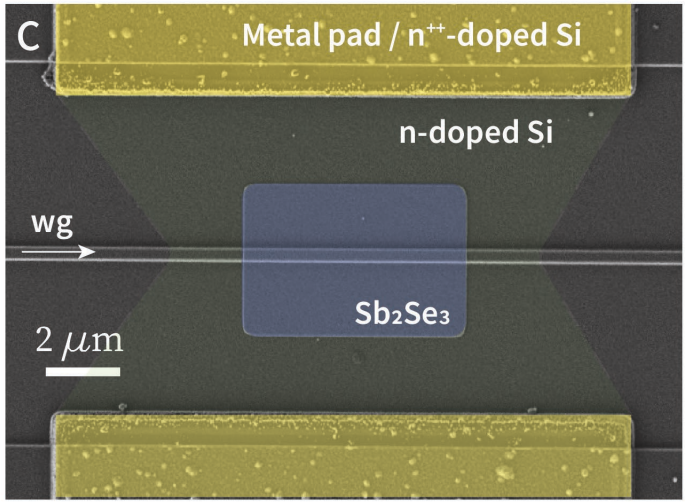
PCM electrical switching using Si micro-heaters





Transparent and CMOS-compatible doped Si micro-heaters

PhotoniX **3**, 26 (2022)

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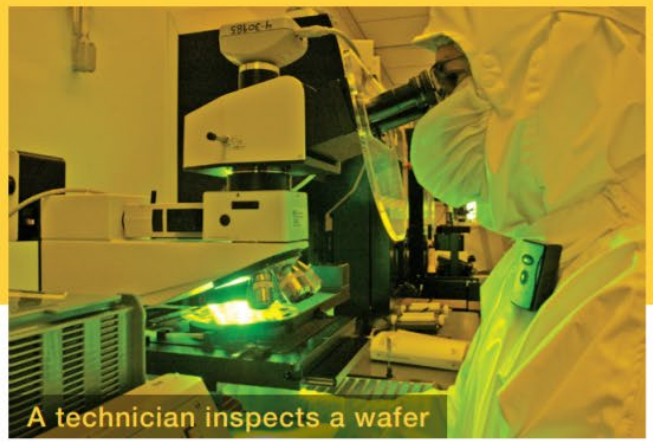
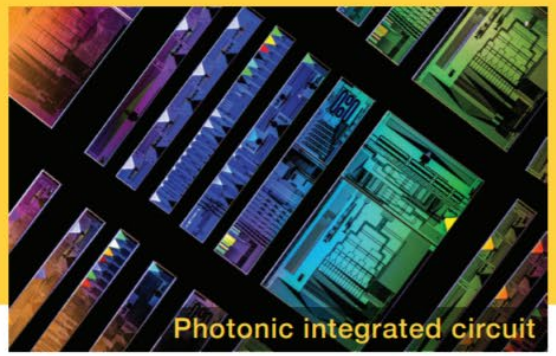
Lincoln Laboratory Microelectronics Laboratory

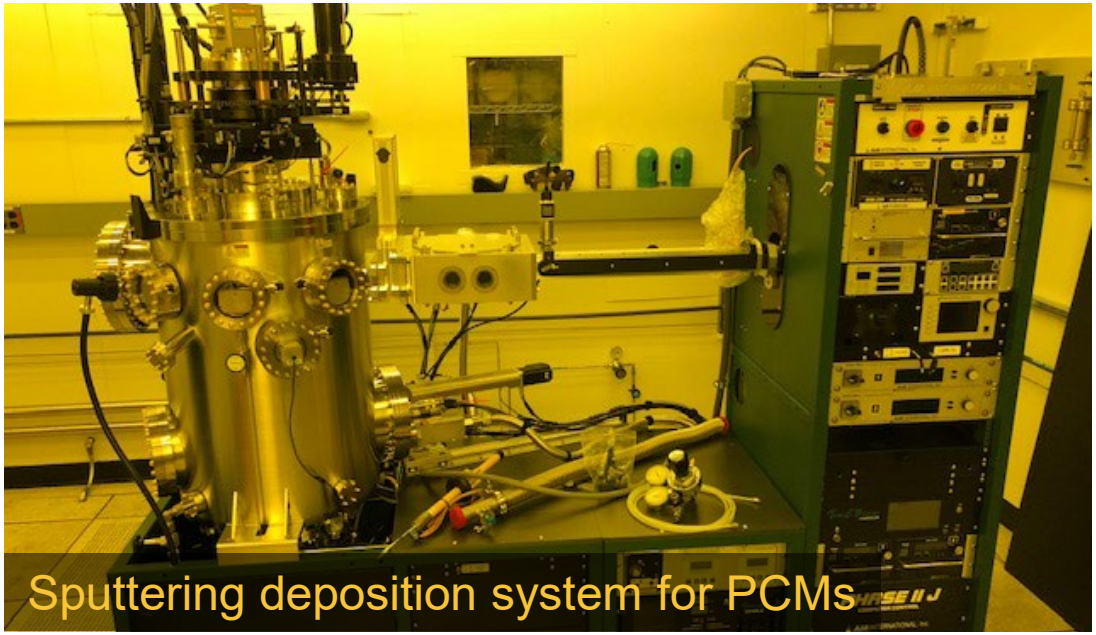
MIT LINCOLN LABORATORY

features

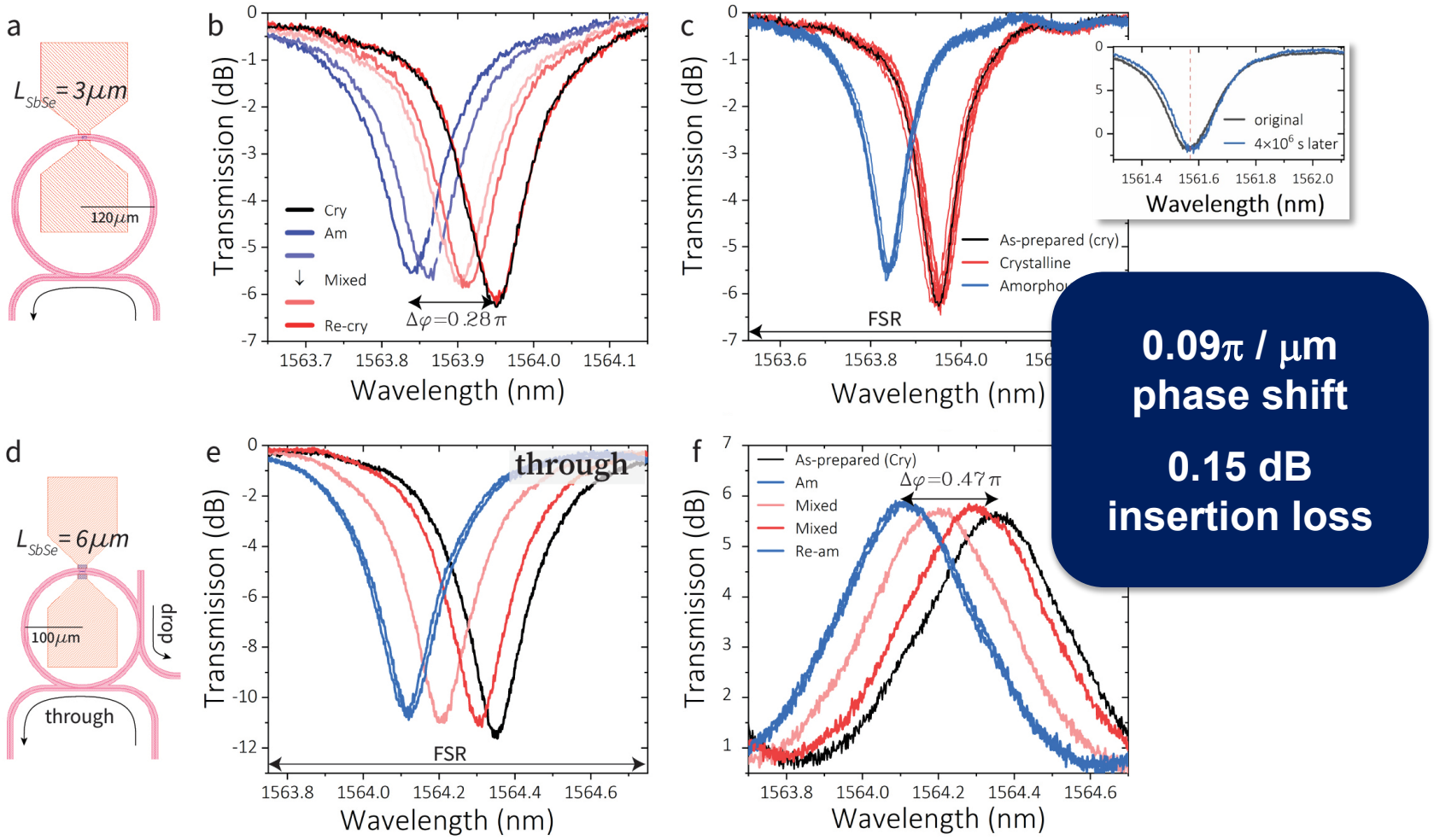
- 90-nanometer CMOS toolset for processing on 200-millimeter wafers
- 193-, 248-, and 365-nanometer lithography
- 4-nanometer electron beam writing
- Molecular-beam epitaxy
- DMEA Category 1A Trusted Design, Aggregation, Foundry Services, Post Processing, and Packaging/ Assembly accreditation and ISO-9001 certification


A technician inspects a wafer


Photonic integrated circuit


Sputtering deposition system for PCMs

Reconfigurable ring resonators



0.09π / μm phase shift

0.15 dB insertion loss

PhotoniX **3**, 26 (2022)

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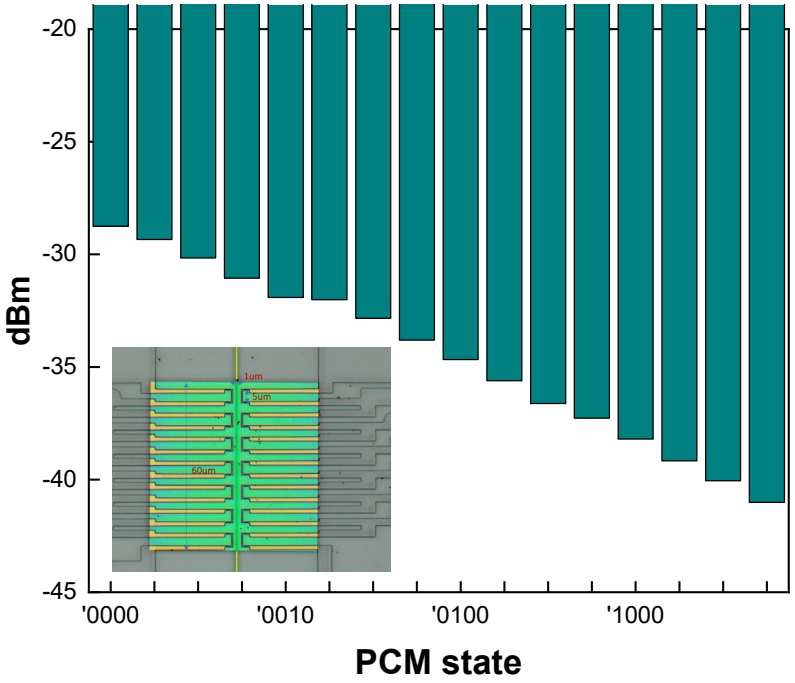
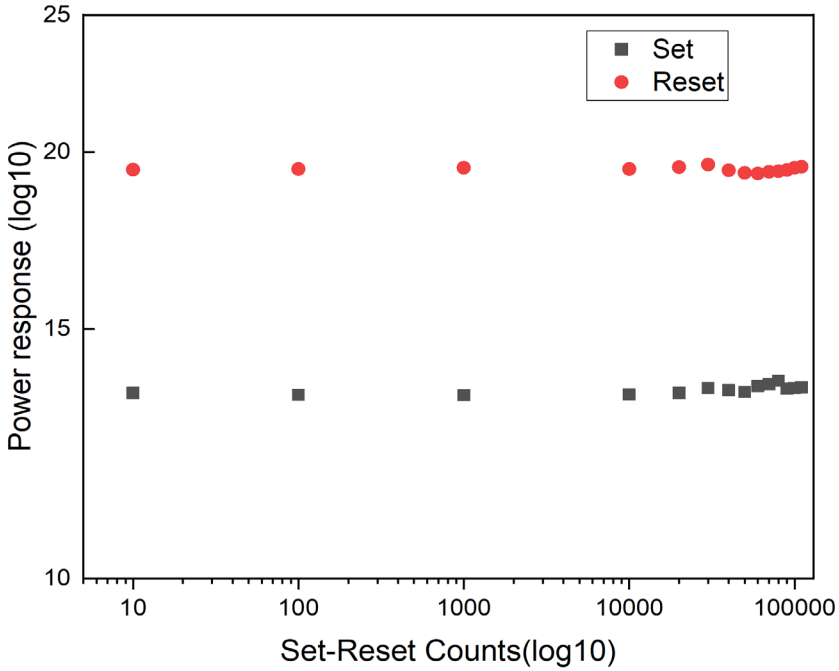
$Ge_2Sb_2Se_5$ PCM switching

with Sorger *et al.*

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC





4-bit electrically programmable photonic memory showing consistent operation over **half million** switching cycles

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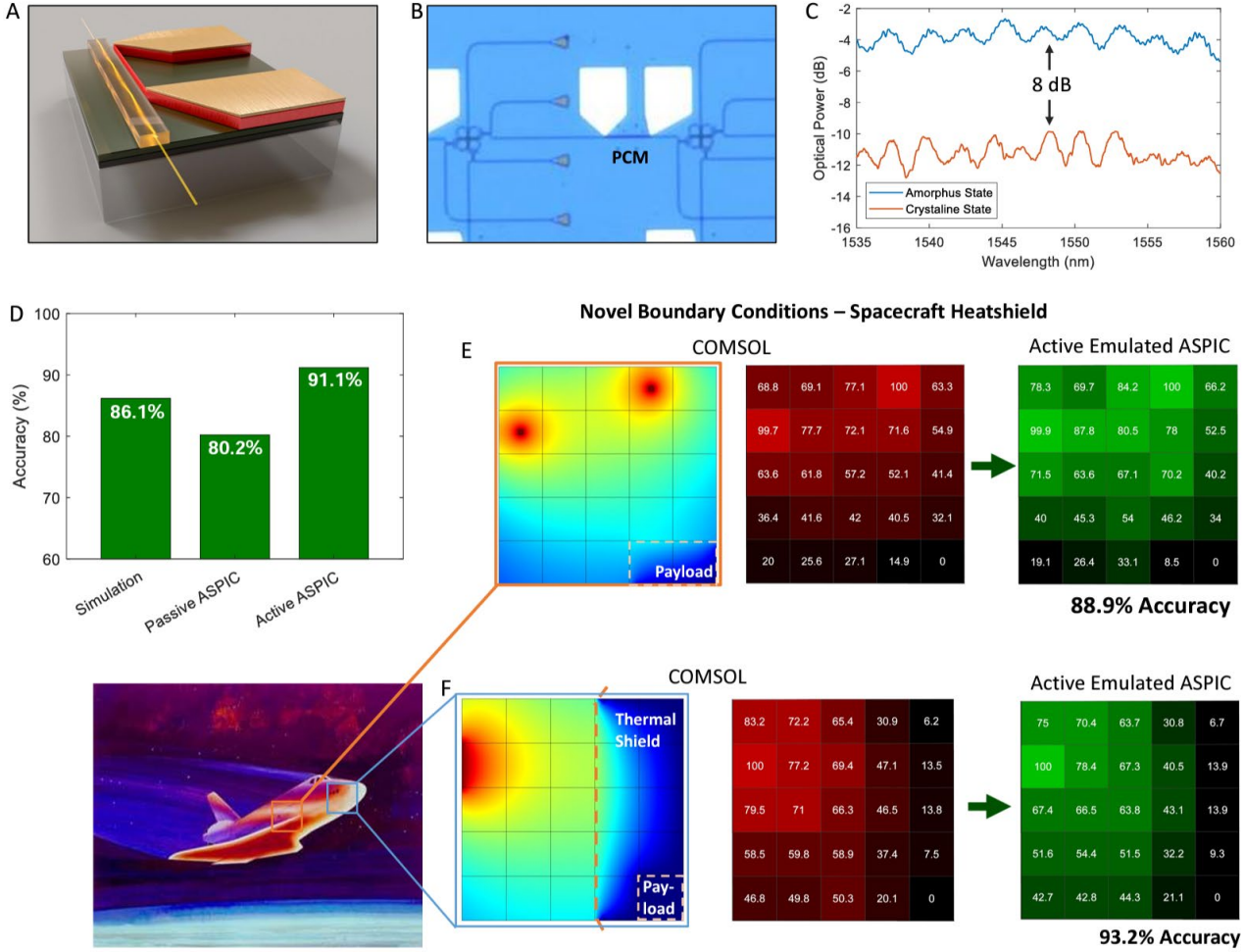
Partial differential equation solver

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC



PCM memories used to store parameters and boundary conditions

arXiv:2208.03588

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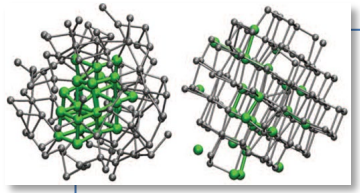
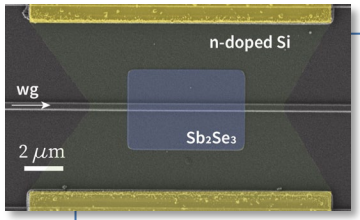
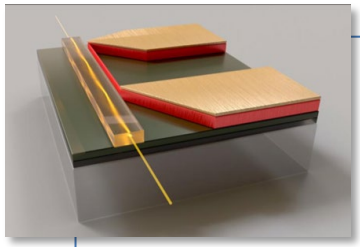
Summary



PCMs are key enablers for energy-efficient in-memory optical computing



We achieved seamless integration of PCMs with photonic foundry manufacturing



PCM-enabled reconfigurable optical analog computing was demonstrated

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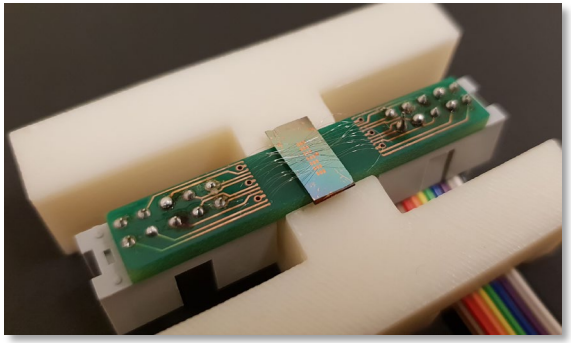
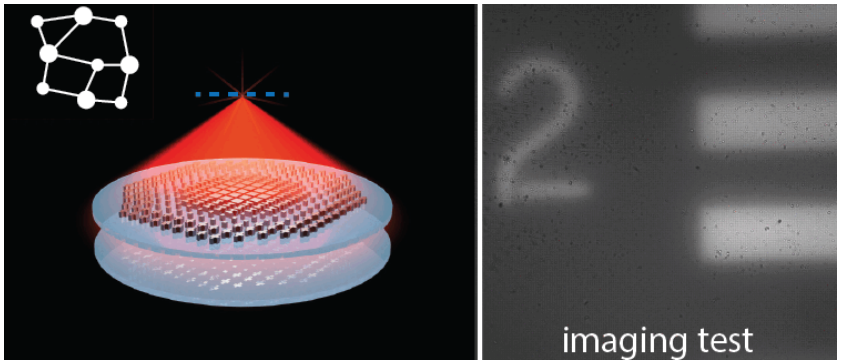
The first electrically switched PCM metasurface:

Nat. Nanotechnol. **16**, 661 (2021)





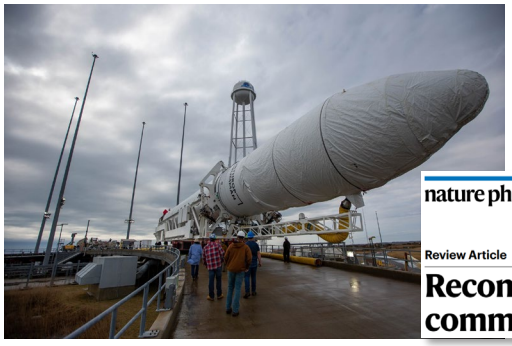
Parfocal zoom lens without moving parts

Nat. Commun. **12**, 1225 (2021)

Adv. Opt. Mater. **10**, 2200721 (2022)

Qualifying PCMs for the space environment

NASA Langley Research Center




nature photonics

Review Article https://doi.org/10.1038/s41566-022-01099-4

Reconfigurable metasurfaces towards commercial success

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