Low-loss Non-volatile Electrically Reconfigurable Integrated Photonic Switch

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We demonstrated a nonvolatile electrically tunable integrated photonic switch based on Phase Change Materials (PCMs) GST and Sb_2S_3.

Reconfigurable silicon photonics

- ✓ Thermo-optic / electro-optic effects
- ✓ Challenges: small tuning, volatile → large footprint, energy consumption

- Phase-change materials (**PCMs**)
  - ✓ High optical contrast (Δn > 1) between amorphous and crystalline states
  - ✓ Non-volatile ~10 years
  - ✓ Fast (ns), low-energy (fJ/bit), reversible switching with high cyclability (10^{15}).
  - ✓ Excellent scalability

Highlights

> An energy-efficient, low-loss, low-voltage, compact, non-volatile, reprogrammable silicon photonic platform.

> high endurance with cyclability >500

> Electrical tuning of GST achieved by integrated Si PIN heater

> Actuation of Sb_2S_3 exhibits <10 reduction in Q factor and over 30dBm extinction ratio.

> Applications in microwave photonics, data centers, neural networks, quantum optics ...

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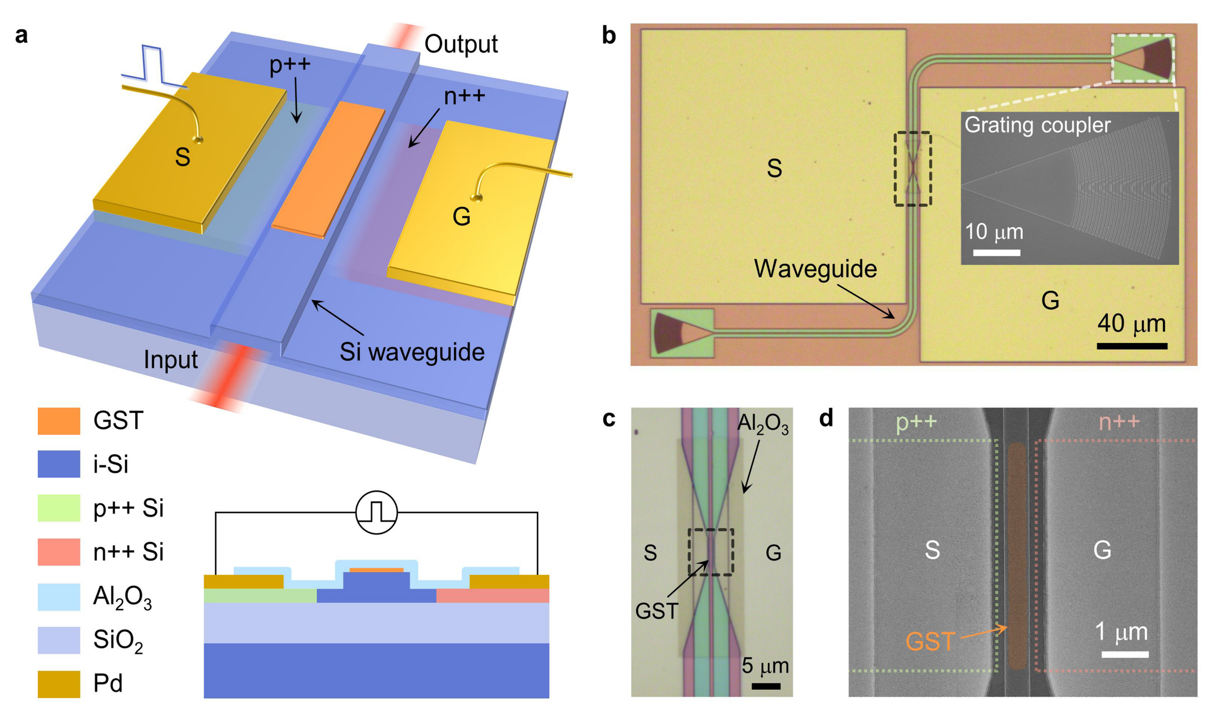
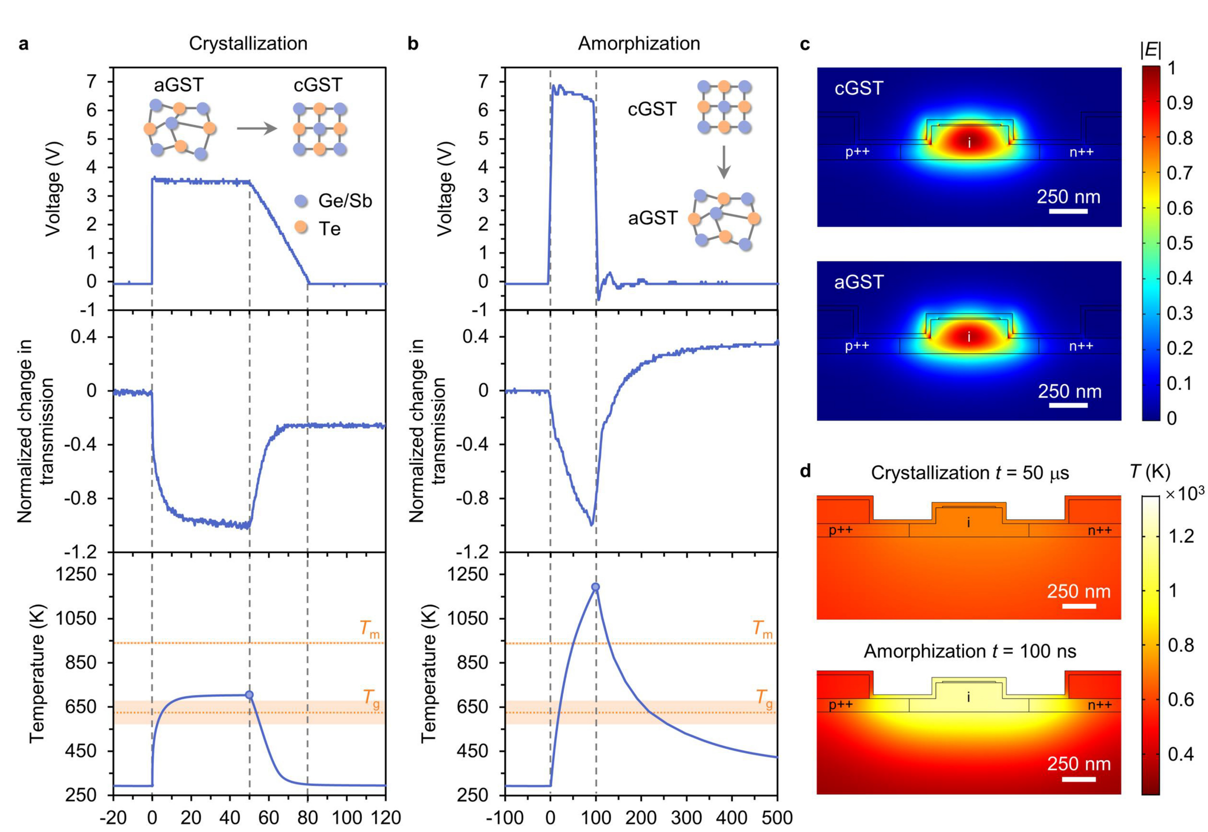
Photonic Switching Units

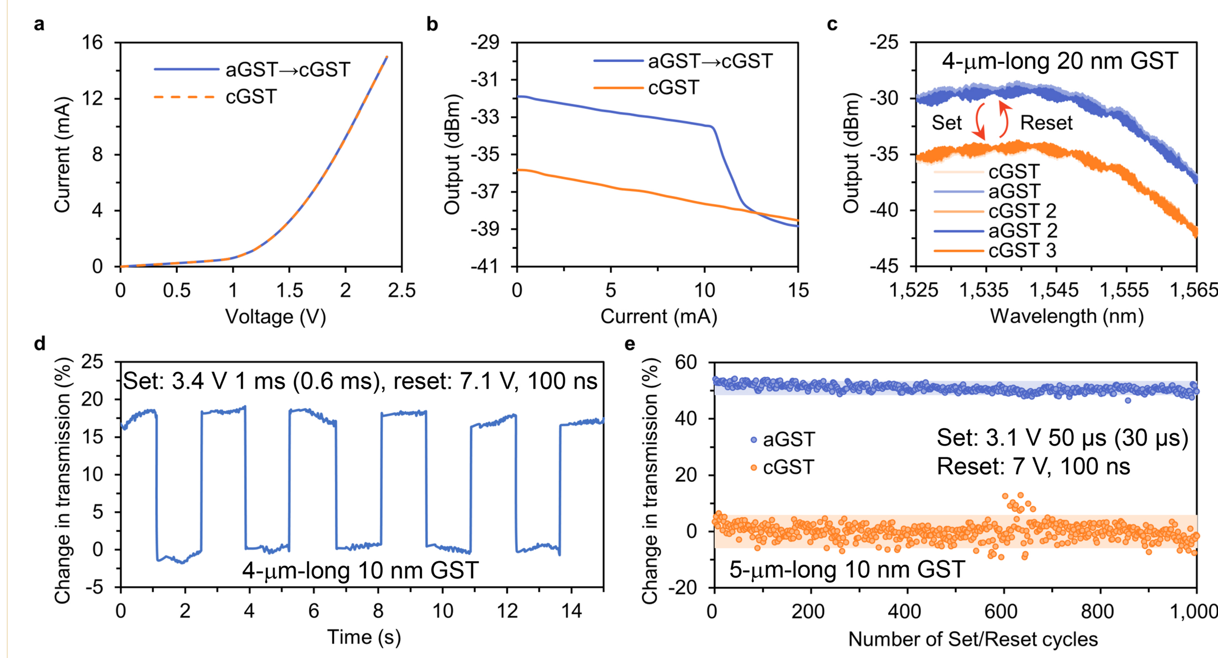
- Design and fabrication
  - ✓ 120 nm partially etched WGs
  - ✓ Heavily doped (10^{20} cm^{-3}) PIN junctions, 200 nm away from ribs
  - ✓ Near-zero extra loss is achieved after doping
  - ✓ Ti/Pd (5 nm/180 nm) contacts
  - ✓ 10 nm or 20 nm GST patches sputtered
  - ✓ Encapsulated by 30 nm ALD Al_2O_3 to protect GST from oxidation and reflowing



- Operating principle
  - ✓ A 5-μm-long switching unit with 10 nm GST
  - ✓ Reset (amorphization): a single pulse with 3.5 V (~10 mW), 50 μs (30 μs falling edge)
  - ✓ Set (crystallization): a single pulse with 7V (~110 mW), 100 ns

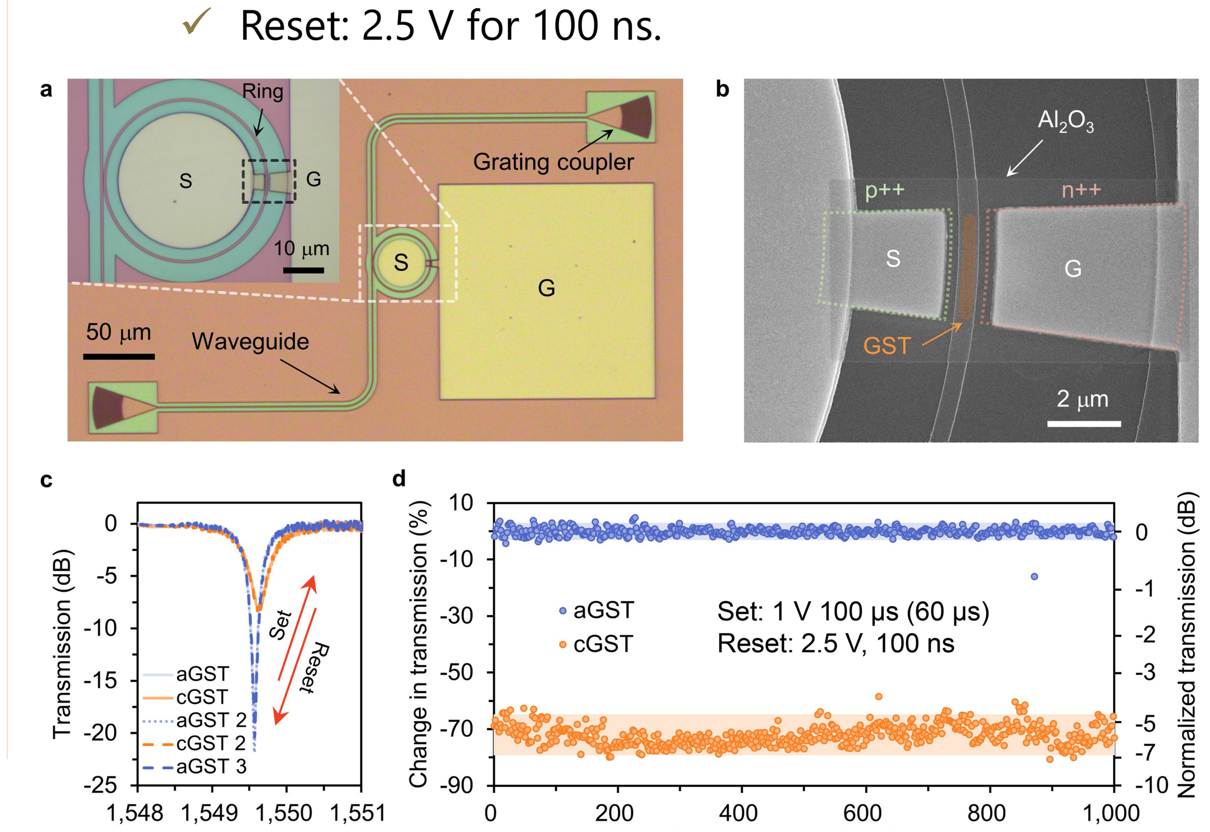


- Performance characterization
  - ✓ Rectification IV curve (GST not in the circuit)
  - ✓ A reduction of output during the current sweep (Si free-carrier and GST thermo-optic effects)
  - ✓ **Reversibly** switched with a high extinction ratio ~5 dB over a broad bandwidth
  - ✓ **High cyclability**: >500 cycles



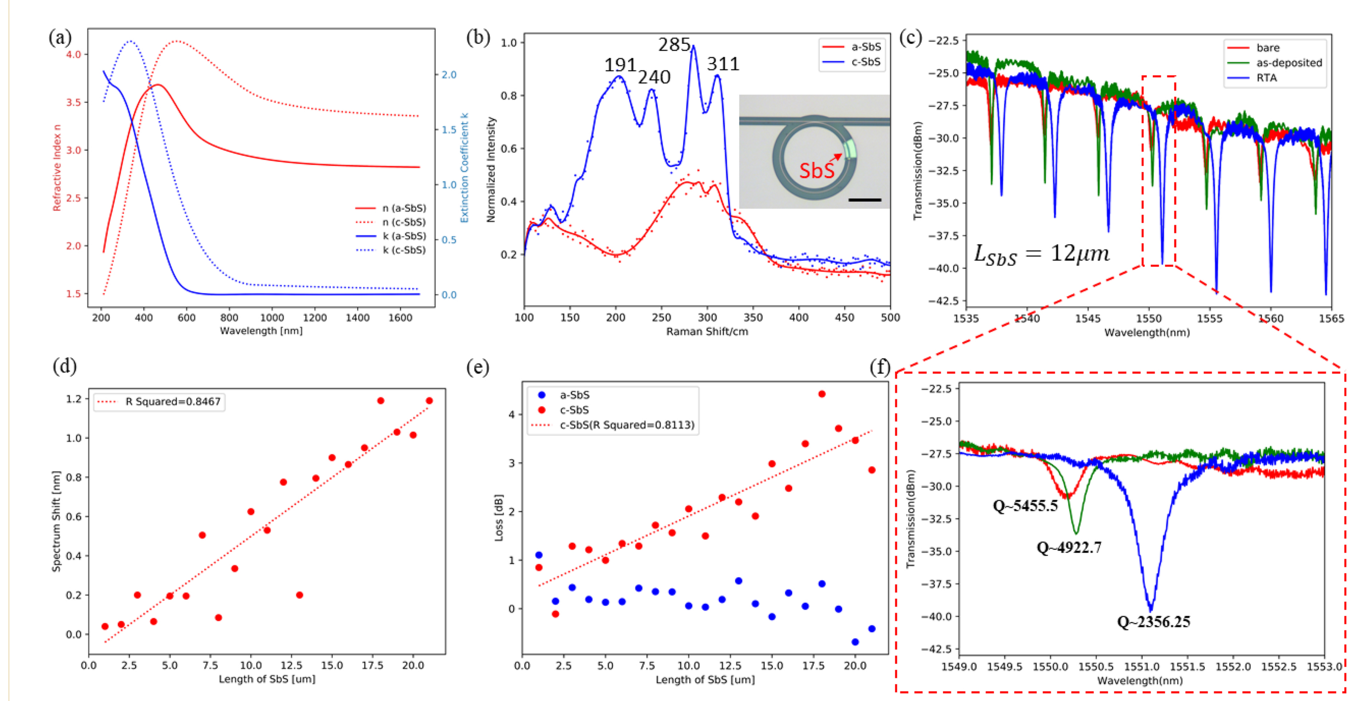
Application in Microrings

- Microrings with 20 μm radius, 3-μm-long switching unit and 10 nm GST
- **High extinction ratio** up to 14.7 dB due to the strong attenuation (~0.02 nm/μm) and optical phase (~0.25 dB/μm) modulation effects of GST
- **Low-voltage** operation
  - ✓ Set: 1 V for 100 μs with a falling edge of 60 μs.
  - ✓ Reset: 2.5 V for 100 ns.

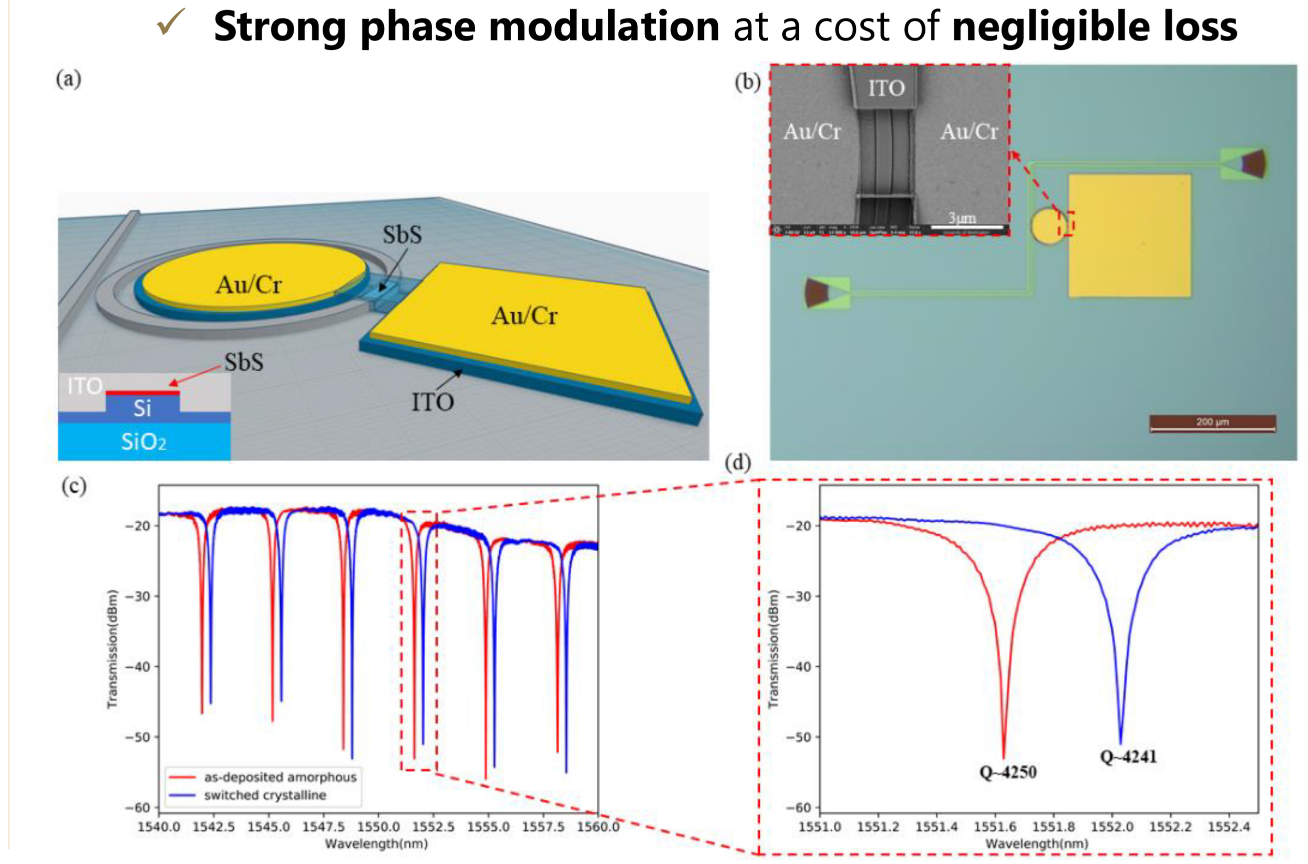


Broadband Transparent PCM

- Wide bandgap PCM Sb_2S_3 (SbS)
  - ✓ Broadband transparency from 610nm to near IR
  - ✓ Bistable phase transition at 250 °C confirmed by Raman
  - ✓ Minimal reduction in Q factor in amorphous state
  - ✓ Attenuation of cSbS is 0.16±0.02dB/μm, almost **50 times smaller** than that of cGST
- Resonance **broadening** and **red-shift**
  - ✓ from aSbS to cSbS



- Electrical actuation of 8 μm SbS by an integrated ITO heater
  - ✓ SbS switched into its crystalline state by a DC voltage sweep(0~1V)
  - ✓ <10 reduction in Q factor
  - ✓ >30dBm extinction ratio caused by a blue shift of 0.4nm
  - ✓ **Strong phase modulation** at a cost of **negligible loss**



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