



Optical RAM: A solution path to “*True*” optical packet switch

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➤ NTT Photonics Labs. & Basic Research Labs.



➤ Osaka University



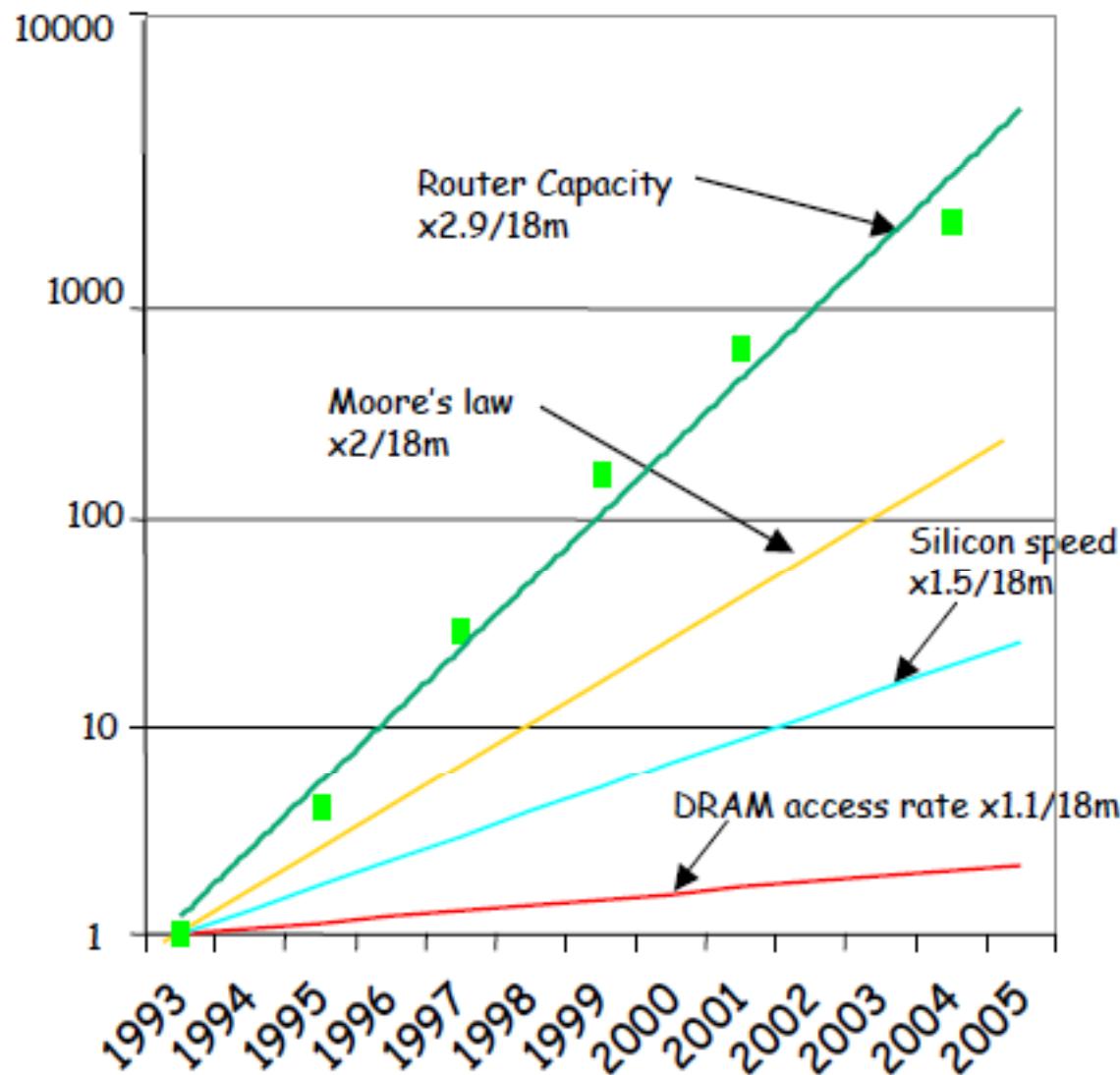
➤ Kyushu University



➤ NEC



Growth of e-router capacity

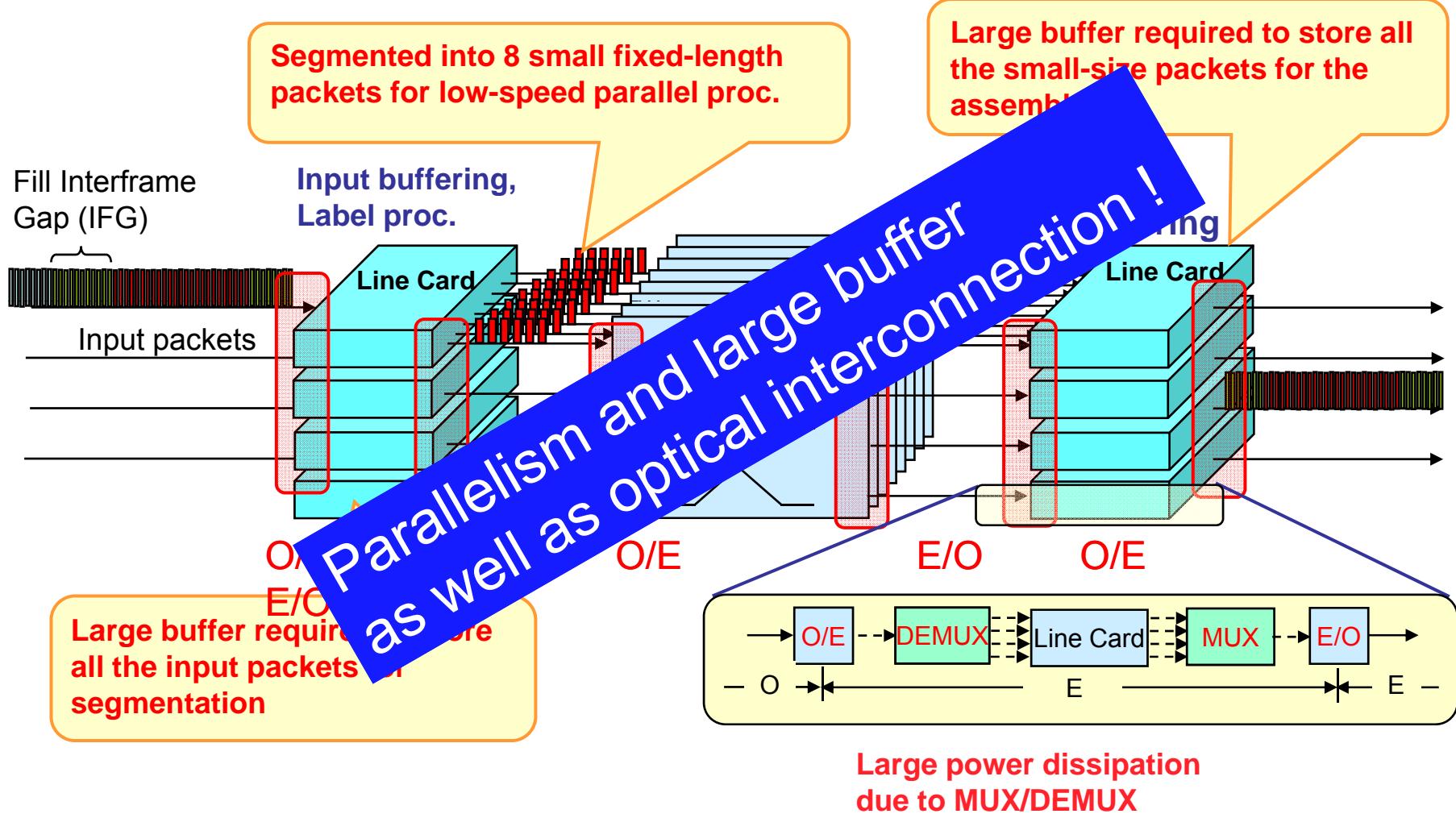


G.Epps, OFC2008, Workshop

Sept.19, 2009 北山

ECOC2009 Workshop "Optics in Computing"

What are problems with conventional e-router?



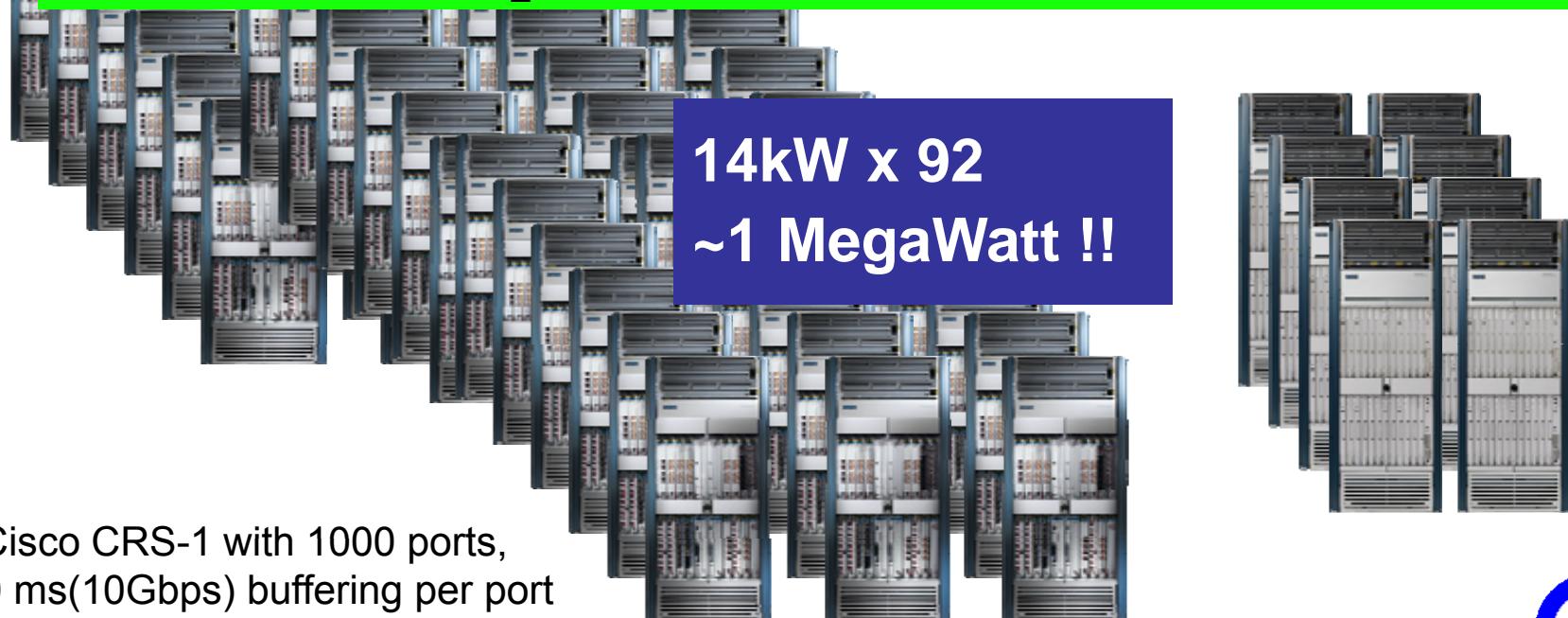
High-end e-routers : A product example

“Cisco will continue to push traditional technology,” by G.Epps

“Parallelism can be pushed further,” by R.Tucker

Is e-router's capacity growth sustainable in speed and power consumption?

Is e-router's CO₂ footprint acceptable for Green IT?



Cisco CRS-1 with 1000 ports,
250 ms(10Gbps) buffering per port

Challenges of optical packet switch

Solution path to the bottlenecks of e-routers

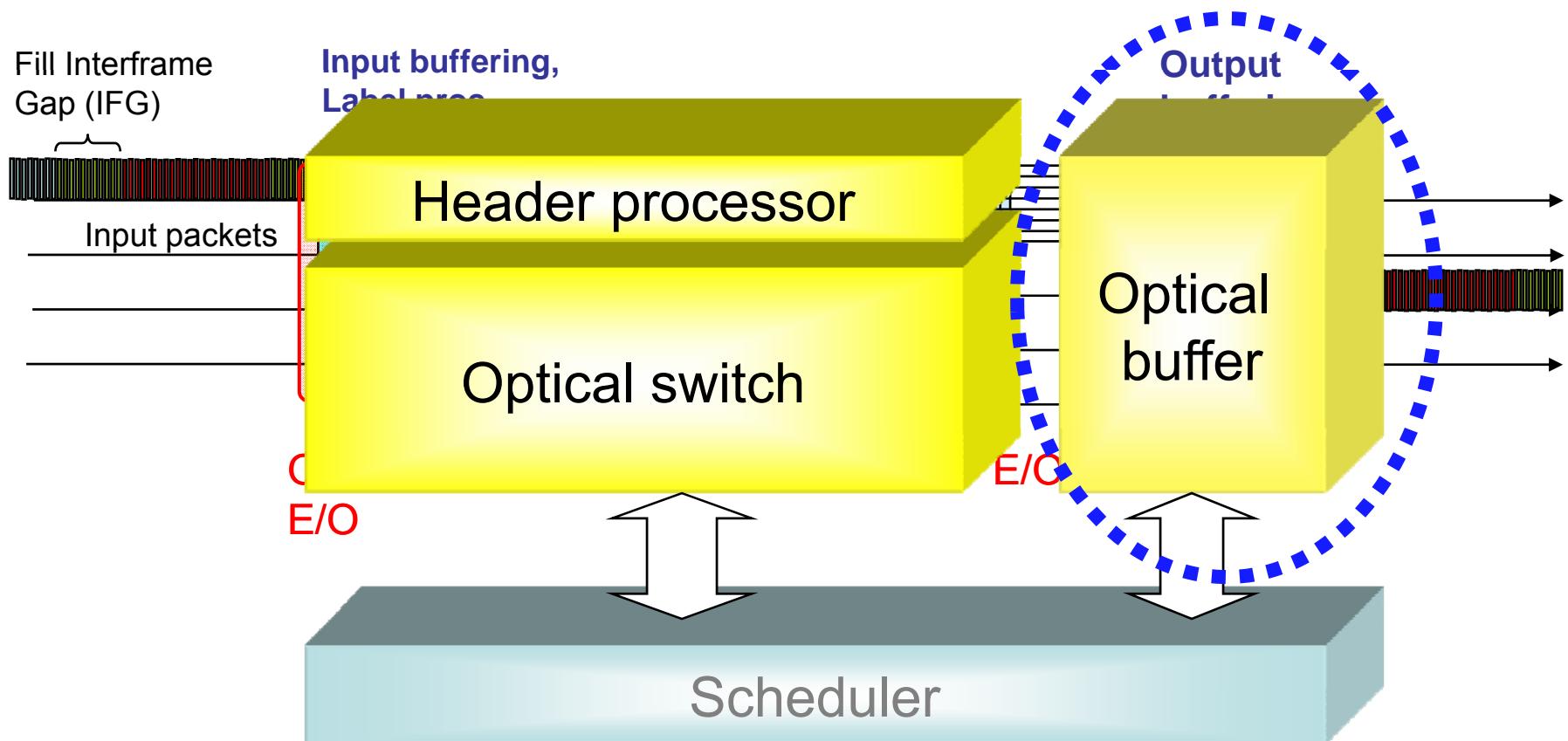
- **Power-consumption bottleneck**
- **Speed bottleneck**

Challenges:

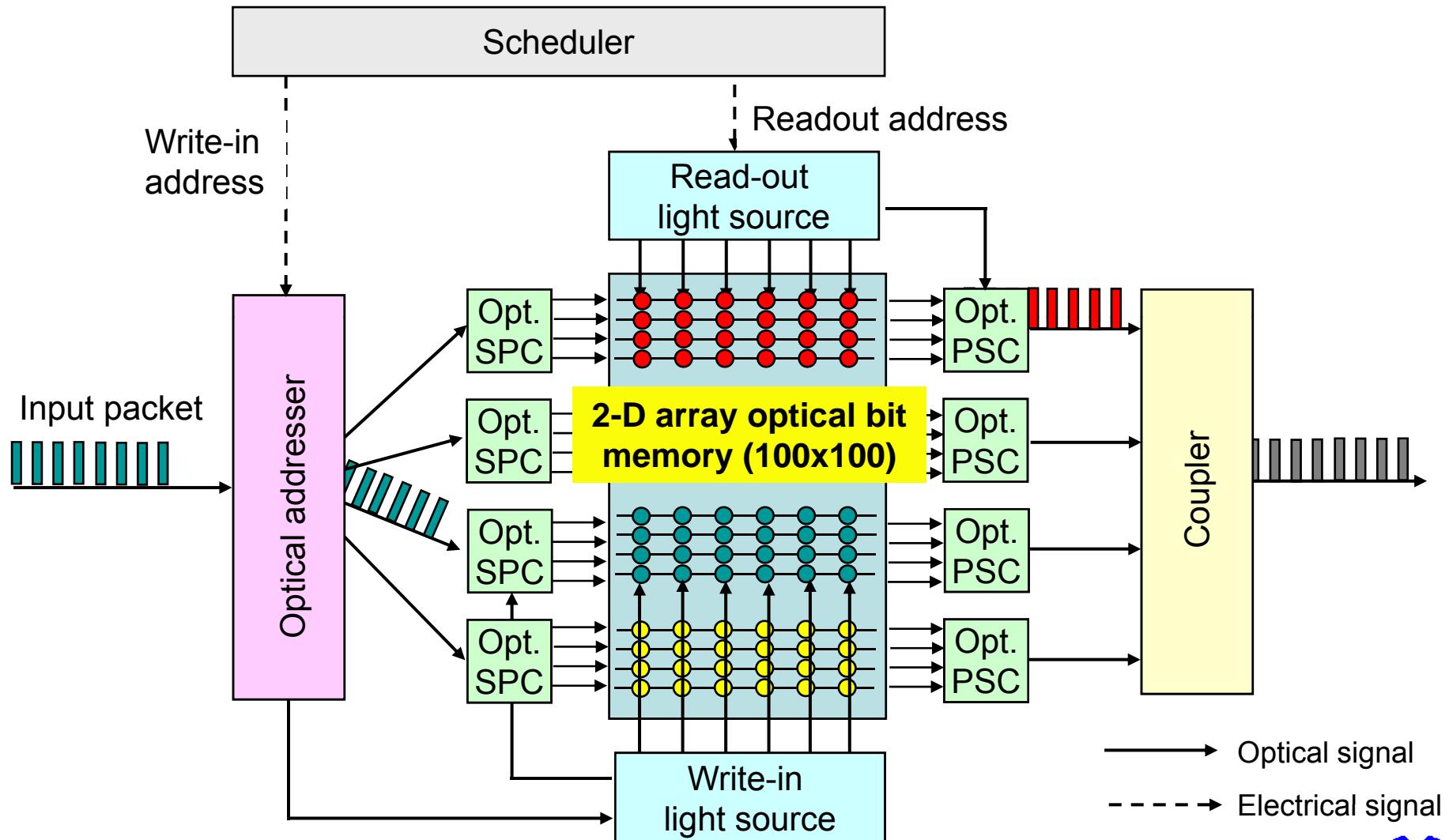
“Clean-slate photonic-native architecture”

Totally different from current e-routers, aiming at small-buffer size, high-speed as well as low-power consumption

Architecture of “True” optical packet switch



Architecture of optical RAM buffer subsystem

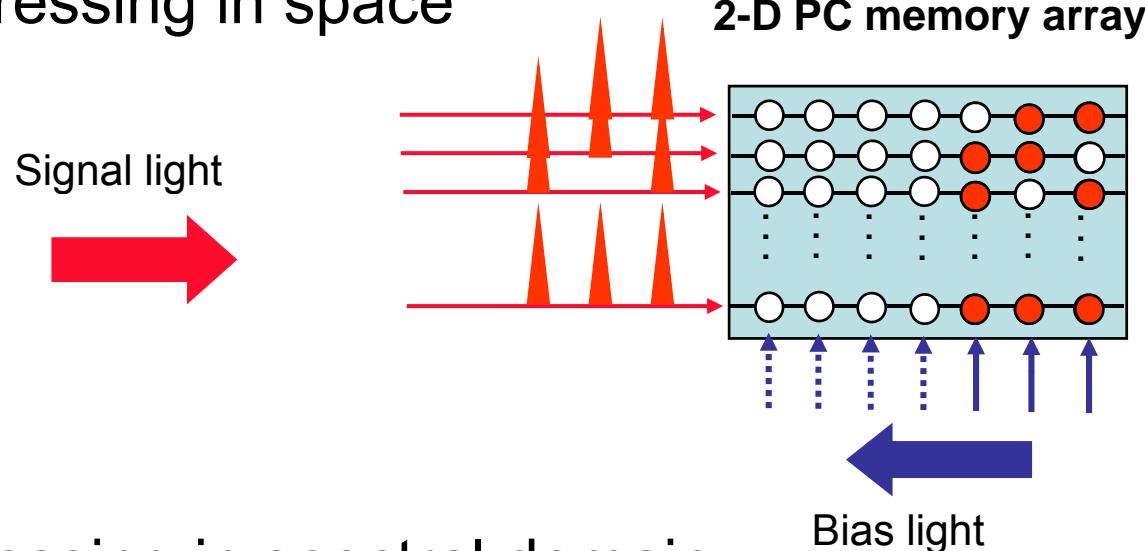


SPC: Serial-to-parallel converter

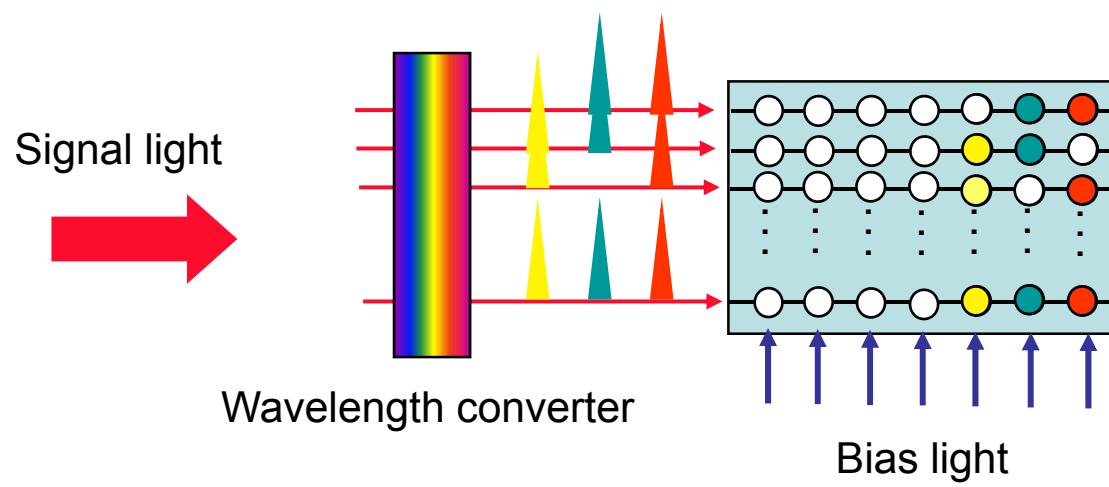
PSC: Parallel-to-serial converter

Optically “Write/Read” techniques

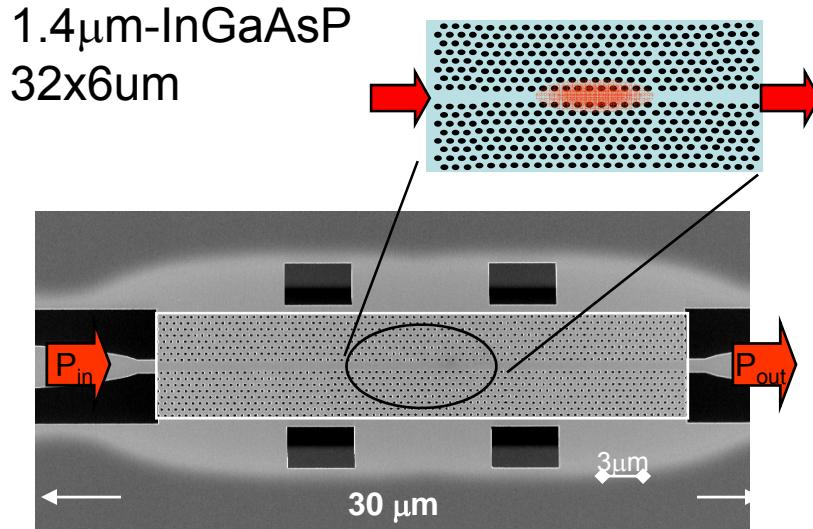
i) Addressing in space



ii) Addressing in spectral domain

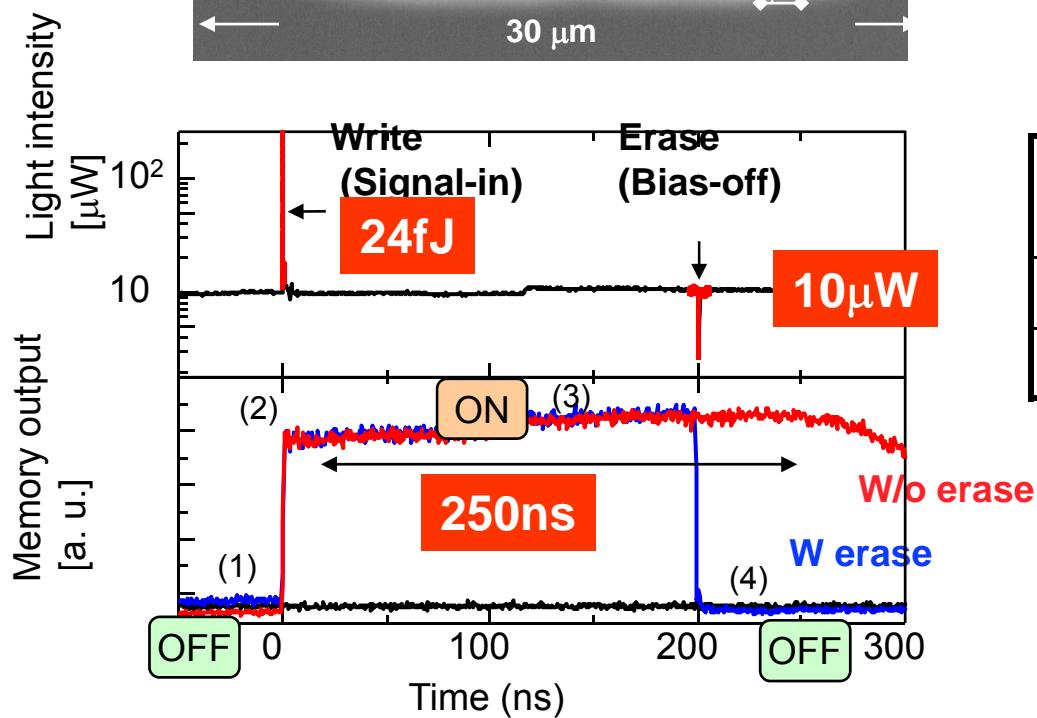


InGaAsP PC resonator



PhC engineerings

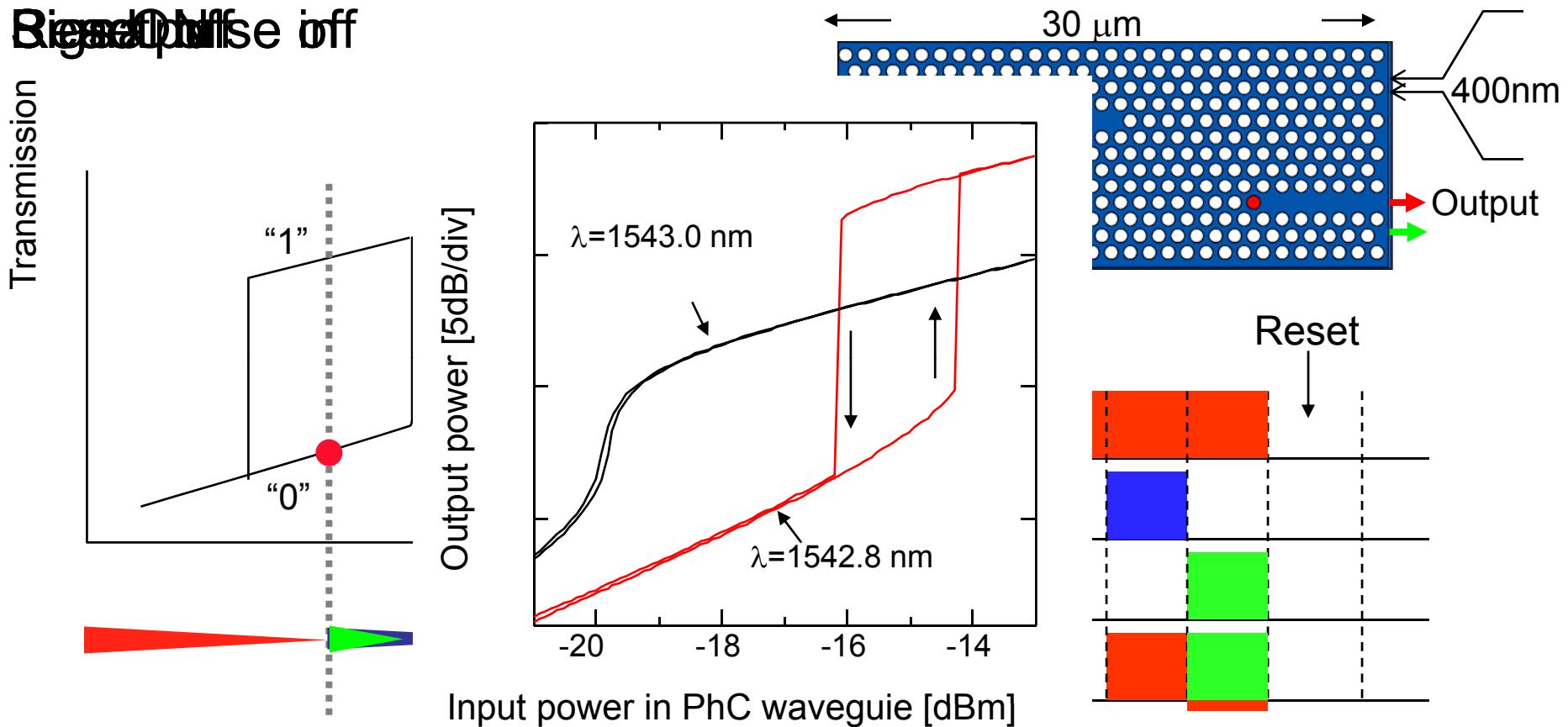
- Reducing adversary thermal effect by smaller PhC area, bandgap narrowing, smoothing PhC surface
- Fast heat diffusion
- Protect carrier diffusion using BH



Minimum power of bias light	10 μ W
Energy of signal light	24 fJ
Retention time	250 ns

Note: 1500B Ethernet frame~300ns@40Gbps

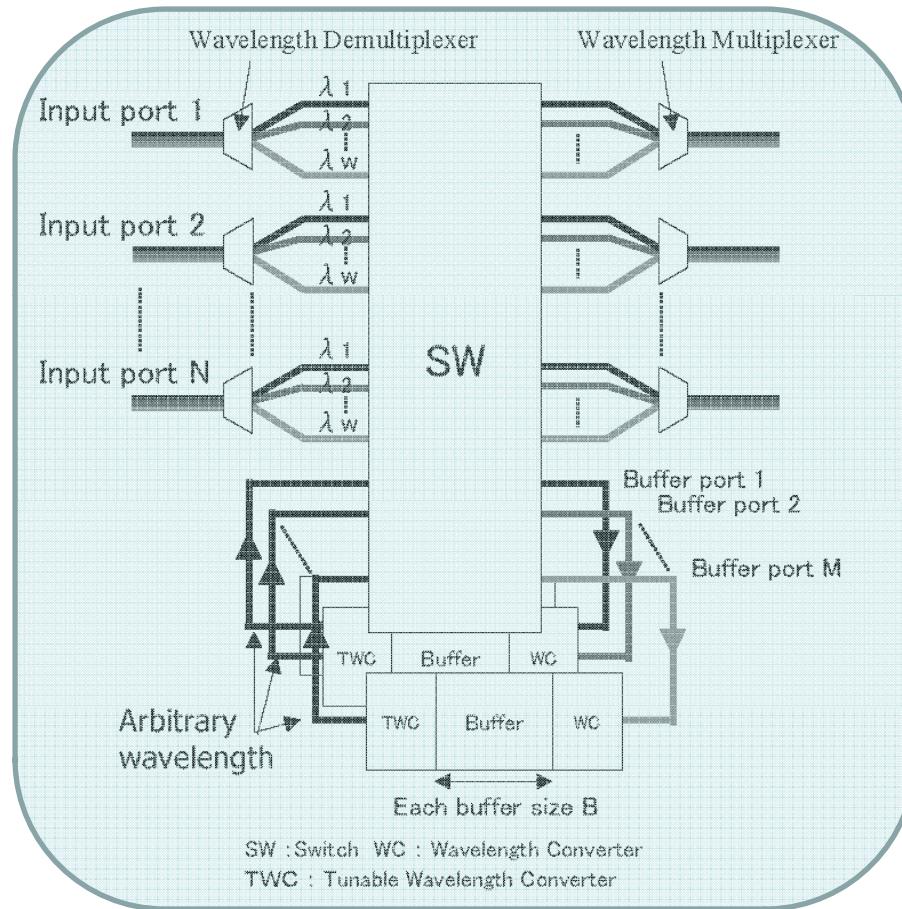
Optical bistable operation of PC resonator



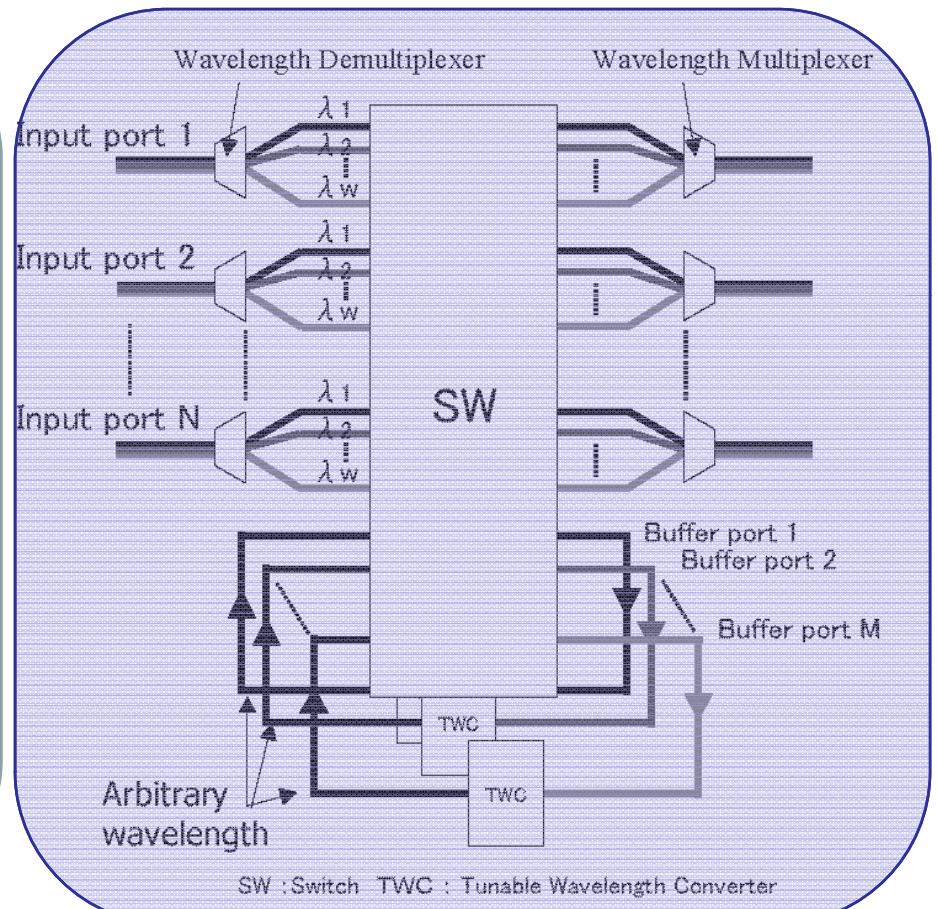
- Challenges
 - Long retention time
 - High-dense integration up to 100k~1M

Switch architectures : Optical RAM vs. WC

w/ Optical RAM buffer

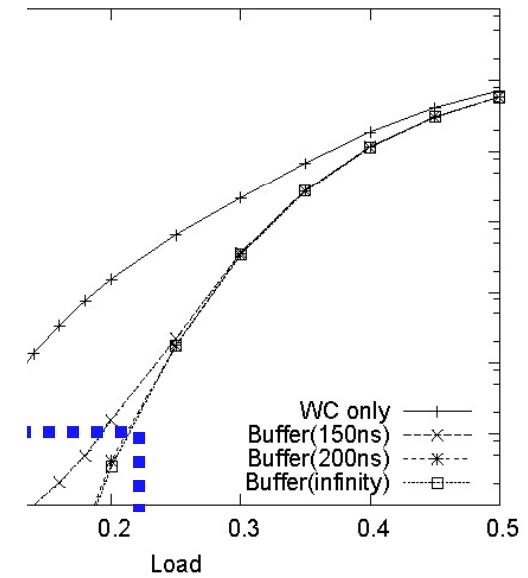
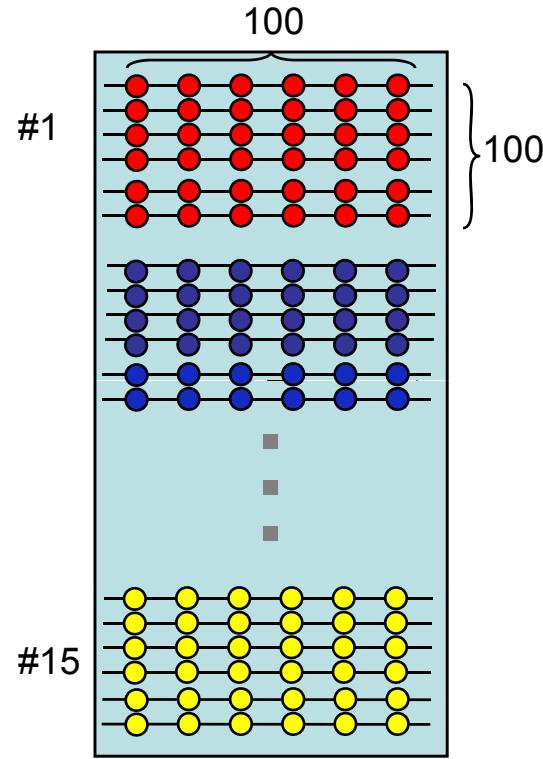
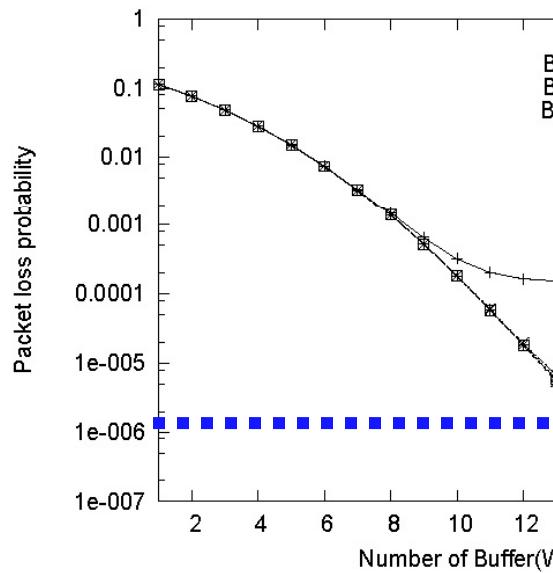


w/o Optical RAM buffer



Packet loss rate

- Poisson arrival
- Buffer size=1500E
- 4x4 sw, $8\lambda s$, M sh
- Packet lenahs: 40



- Contention cannot be resolved with only wavelength conversion w/o buffer but solved with small buffer
- Buffer retention time **~200ns** shows a low packet loss rate with 15 buffer planes, 22500B (=180kbits) in the switch up the load of 0.2

Power consumption : How far we can go?

	Currently	In 2015~2019
e - Router	1 MW (14nW/bit)	0.5 MW
OPS	200~300 kW Using O-E-O buffer	100~50 kW Using optical RAM

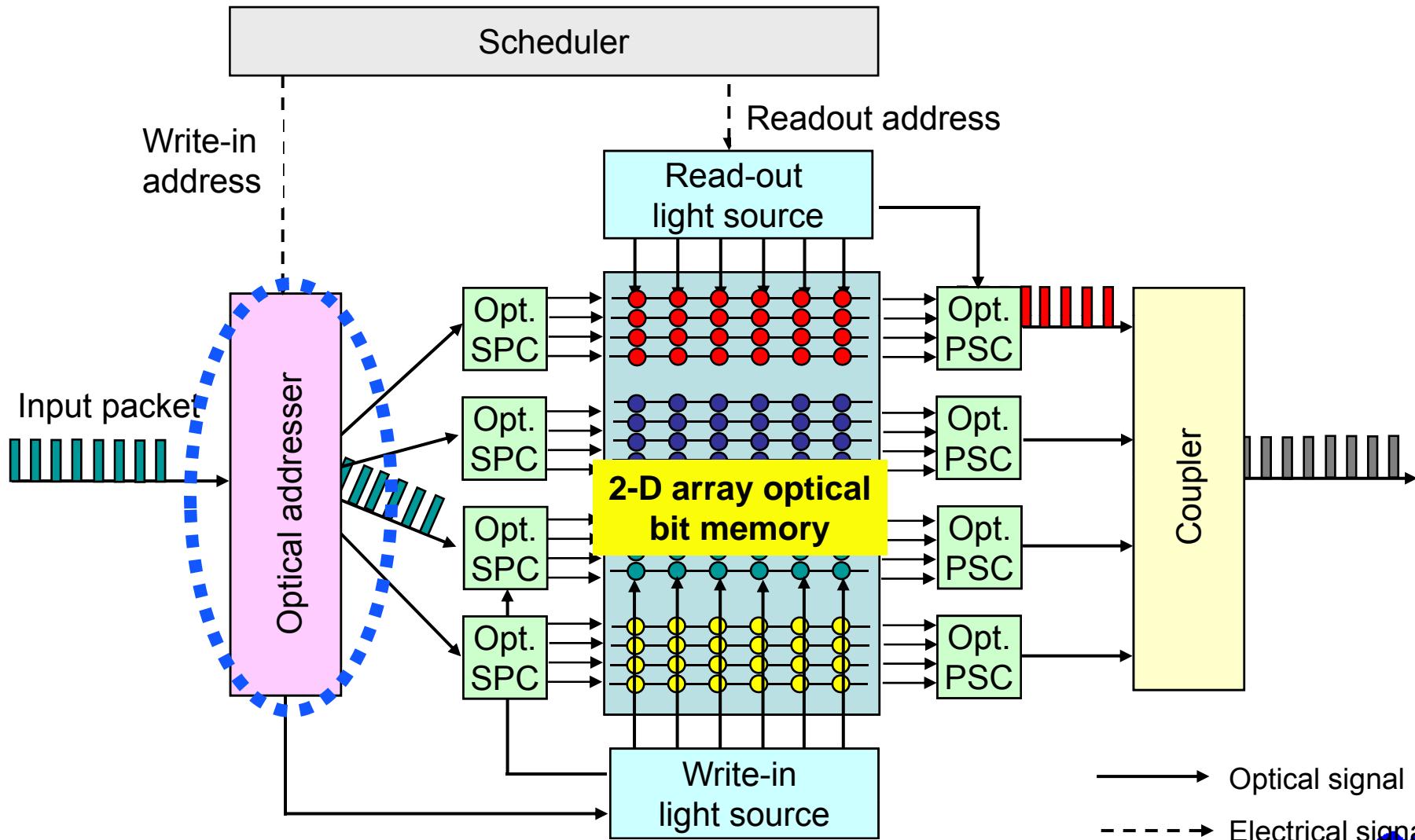
The diagram illustrates the projected reduction in power consumption for two key components over the next five years. For the e-Router, the power consumption is currently 1 MW (14nW/bit), which is expected to drop to 0.5 MW by 2019, representing a reduction of 1/2. For the OPS, the power consumption is currently 200~300 kW, achieved by using O-E-O buffers. This is projected to drop to 100~50 kW by 2019, achieved by using optical RAM. The reduction for the OPS is indicated as 1/5~1/7 and 1/10~1/20.

Note: 16x16x 72 SWs @ 40Gbps

Thank you !

Questions?

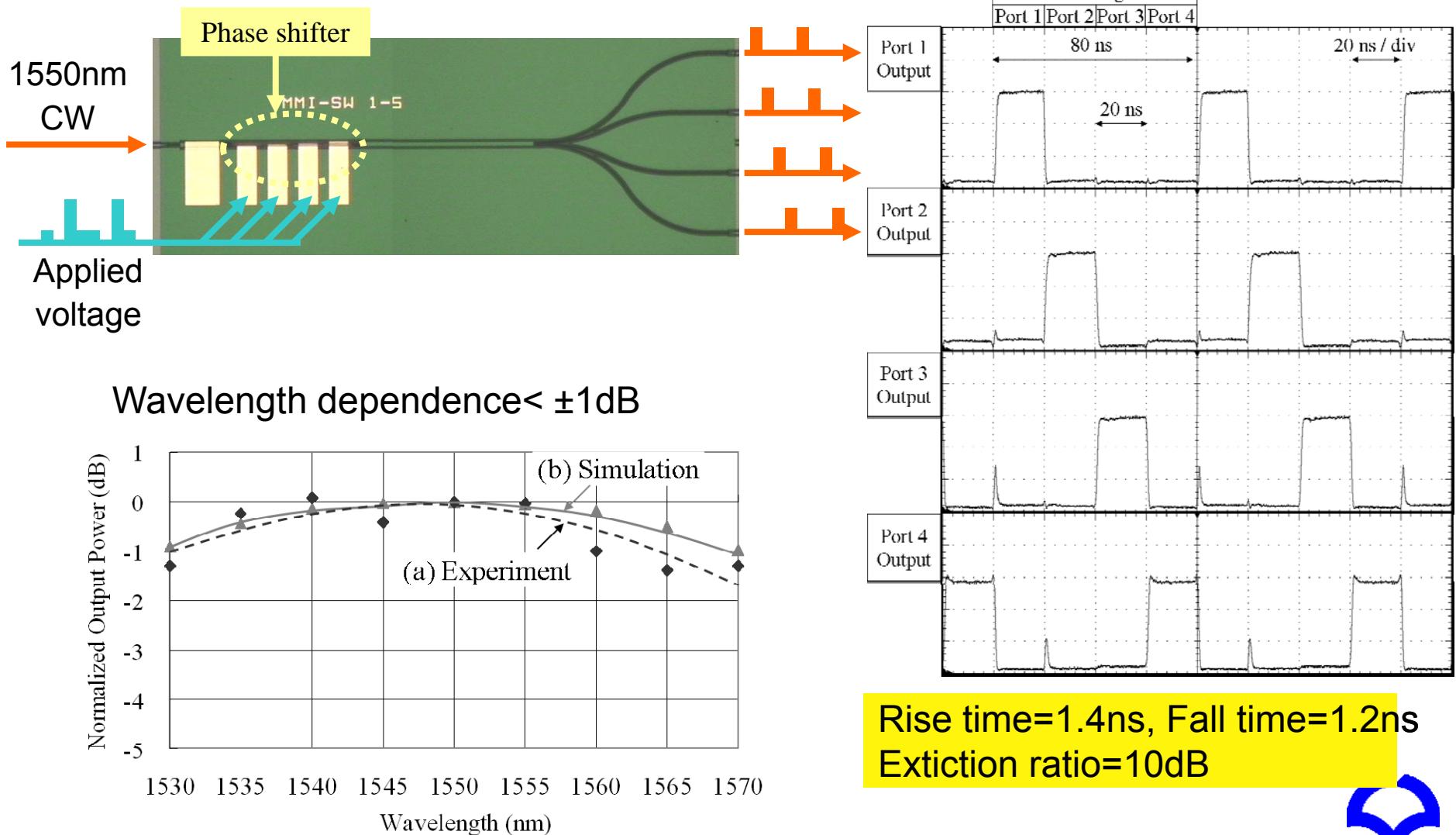
Architecture of optical RAM buffer system



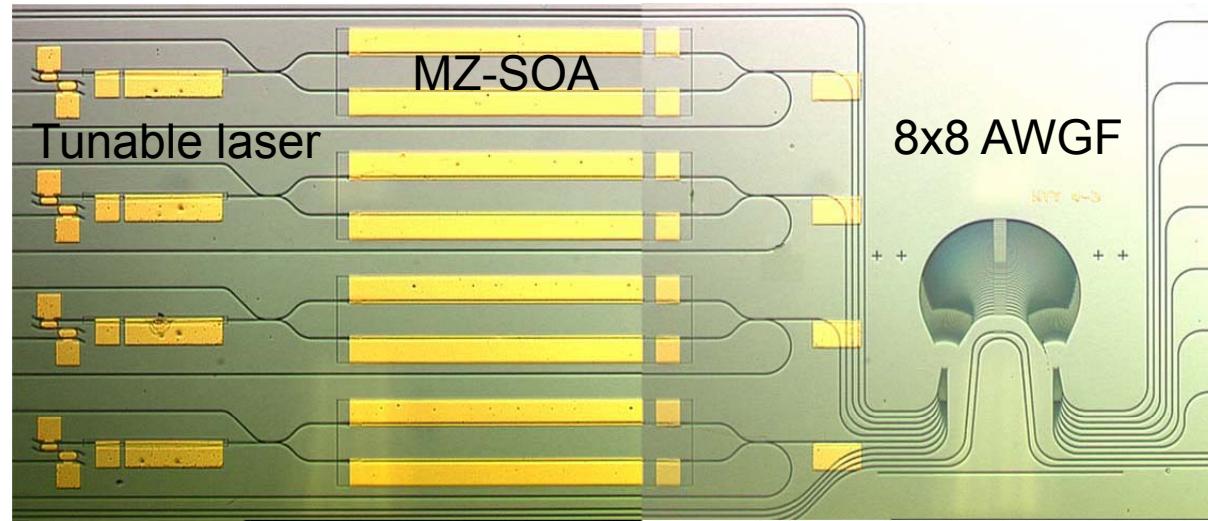
SPC: Serial-to-parallel converter

PSC: Parallel-to-serial converter

Optical addressing in space using MMI switch



Optical addressing in spectral domain

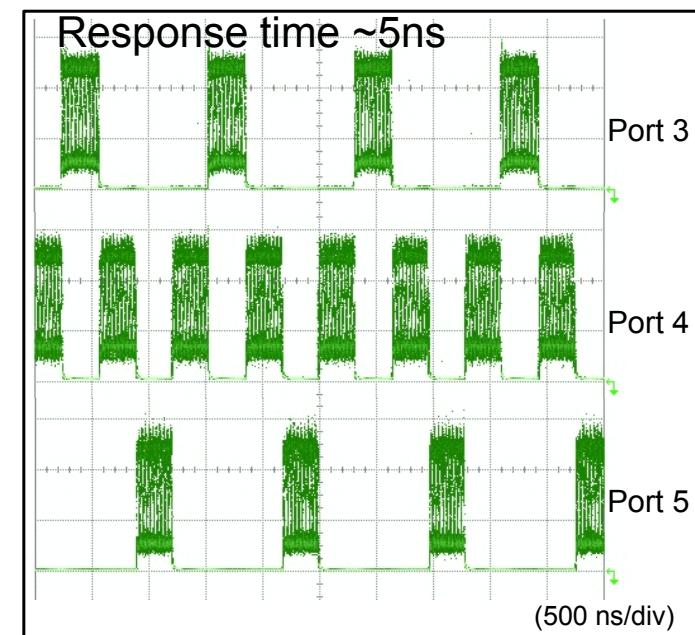


Requirements for Tunable laser

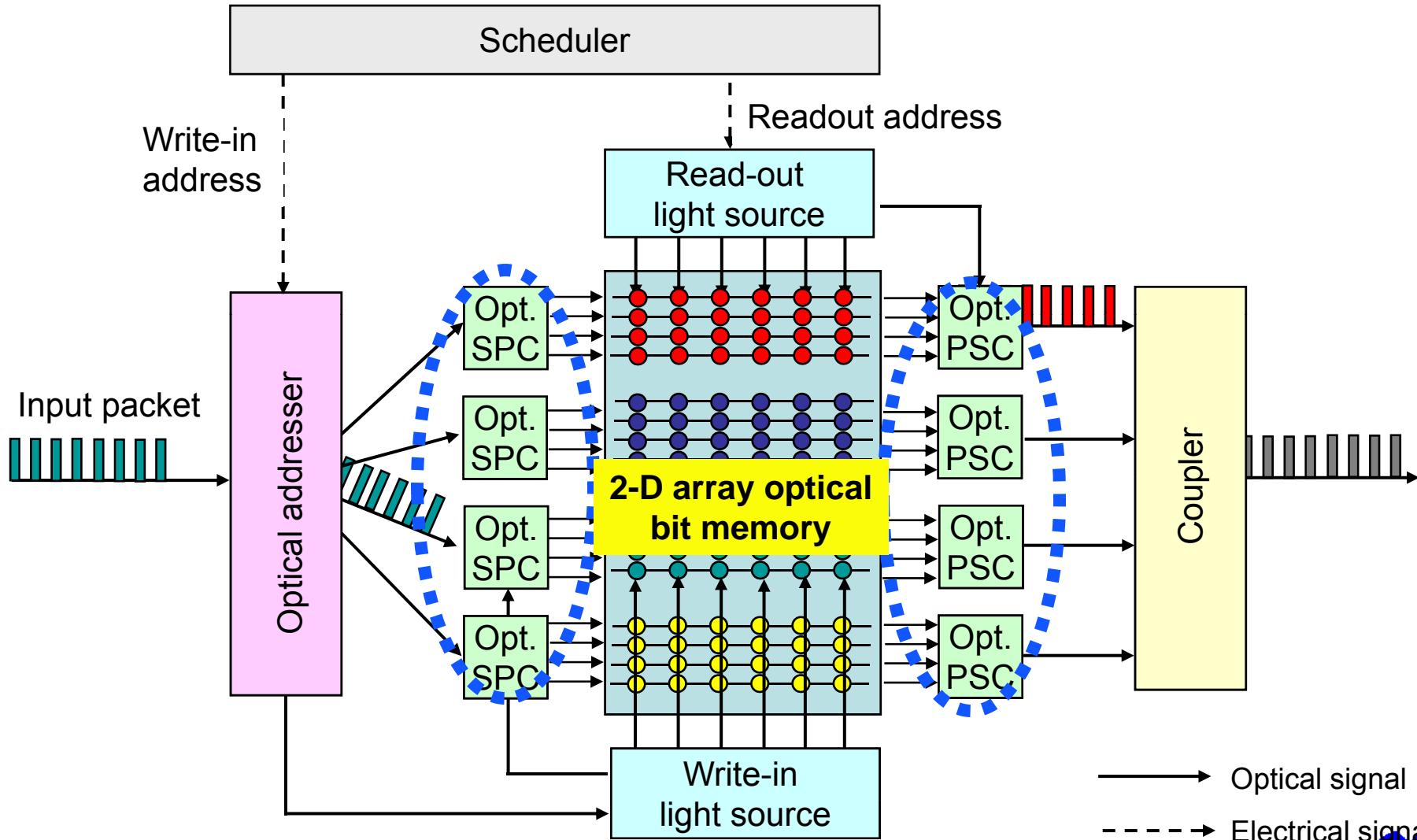
- { *Compact*
- Easy to integrate other components*
- Low tuning current*



Compact wavelength routing switch
5.1mm x 2.1 mm



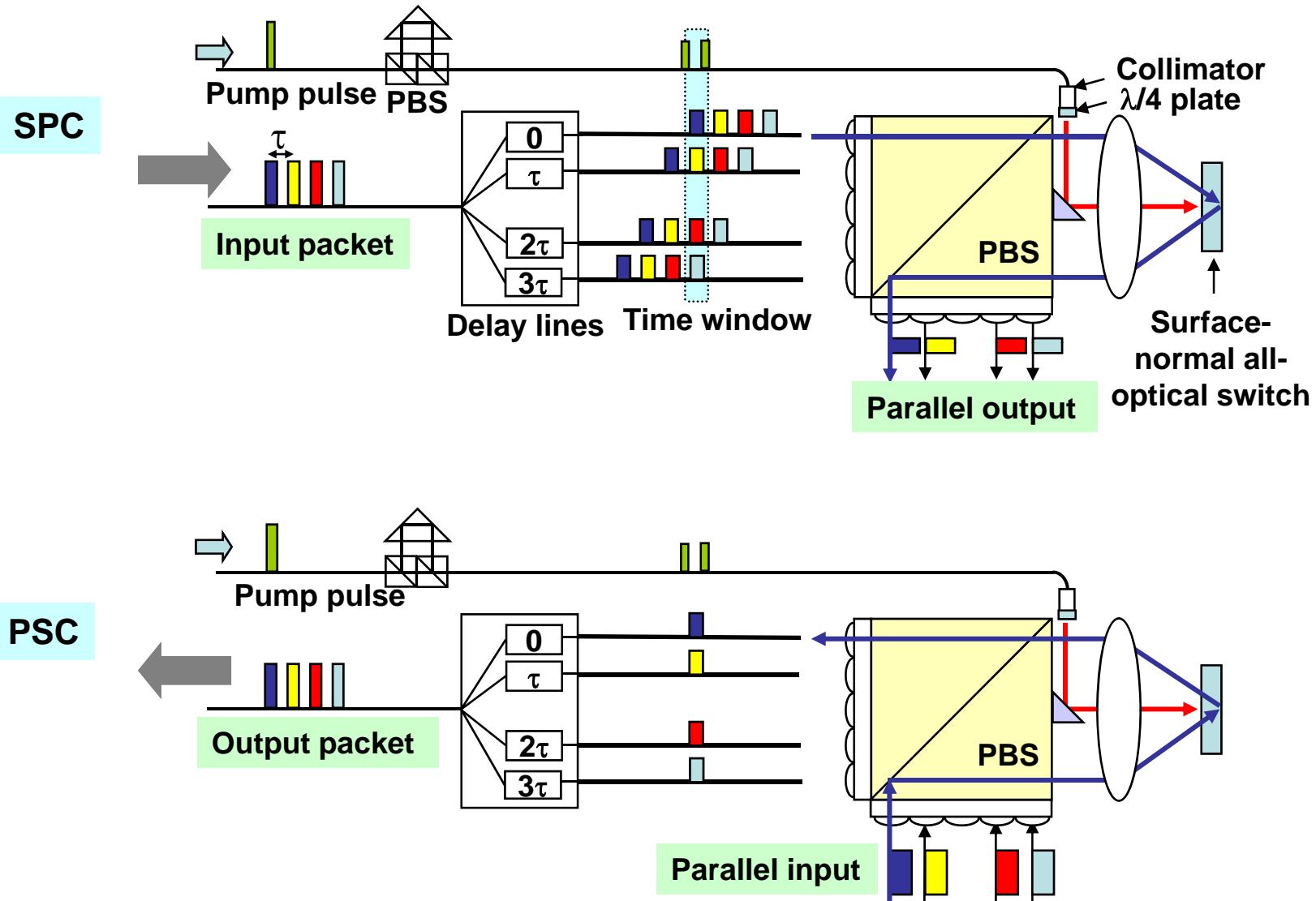
Architecture of optical RAM buffer system



SPC: Serial-to-parallel converter

PSC: Parallel-to-serial converter

All-optical SP/PS bidirectional converter



Optical memory devices

	All-optical RAM				FIFO (First-in-first-out)			
	Bit-by-bit memory via bistability				Contl. of prop. length		Contl. of GV	
	Passive (non-radiative)		Active (radiative)		Fiber loop		Material dispersion	Waveguide dispersion
	Micro-cavity		Surface-emission	Waveguide	Fiber	Semicon.	Fiber Semicon.	Semicon.
	Photonic crystal	Micro ring	Pol. bistability	MMI-BDL flip-flop	Opt.sw + fiber	Quantum wire	EIT, CPO, FWM	Photonic Crystal
Cell size	10 μm^2	100 μm^2	1000 μm^2 [*]	50000 μm^2	Large	Compact	Compact	Compact
Power consumption	~10 μW	~100 μW	~10mW	~100mW	1 W/pkt ^{**}	2W/pkt ^{**}	-	-
Access speed	~10ps	~10ps	7ps	<100ps	A few ns ^{***}	A few ns ^{***}	A few ns ^{***}	A few ns ^{***}
Access	Parallel/serial	Parallel/serial	2-D parallel	Parallel	Parallel	Parallel	Parallel	Parallel
Notes	<ul style="list-style-type: none"> • λ-sensitive • PDL 		<ul style="list-style-type: none"> • PDL • All-optical shift register • Large-scale s/p conv. 		<ul style="list-style-type: none"> • FIFO • Discrete time • Small capacity 		<ul style="list-style-type: none"> • Narrow bandwidth **** • Short time storage • Small capacity 	

* <10 x 10 μm^2 + I/O=>30 x 30 μm^2

** Depending on optical amplifier count

*** Speed of optical switch

**** < 20GHz

Note: SRAM: <0.6 μm^2 , <1 μW , <2ns w/o O-E-O

Buffer size for packet routers

Rule of thumb

#1: Larger the buffer size is, the lower the packet loss probability becomes.

#2: TCP requires the buffer capacity B;

$$B = RTT \times \text{Link capacity}$$

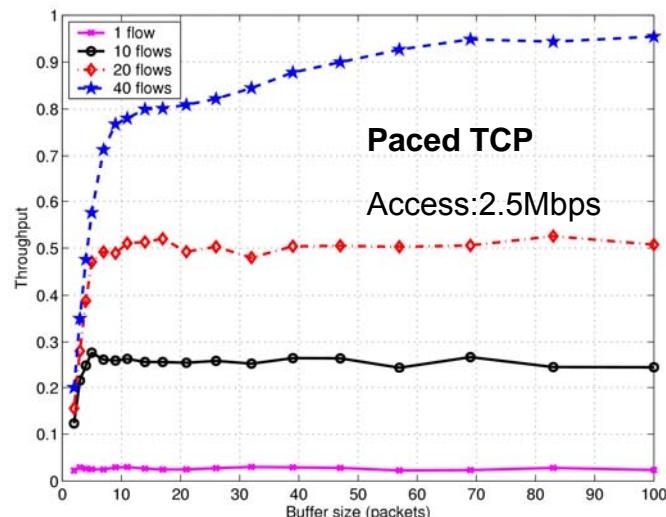
Note1: For RTT=250 ms@40Gbps, B=10 Gbits => 36Mbit-SRAM x 300

Note2: OC192 (10Gbps) line card has a 1.6Gbits buffer (13k Ether packets).

Recent findings

Good news for all packet routers !

- Buffer size can be reduced to $B=RTT \times \text{Link capacity} / \sqrt{n}$ (n : connection count) .
Ex. Buffer size for 1Mbps flows x 40,000 @40Gbps can be reduced from 10Gbits to 50Mbits
- Paced TCP can further reduce the buffer size down to 10~20 packets.



Issues

- Is this only the case with ADSL?
What happens to > gigabit access?
- Is it practical that TCP has to be replaced with another TCP at end hosts?

M. Enachescu, Y. Ganjali, A. Goel, N. McKeown, and T.Roughgarden. Part III: Routers with very small buffers. *ACM/SIGCOMM CCR*, 2005.

M.Wang, *Globecom2007, G06P04 (Washington DC., Dec.208)*.

Architecture of conventional e-router

