Chip-Scale Photonic Logic and Switching with InGaAsP/InP Microresonators

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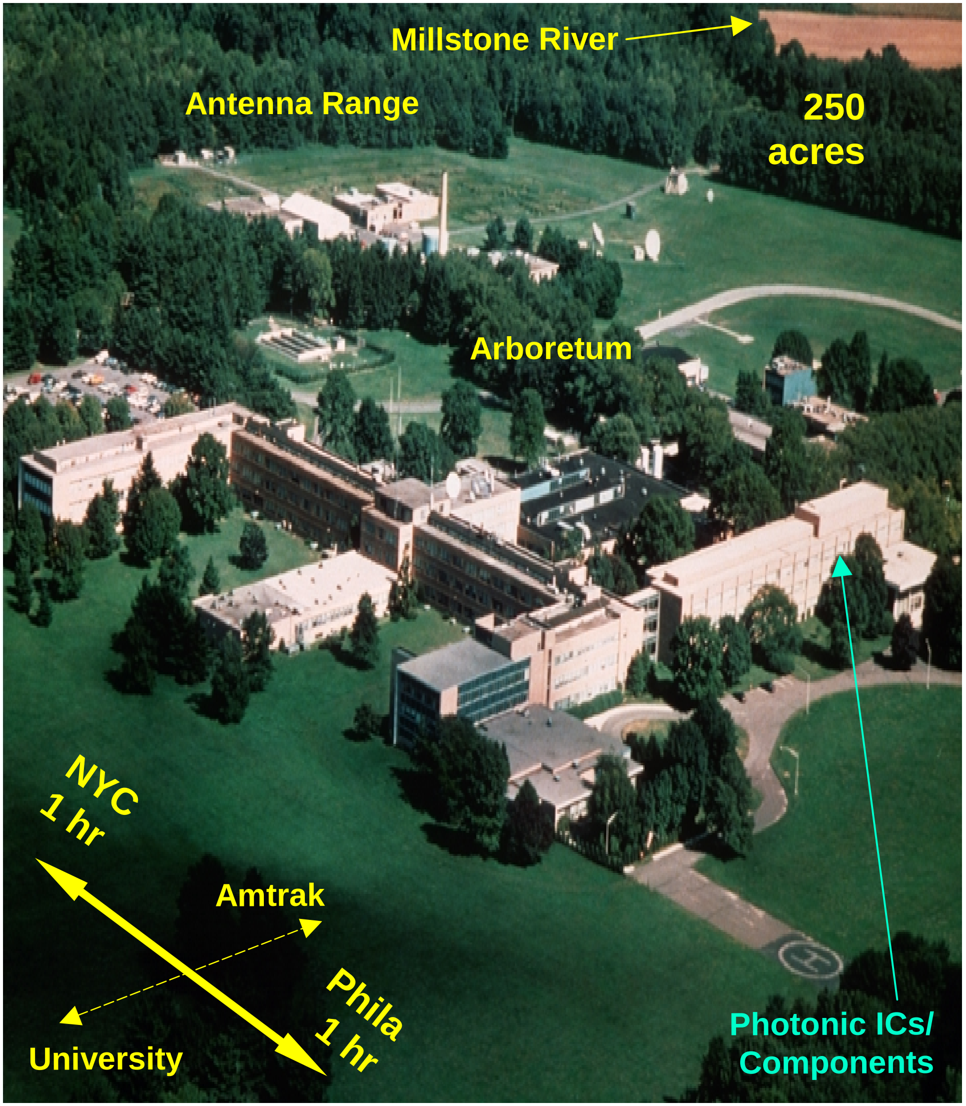
Sarnoff Corporation: Photonic ICs & Components



- Princeton, New Jersey location
- Former RCA Labs (est. 1942)
- Subsidiary of SRI International
- Our business is innovation services
- ~50/50% Gov't-Commerical customers
- 50 years of photonics

- The Sarnoff Model
  - Technology Transition
  - Sarnoff Spin Out companies
    - 3 Photonics Companies
    - More coming
  - Reward Employees
    - Equity, Royalties
  - Continue to keep "A-team" available for the most advanced development

The Sarnoff Perspective on Diode Laser Materials: first Threshold, then Power, now Efficiency

- 1960s & 70s
  - Basic Materials
- 1980s-1994
  - CDH-LOC; CSP
  - MIC Arrays (PILOT)
- 1989-95
  - MOPA
  - Tapered Amplifier MOPA
- 1994-2000
  - Broadened WG

A Brief History of Laser Diode Materials

First Era (1964-1982):
Increase Temperature

Second Era (1982-2000):
Increase Power

Third Era (2000-2018?):
Increase Efficiency

RCA/Sarnoff and SRI/Sarnoff Pioneers Have Set the Standards for Laser Performance at Wavelengths from 0.8 to 3 μm

Sarnoff Photonics: Capabilities

- Highest efficiency, low noise diode laser materials
- Highest efficiency InP 1550 nm modulator materials (10x better than current literature)
- Lowest loss waveguides (0.1 cm^{-1})
- Deeply etched waveguides
- Lowest noise InP-based mode-locked lasers
  - Highest powers (165 W)
  - Lowest noise (fsec jitter, 1e-4 amplitude noise)
  - Shortest pulses (200 fsec)
  - Coding technologies
- First 894 nm VCSEL (Atom. Clock)
- Laser conjugator devices
- Bistable devices
- Mid-IR Lasers
- Unique source of AlGaAs DFBs (791, 830 nm)
- Narrowest linewidth DFB lasers (10 - 100 kHz Gaussian & Lorentizian linewidths)
- Advanced InP ring microresonator & integration
  - Q of 20,000 demonstrated
    - Few GHz bandwidth
  - Lateral = simple fabrication
- Highest efficiency thermophotovoltaic cells (not released for publication)
- Exciting *new* 1550 nm platform integration technology (not released for publication)

Sarnoff Facilities

- Standard processing
- Facet coating to 1e-4
- E-beam lithography
- Holographic gratings

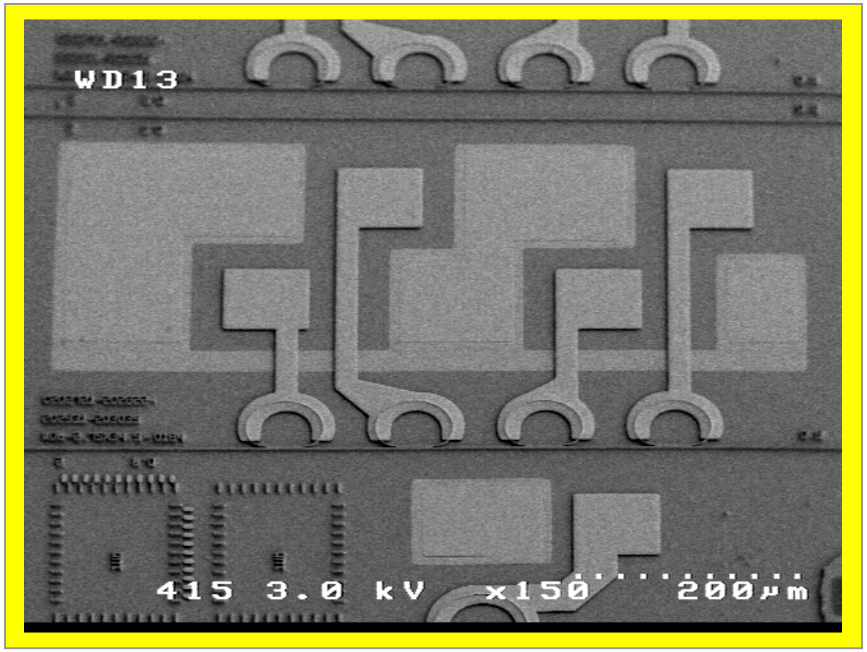
- Advanced dry etching (ICP)
- Low capacitance processes
- OMCVD (3 reactors)
  - GaAs, InP, GaSb, and GaN
- MBE/MOMBE (2 chambers)
  - GaAs, GaSb currently

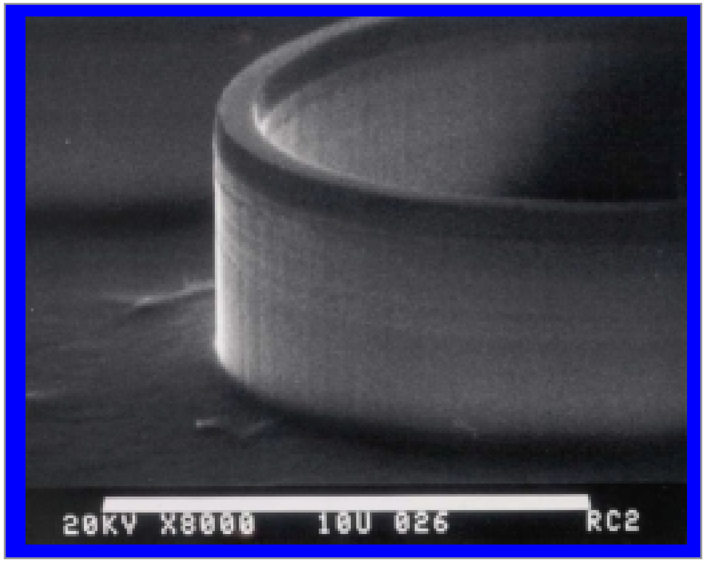
- Advanced packaging
- Ceramic fabrication
- Commerical high-speed IC design group (SiGe)

- MEMS foundry
- Si foundry

Concept

- Ring resonators with tightly confined, deeply etched waveguides.
- Low loss (0.1 cm^{-1}), transparent waveguides

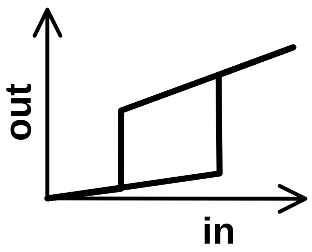




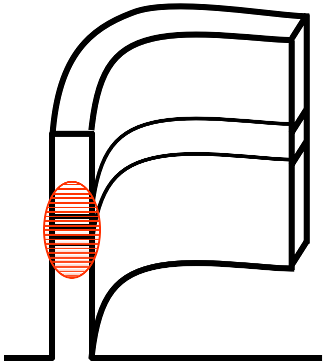
- Nonlinearity enhancement due to power buildup in rings
- Complex functionality on a small scale

Ingredients

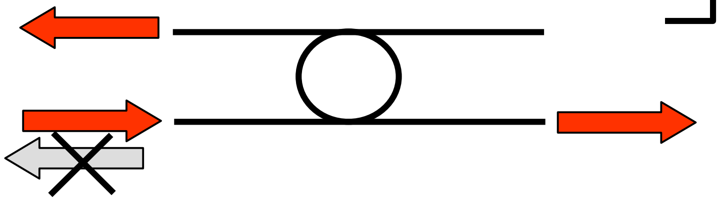
- Resonant cavities
  - High power density → enhanced nonlinear effects
  - Wavelength selectivity → bistability



- Strongly confined waveguides (sub-μm width)
  - High power density
  - Tight bends, small size → compact integration

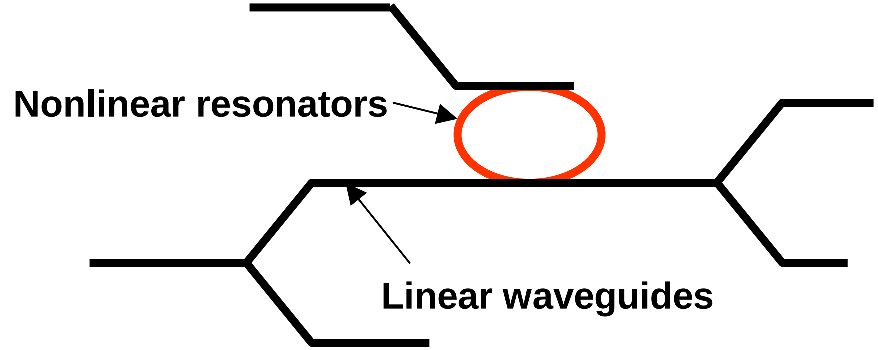


- Ring resonators
  - Unidirectional



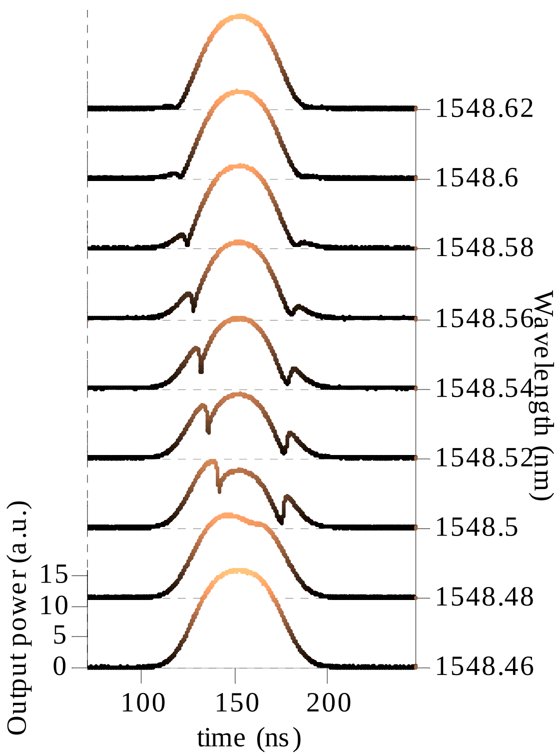
Circuits

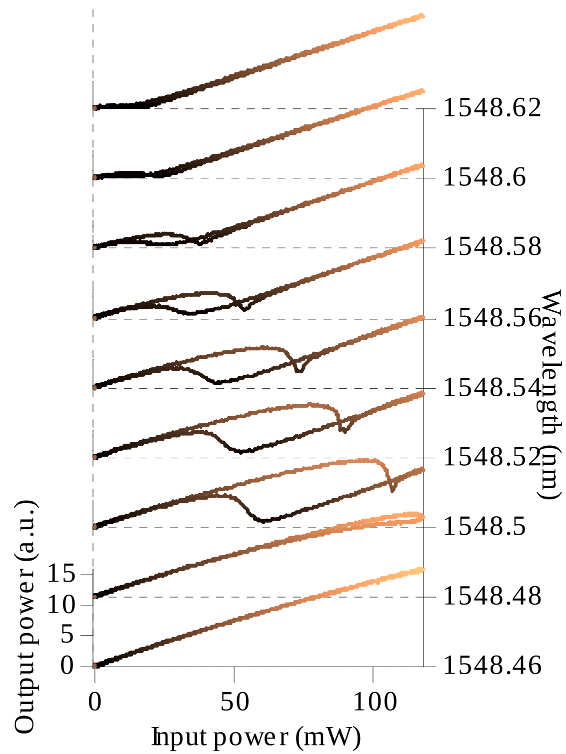
- Ring resonator with high finesse: → large power enhancement
  → nonlinearity only in resonator

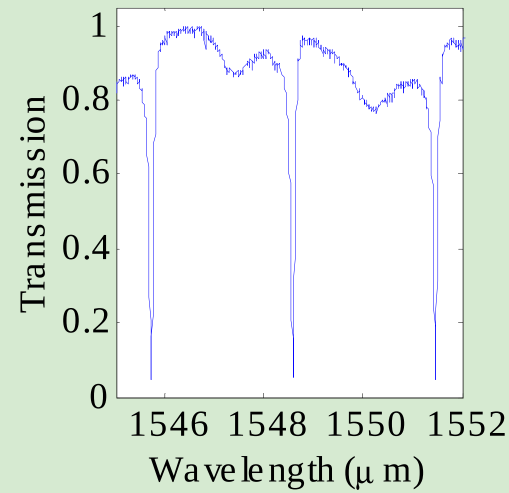


- Bistability and memory: → photonic logic
  → buffering
  → optical switching
- Wavelength selectivity: → λ-selective 2R regeneration
  → selective λ-conversion

Demonstration of Bistability in Ring Microresonators







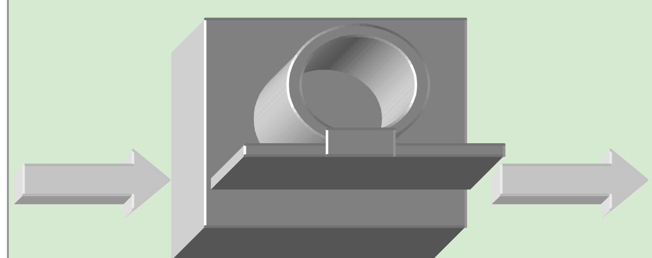
CW transmission (low power)

Periphery: 200 μm

Waveguide width: 1 μm

Q = 20,000

Finesse = 35



Bistability observed with 50 nsec input pulses
→ non-thermal, carrier induced effect

100 psec storage time per ring – 1.6e7 psec cm^{-2}