National Institute of Advanced Industrial Science and Technology
AIST

VICTORIES
Vertically Integrated Center for Technologies of Optical Routing toward Ideal Energy Savings

Optical network system for next generation data center

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ASCI2015, 2014.1.28, International Congress Center EPOCHAL TSUKUABA

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- Special Coordination Funds for Promoting Science and Technology of Ministry of Education, Culture, Sports, Science and Technology (MEXT).

Outline

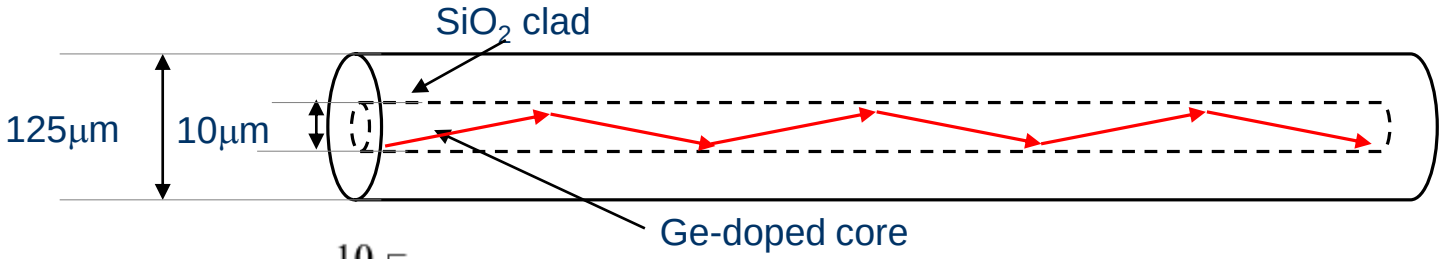
- Light waves in information systems
  - Optical fibers
- Advanced technologies in optical communication systems
  - Modulation format
  - Dense Wavelength Division Multiplexing (DWDM)
  - Reconfigurable Optical Add Drop Multiplexer (ROADM)
  - Light sources for DWDM
- Dynamic Optical Photonic Network (VICTORIES Project)
  - OXC switches
- Wavelength bank and distribution systems for data center
- Summary

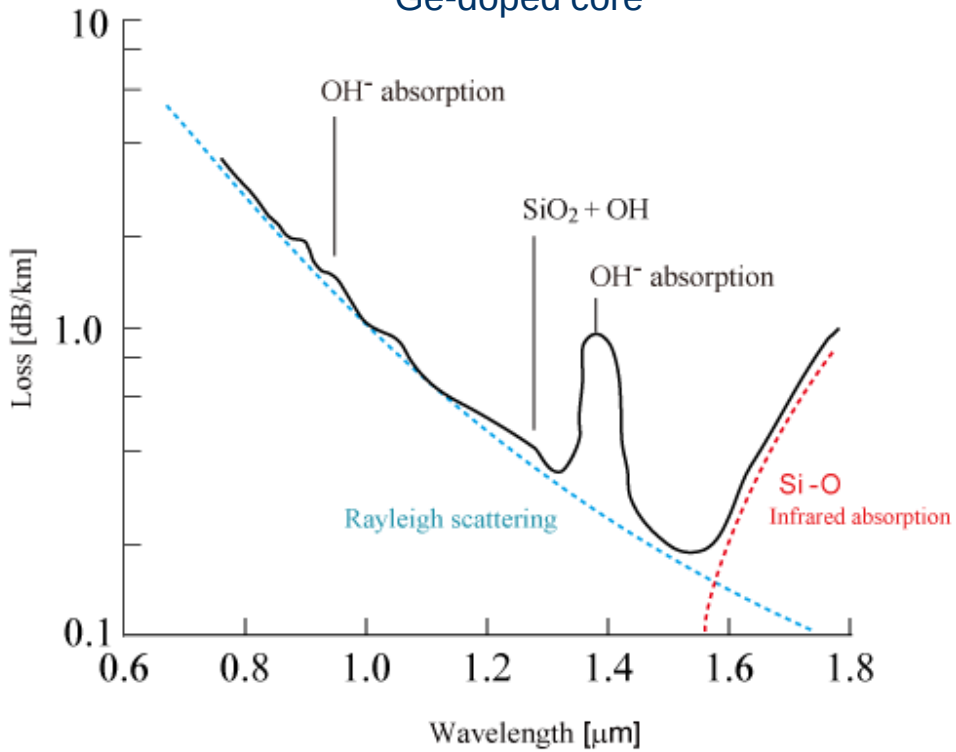
Light waves in information systems

	Electric current /Voltage	Radio waves	Light waves
Medium	Cupper wires	Free space	Optical Fiber
Wavelength	1 - 30 cm	1mm – 1 km	0.6 – 2 μm
Bandwidth	< 10 GHz	< 100 GHz	< 10 THz
Distortion	Large	Large	Small

Light waves are suitable for transmission of huge capacity information with small signal distortion.

Optical Fiber as transmission line





- Low loss of 0.2dB/km at 1.55 μm wavelength range (one-tenth per 50km) enables long distance transmission systems such as submarine cable systems.
- Signal loss is negligible in short transmission of few km such as data-center network.

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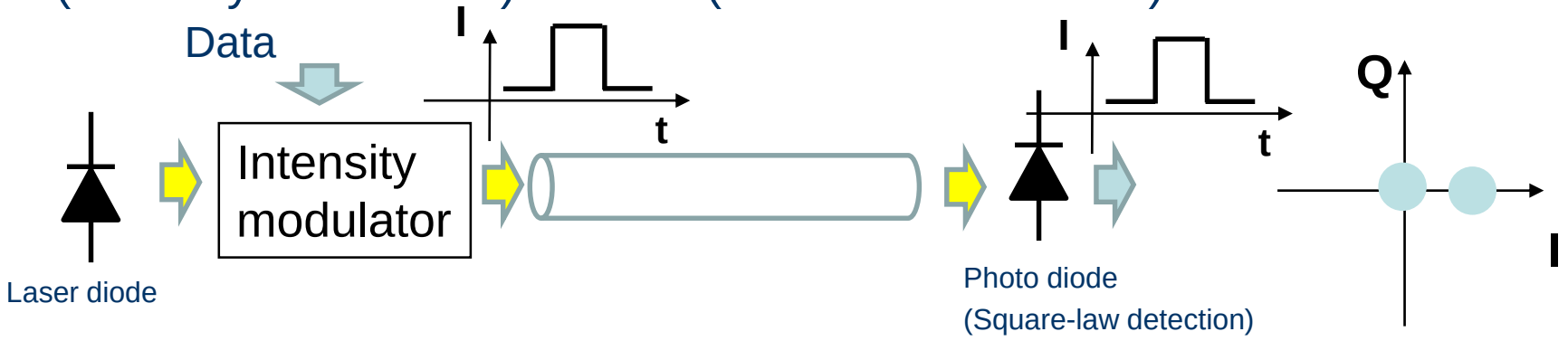
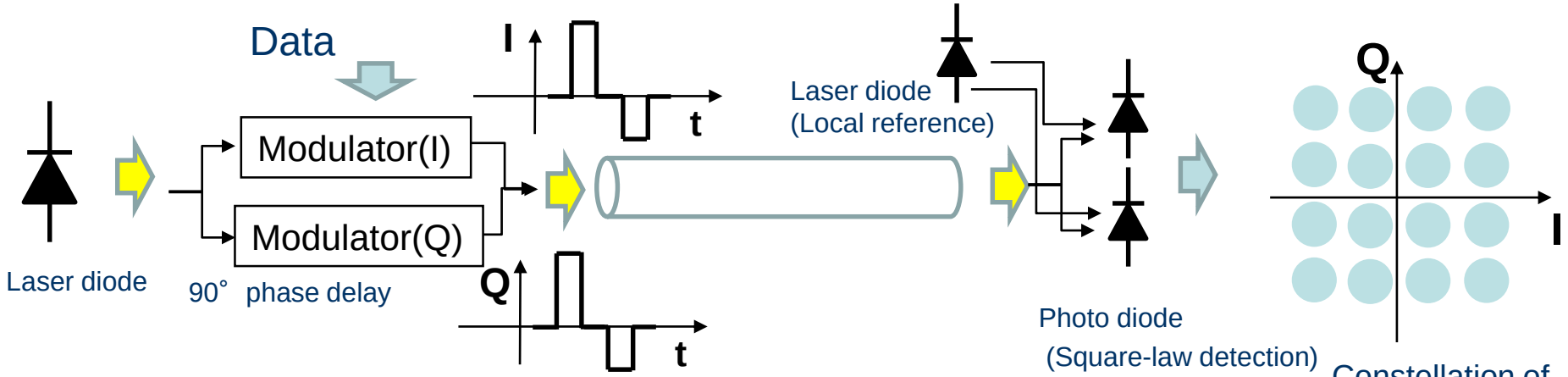
Modulation format

- IM (Intensity Modulation) format (Bit rate < 40 Gbit/s)



  - Wired systems adopt this format commonly.
  - Simple transmitter/receiver can be used.

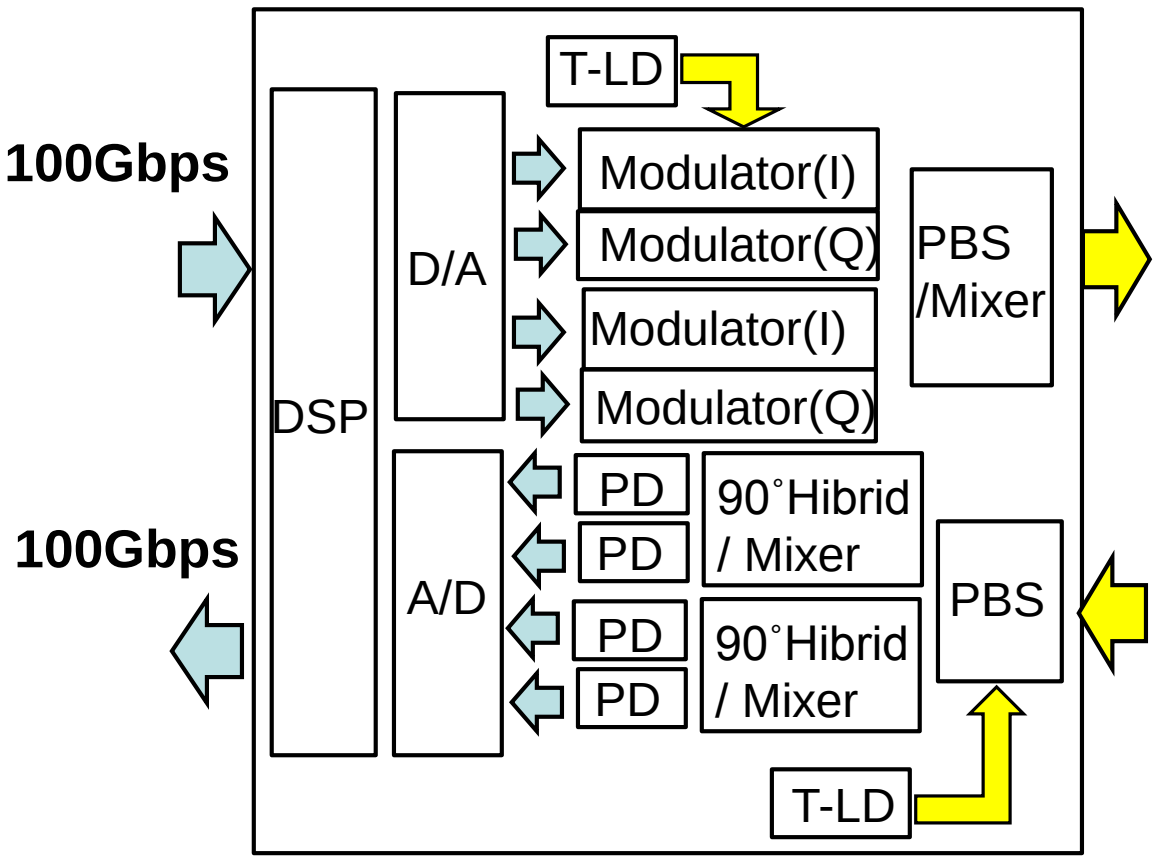
- QAM (Quadrature Amplitude Modulation) format (Bit rate > 100 Gbit/s)



  - Wireless systems adopt this format commonly.
  - Multiple value data can be used.

100 Gbit/s transceiver

Digital coherent transceiver



Merit

- **Flexible**
  - **Format**
  - **Baud rate**
- **Many function**
  - **Carrier recovery**
  - **Equalization**
  - **Dispersion compensation**
- **Monitoring**

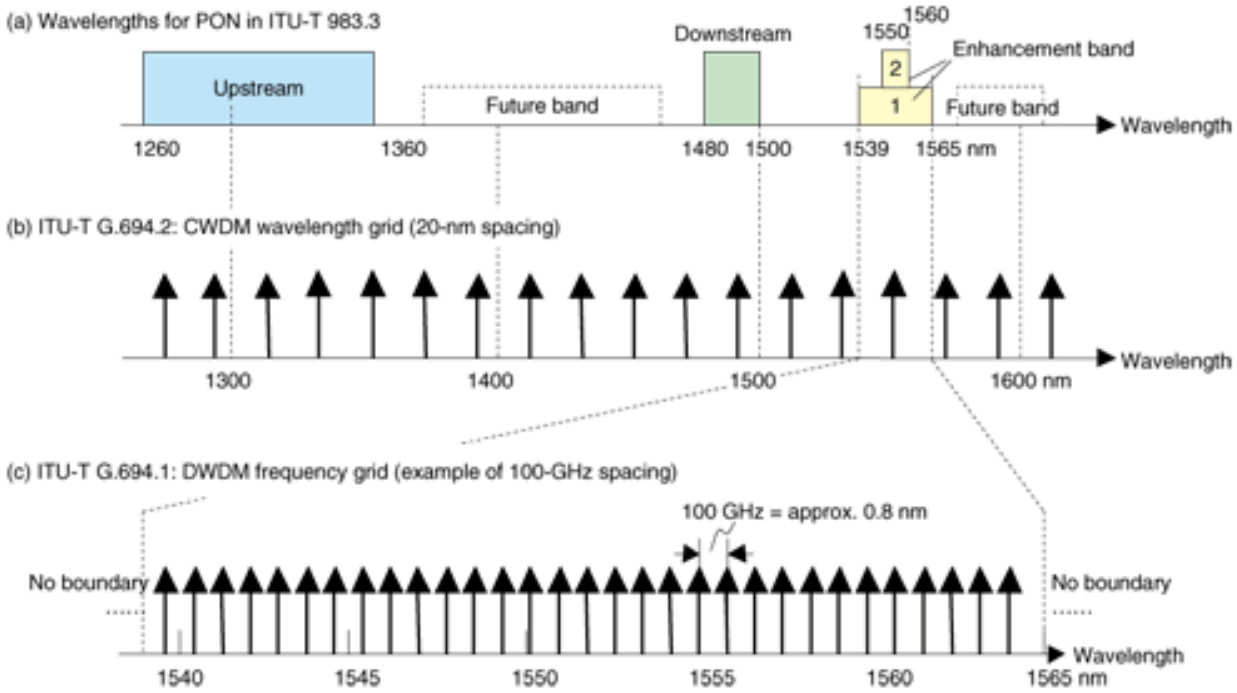
Demerit

- **High power consumption**
- **High cost of DSP**
  - **only for linear calculation**
- **High speed D/A and A/D**

- Digital signal processors (DSP) enable 100Gbit/s systems of DP-QPSK 25 Gbaud.

DWDM systems

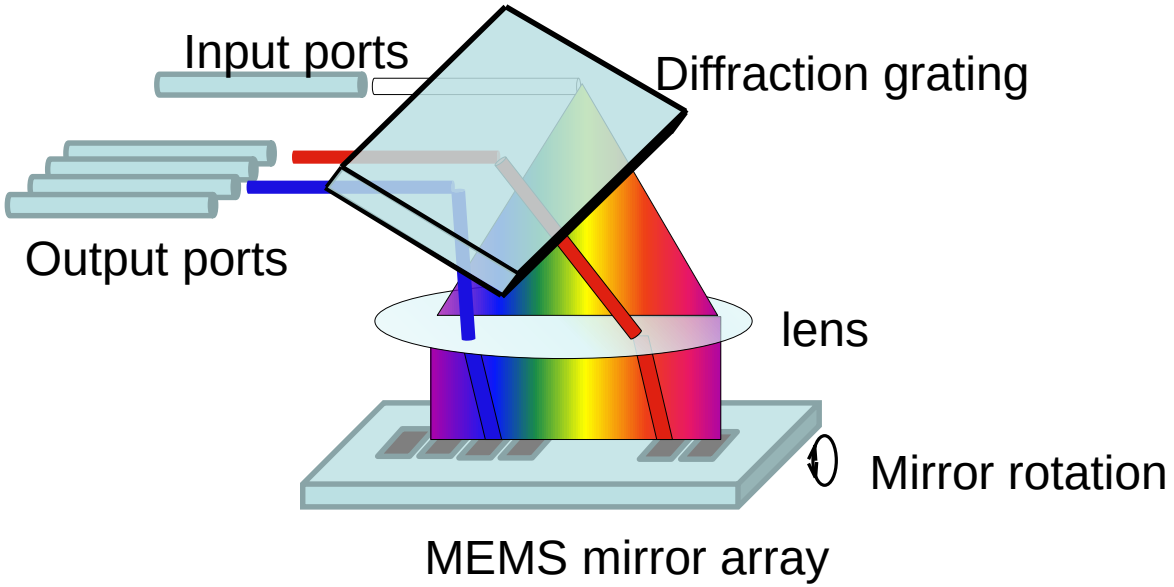
The International Telecommunication Union (ITU) devides wavelengths into grids with a width of 12.5, 25, 50 or 100 GHz, and a center 193.1 THz.



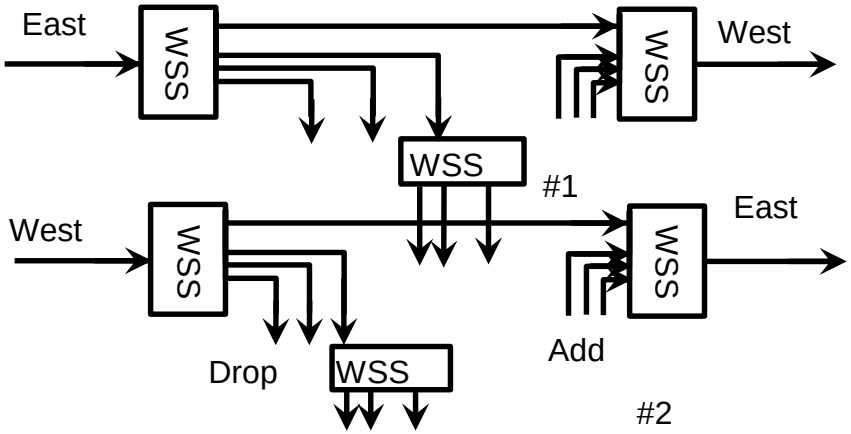
- DWDM provides 100 channels with a bandwidth of 100 GHz in low-loss wavelength bands, called C and L band (1530 – 1625 nm).
- Flexible gird system provides 800 channels with a bandwidth of 12.5 GHz.

Reconfigurable Optical Add Drop Multiplexer(ROADM)

- Wavelength selectable switch (WSS)



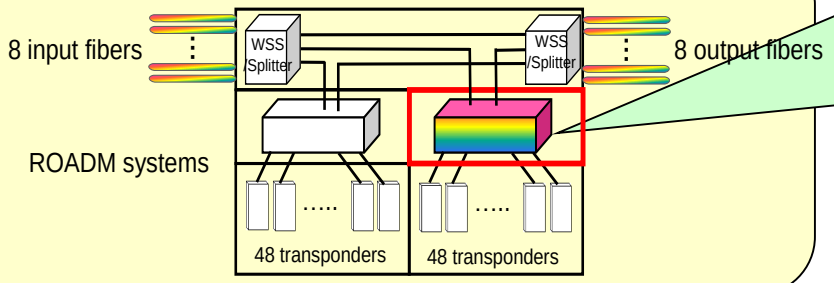
- CDC(Colorless Directionless Contention-less) ROADM by WSS's



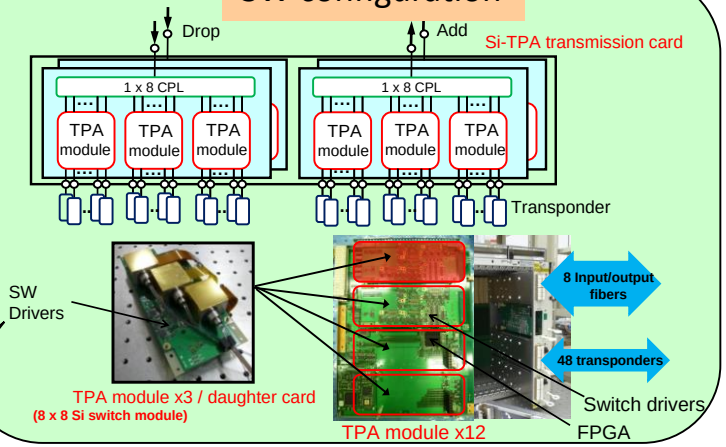
ROADM systems are widely used in Metro ring systems.

CDC-ROADM based on Si-Photonics SW (AIST-NEC)

Next Gen. ROADM

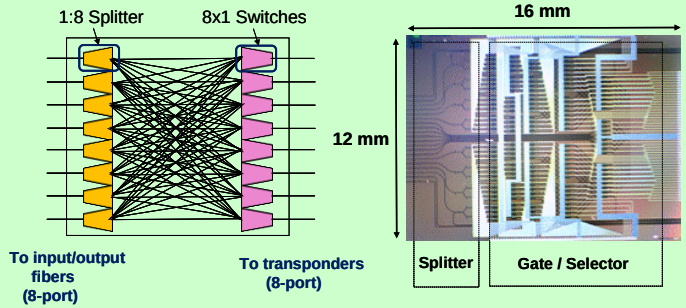


SW configuration



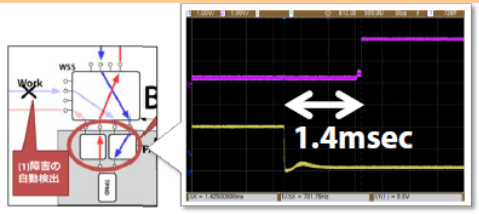
- Maximum 24 ports per daughter card
- Maximum 96 ports per ROADM

Si-Photonics Optical SW



- 8×8 split&select Si-Photonics SW Chip
- 12×18mm ^{2} size

Performance testing: Protection operation



- 1.4ms switching time
- Cut buffer memory by short switching time
  ex.100Gbps/ch 10ms means 1Gb/ch（125MB/ch）
  Requiring < 10ms switching time including TPND sync time.

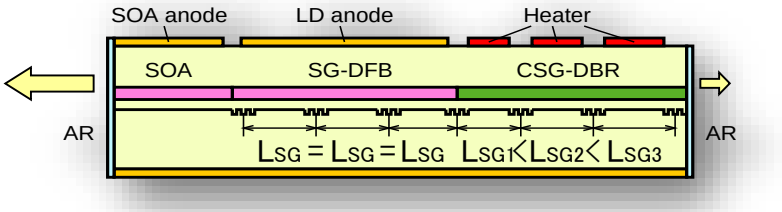
T. Hino et al., ECOC2012：Tu.3.A.5

Light sources in DWDM systems

- Wavelength tunable laser

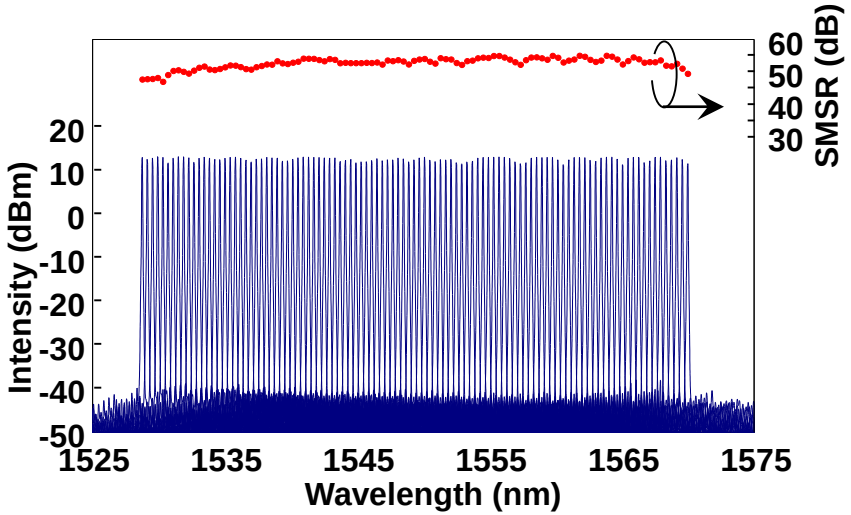
Example of wavelength tunable Laser diode

- Single stripe monolithic chip
- DR (DFB + DBR) structure
- Integrated heaters for wavelength tuning



CSG-DR-DFB LD (SEI)

Wide tuning range (40 nm) & high SMSR (> 45 dB)



- Frequency comb generator

High quality optical comb/ultra-short pulse through highly nonlinear fibers.

C+L-band
40 dB OSNR

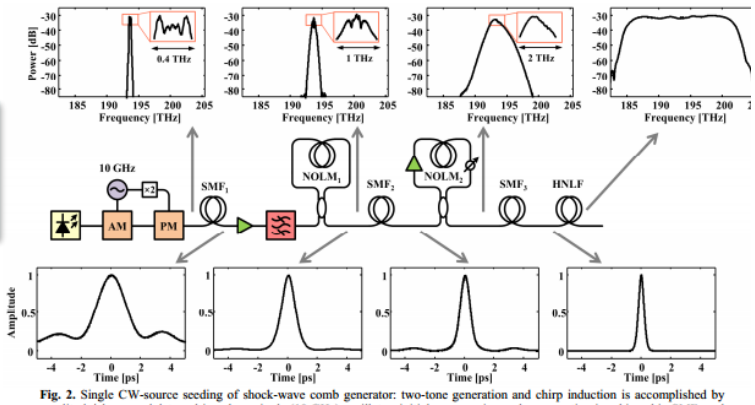


Fig. 2. Single CW-source seeding of shock-wave comb generator: two-tone generation and chirp induction is accomplished by amplitude/phase modulators driven by a single (10 GHz) oscillator; initial compression and regeneration is achieved in SMF_1 and $NOLM_1$, with subsequent compression/regeneration (SMF_2/$NOLM_2$) resulting in 250 fs seed for mixing stage (HNLF). Measured spectral/temporal evolution is shown in insets.

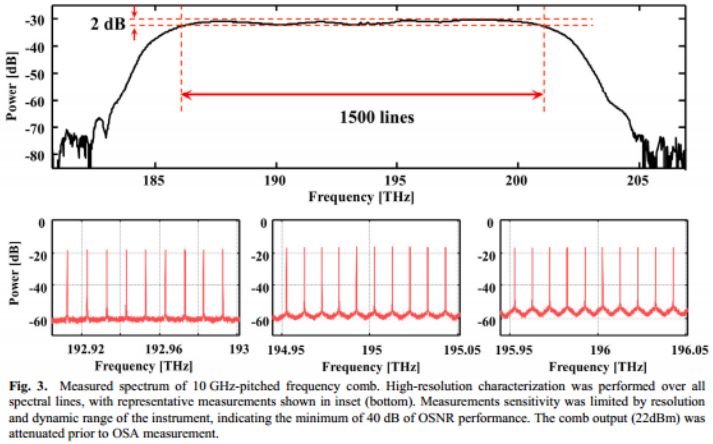


Fig. 3. Measured spectrum of 10 GHz-pitched frequency comb. High-resolution characterization was performed over all spectral lines, with representative measurements shown in inset (bottom). Measurements sensitivity was limited by resolution and dynamic range of the instrument, indicating the minimum of 40 dB of OSNR performance. The comb output (22dBm) was attenuated prior to OSA measurement.

V. Ataite et al. (UCSD), OFC NFOEC 2013, PDP5C.1

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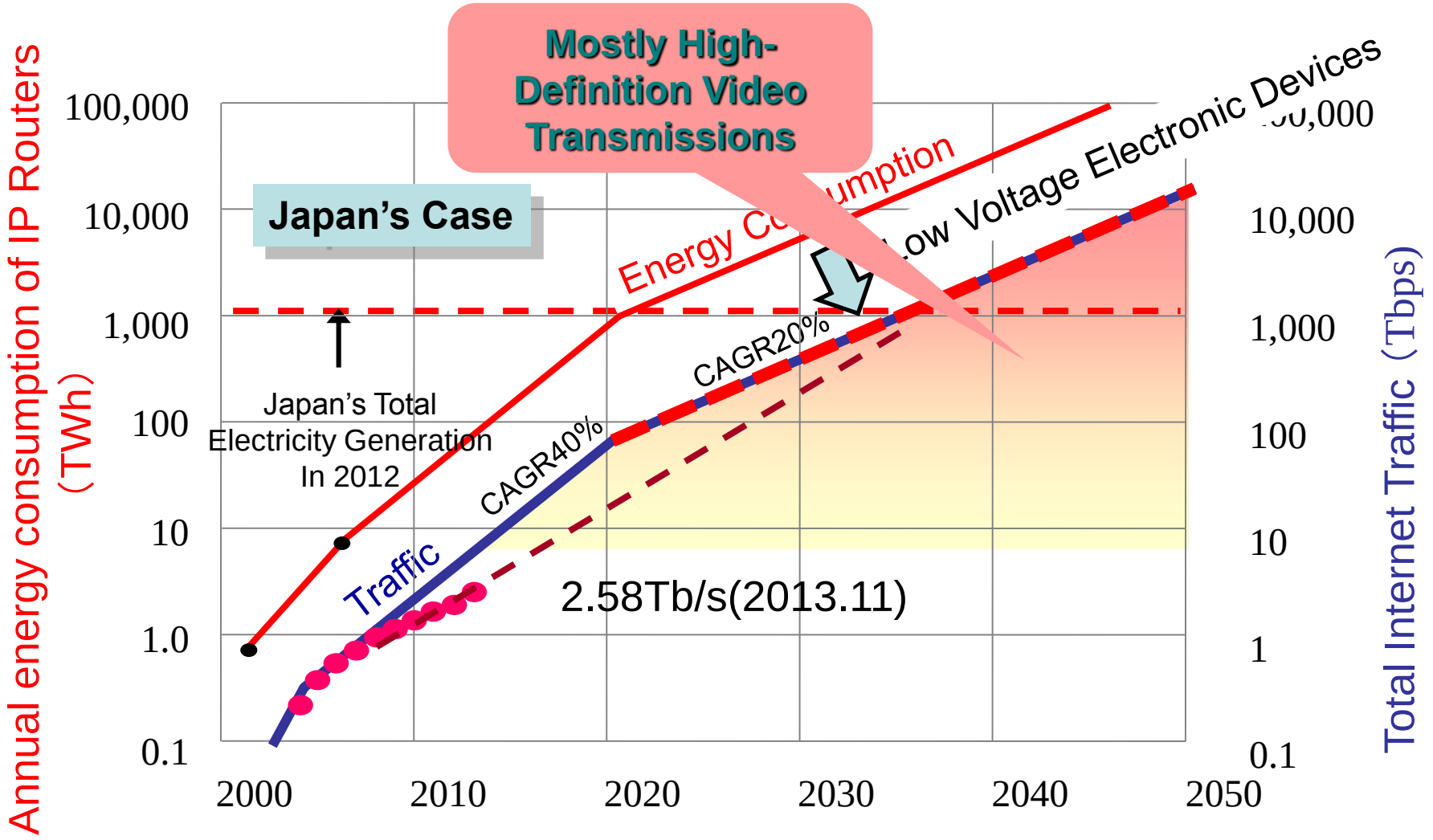
What is VICTORIES?

- VICTORIES stands for
  - Vertically Integrated Center for Technologies of Optical Routing toward Ideal Energy Savings
- Who supports and participates?
  - Project for Developing Innovation Systems of the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan
  - National Institute of Advanced Industrial Science and Technology (AIST), Japan
  - 10 Collaborating Telecom Companies
  - Cooperation with Japan Broadcasting Corp.

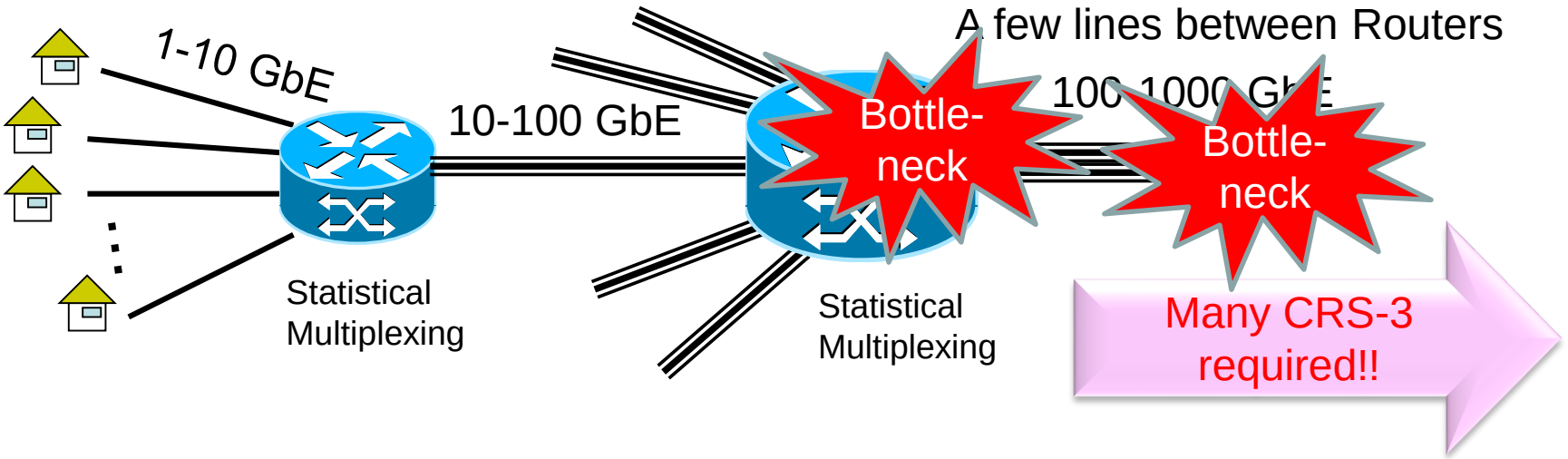
Energy consumption: the ultimate bottleneck



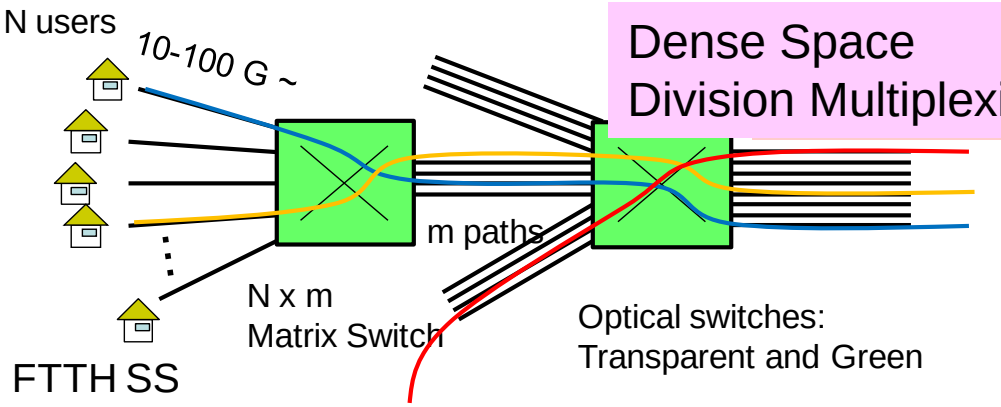
- The current technologies can't scale to the increasing traffic in future.
- 3-4 digit energy saving is necessary, which means we need a new paradigm.

Optical switches with SDM *is* the solution..

- **Conventionally exchange digital packets: Aggregate-and-Transport**



- **→ New Scheme: Exchange end-to-end numerous fibers in parallel!!**



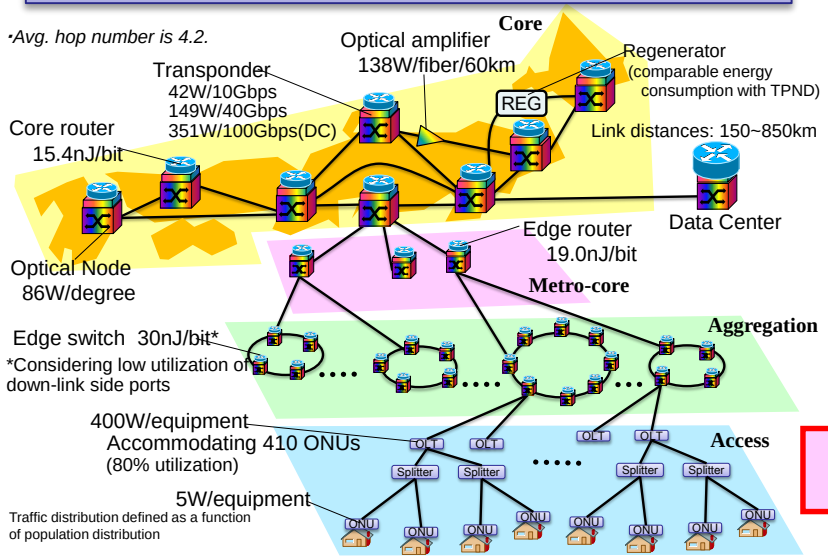
Dense Space Division Multiplexing

SDM path connections rather than packet-based Aggregate-and-transport

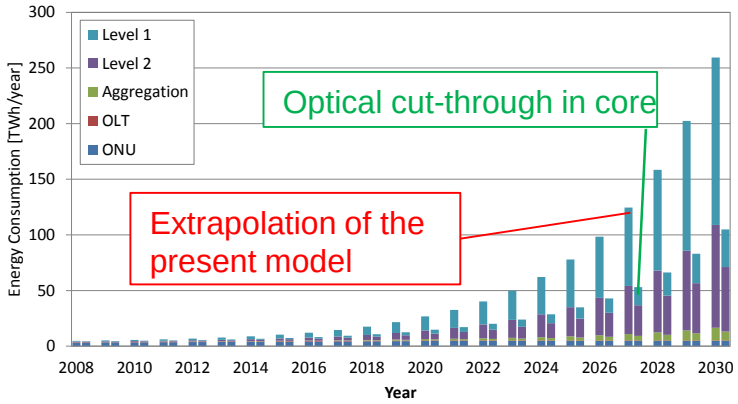
For more detail, see S. Namiki et al., JSTQE early access

Dynamic Optical Path Network (DOPN) for ultra-low energy

Optical Cut-through of Core NW

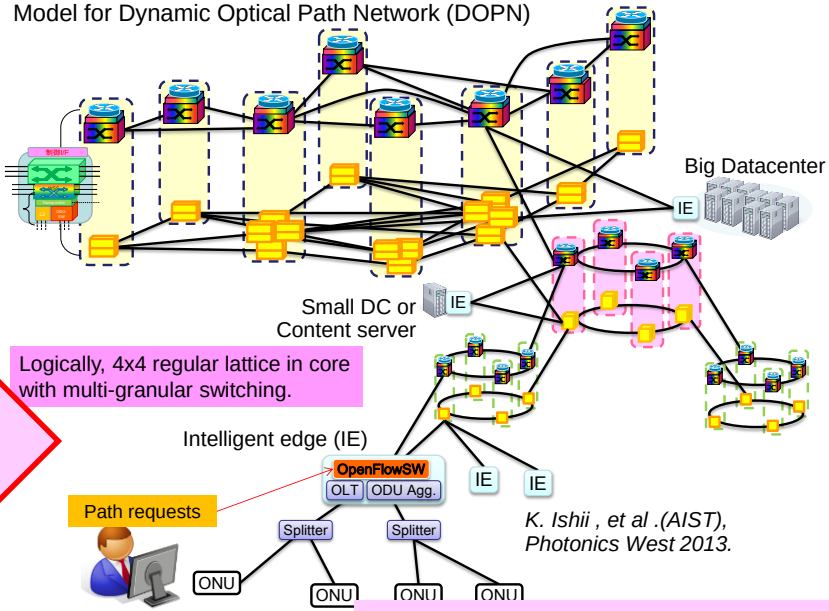


K. Ishii (AIST), et al., ECOC2013.

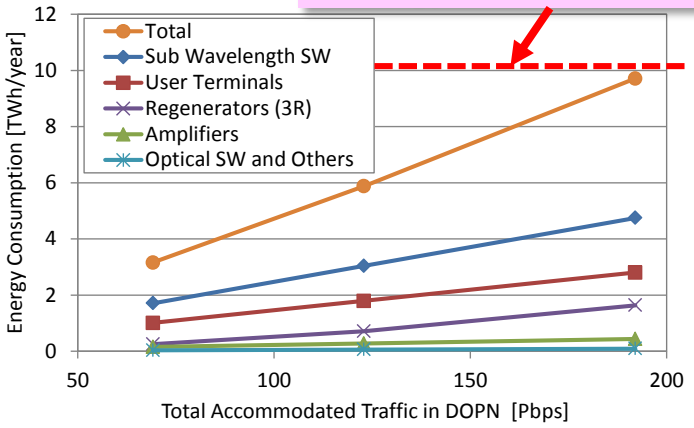


The energy reduction by optical cut-through is not large enough.
The energy consumption at edge routers is dominant.

Optical Cut-through of All NW



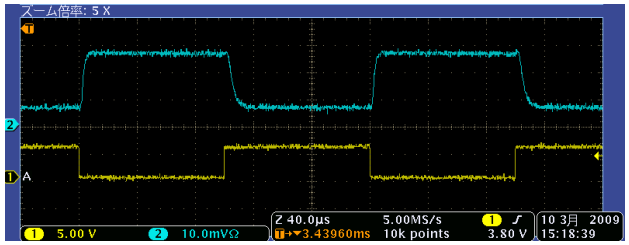
Energy consumption Today

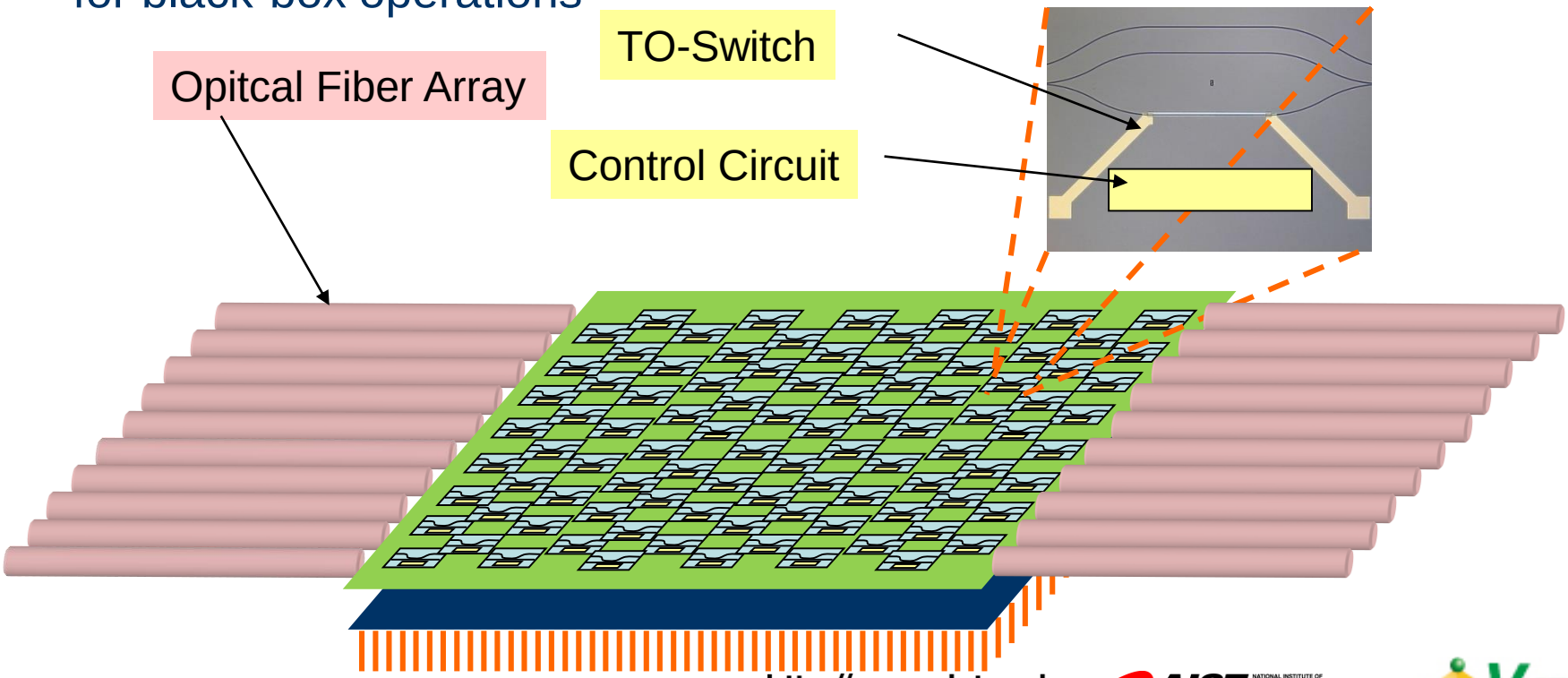


http://www.aist.go.jp AIST NATIONAL INSTITUTE OF ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY (AIST) VICTORIES

Optical cross connect switch (OXC) using Silicon Photonics

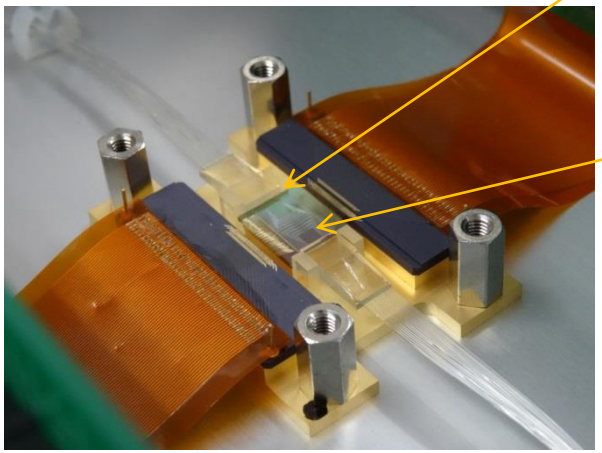
- 32x32 Matrix Switch for 512 x 512 Clos network
- Need only a few Ws
- Within a few cm^2 Chip
- ~μsec fast thermo-optical switching
- Integration with control circuits
  for black-box operations

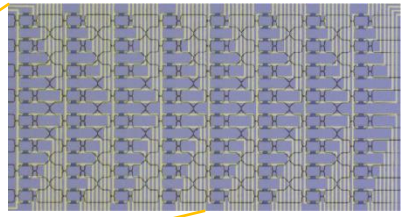




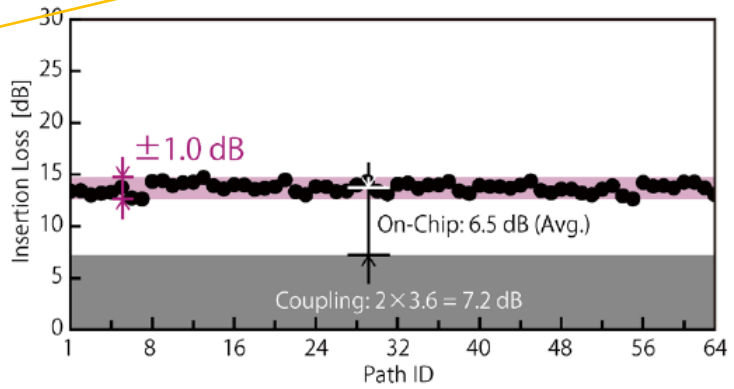
8x8 switches and pol. diversity

8×8 PILOSS TO-SW module

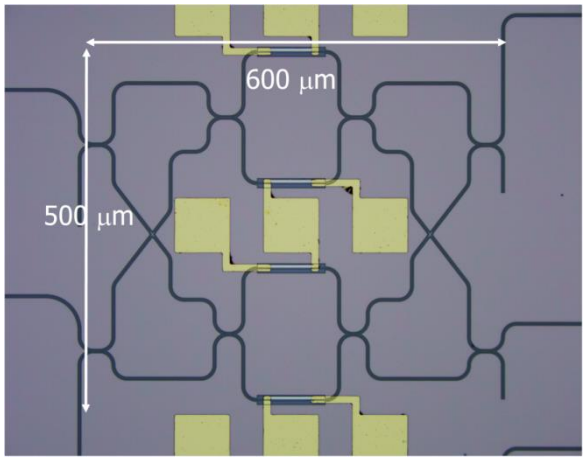


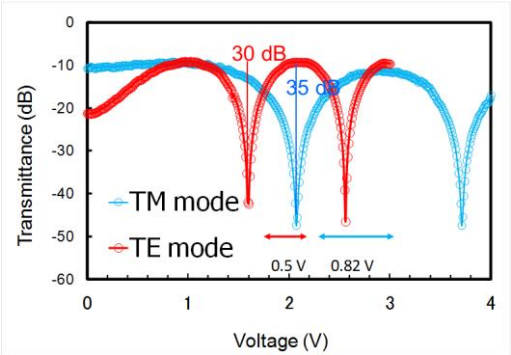


Suzuki et al.,
PD2.D.2, ECOC2013



Integrated polarization diversity for polarization insensitive operations





Kim et al., *We.4.B.5, ECOC 2013*

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Scales of high performance computers and data centers

	K-computer 2012	Post K-computer (FX100) 2015	Exa-scale (K x 100) 2020~2023	Google class DC* circa 2013	Desired Big Data DC Circa 2025
Total number of nodes	88,128	≧100,000	70,000~ 200,000	~300,000	100,000
Number of nodes per rack	102	216	200~	40 ~ 45	100
Tflop/sec per node (CPU)	0.128	≧1	2~16	0.15	> 2
Bandwidth per link (Gbps)	40	100	4T	***1***	>1T
Total link bandwidth per node (Gbps)	160	2 Tbps (Optical)	16T?	***1~***	> 4T
Total NW capacity	14.1 Pbps	~ 200 Pbps	3.2 Ebps	~ 360 Tbps	> 400 Pbps

Data center network in 2025

Future data center becomes like HPC

- 100,000 nodes with high computation power
- Wideband connection of 10 Tbps

- Wideband network
  - DWDM
  - Coherent multi-level format
- Low energy consumption
  - OXC switch
- Low cost and high stability
  - Si photonics
  - Wavelength bank systems

Wavelength bank and distribution systems

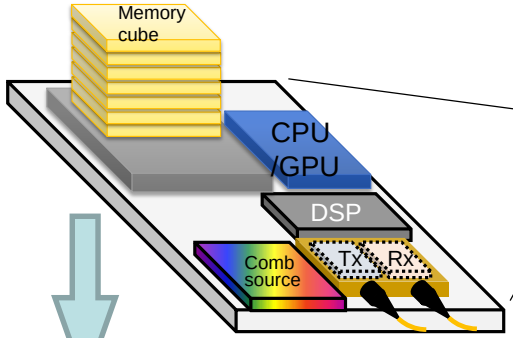
- Large scale (Exa-bit/s) optical switch systems.
- DWDM・multiple value format technology supports elastic wideband connection.
- Low energy consumption by Si-photonics

Under the feasibilty study

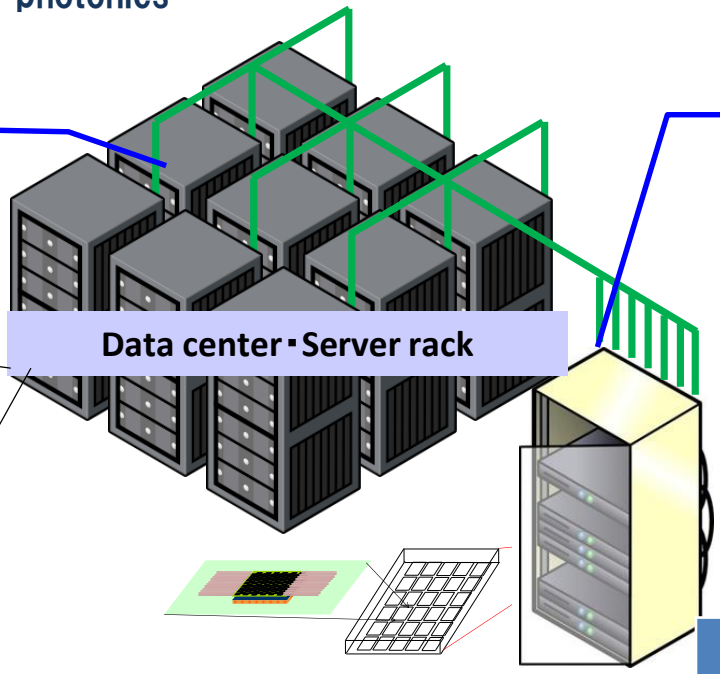
DWDM multiple-value optical interconnection

Si-photonics・Exa-bit/s switch

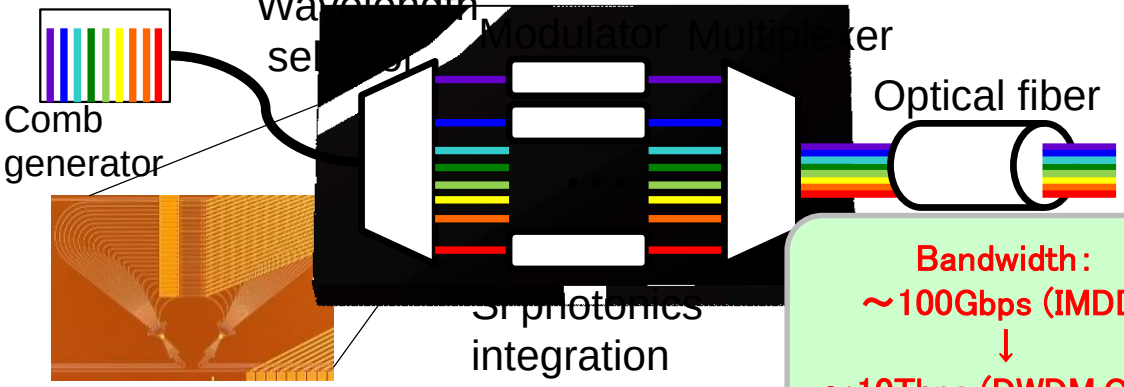
- Small-size・large-scale integration by Si-photonics
- 3D optical wiring by α-silicon
- New architecture is required.



2.5D integrated node



Switching capacity:
~130Tbps (Electronics)
↓
~1Ebps (Optics)



Bandwidth:
~100Gbps (IMDD)
↓
~10Tbps (DWDM,QAM)

Baud rate	QAM	Total Tbps
20 G	64QAM	7.68
20 G	256QAM	10.24
32 G	64QAM	12.29
50 G	16QAM	12.5

*) Wavelength number: 32

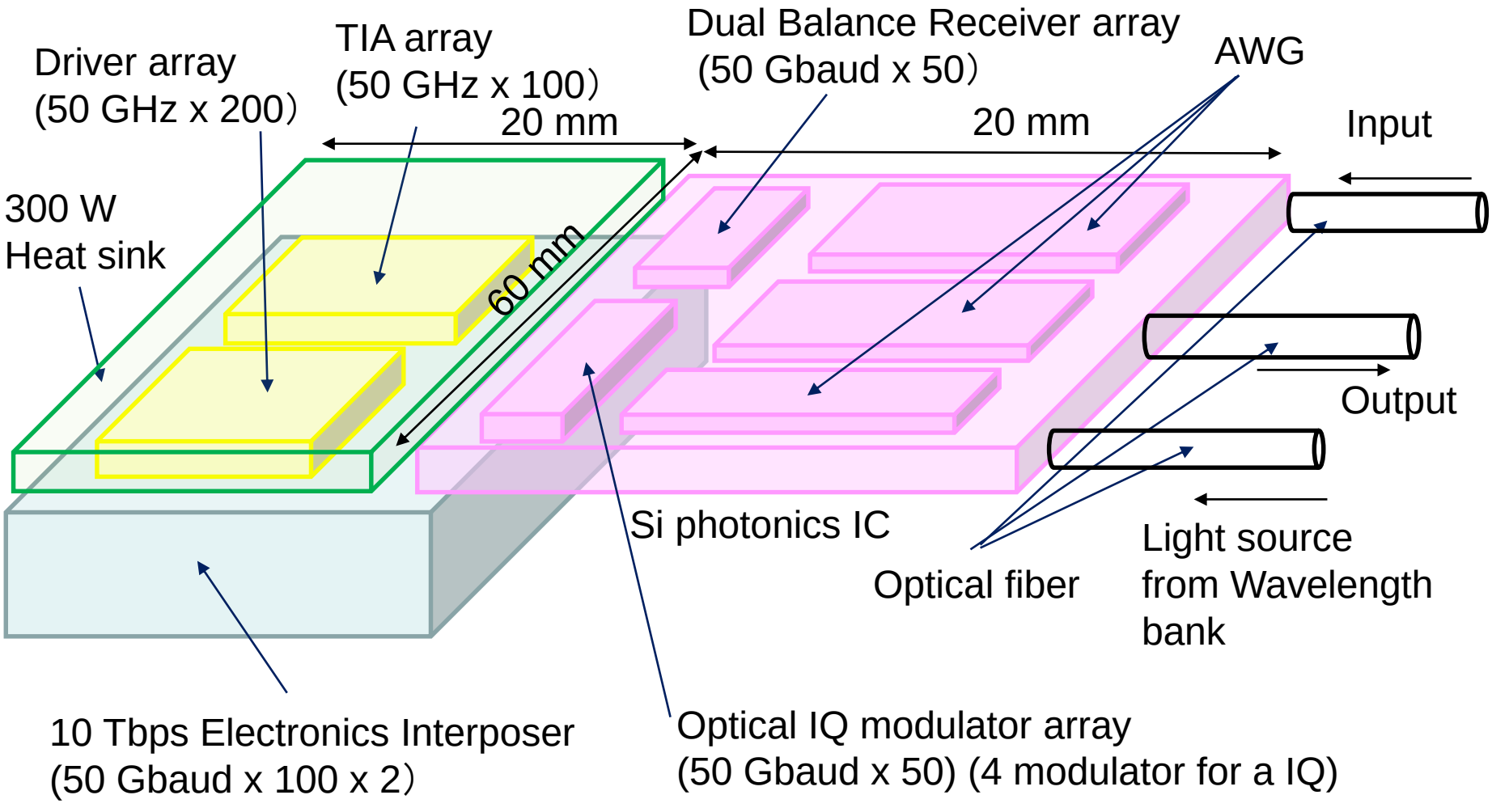
H. Kuwatsuka, *ASCI2015, 2014.1.28.*

Concept of 10 Tbps transceiver

Target in 2025

50 Gaud x 2 (Pol.) x 25 (Wavelength) x 4 (16QAM)

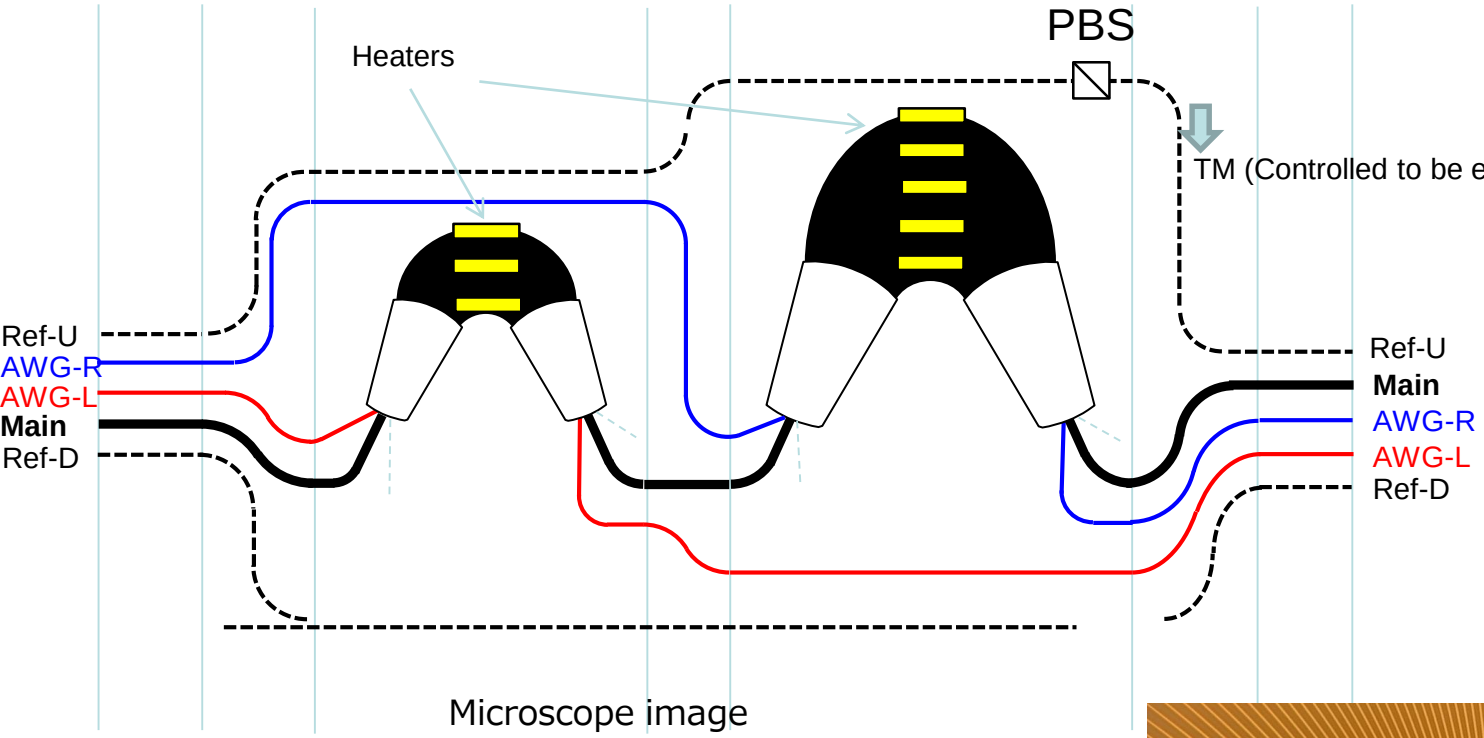
- Power consumption of 300W
- Module footprint of 60 mm x 40 mm



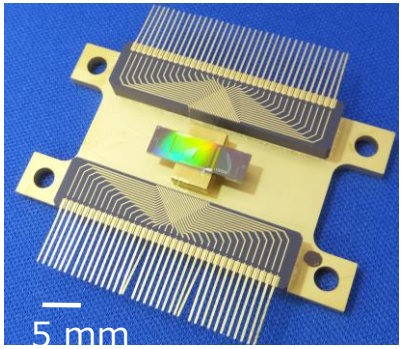
H. Kuwatsuka, *ASCI2015, 2014.1.28.*

Wavelength tunable filter of Si-photonics

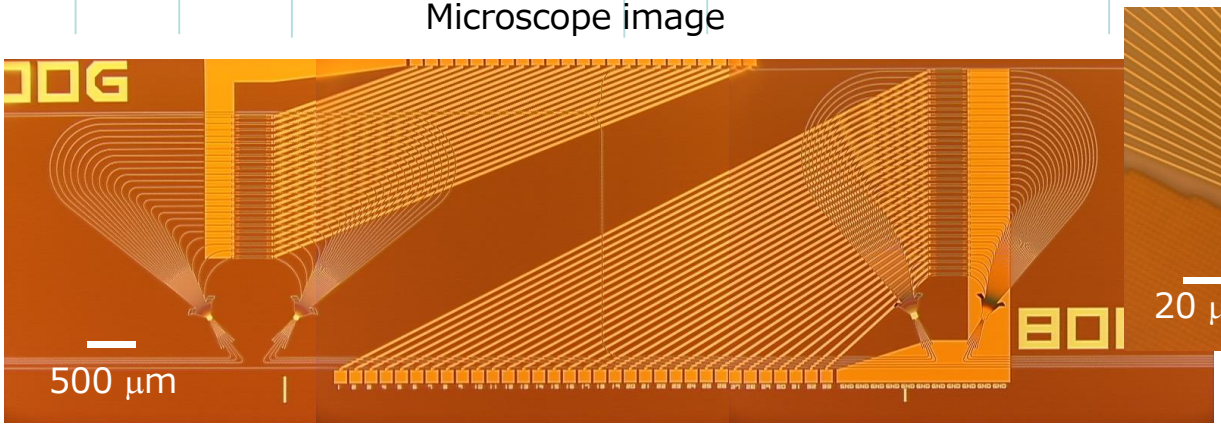
Cascaded AWG's with different FSR

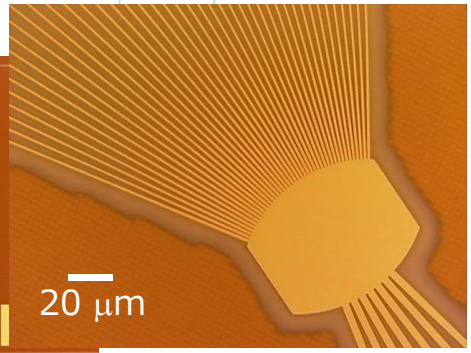


Tunable filter on ceramic interposer



Microscope image





Optical power level diagram in wavelength bank systems

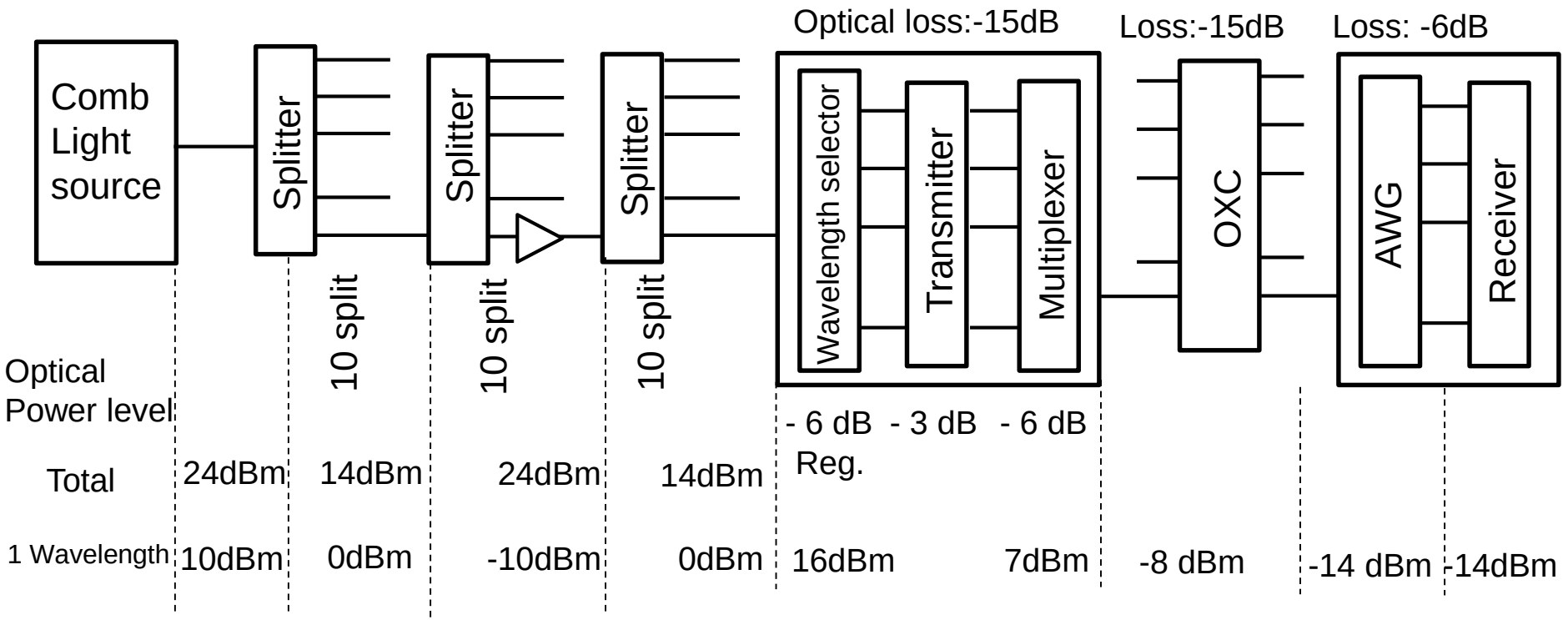
Wavelength bank
100 sets

20dB Amp.
1000 sets

Node (Transmitter)
100,000 sets

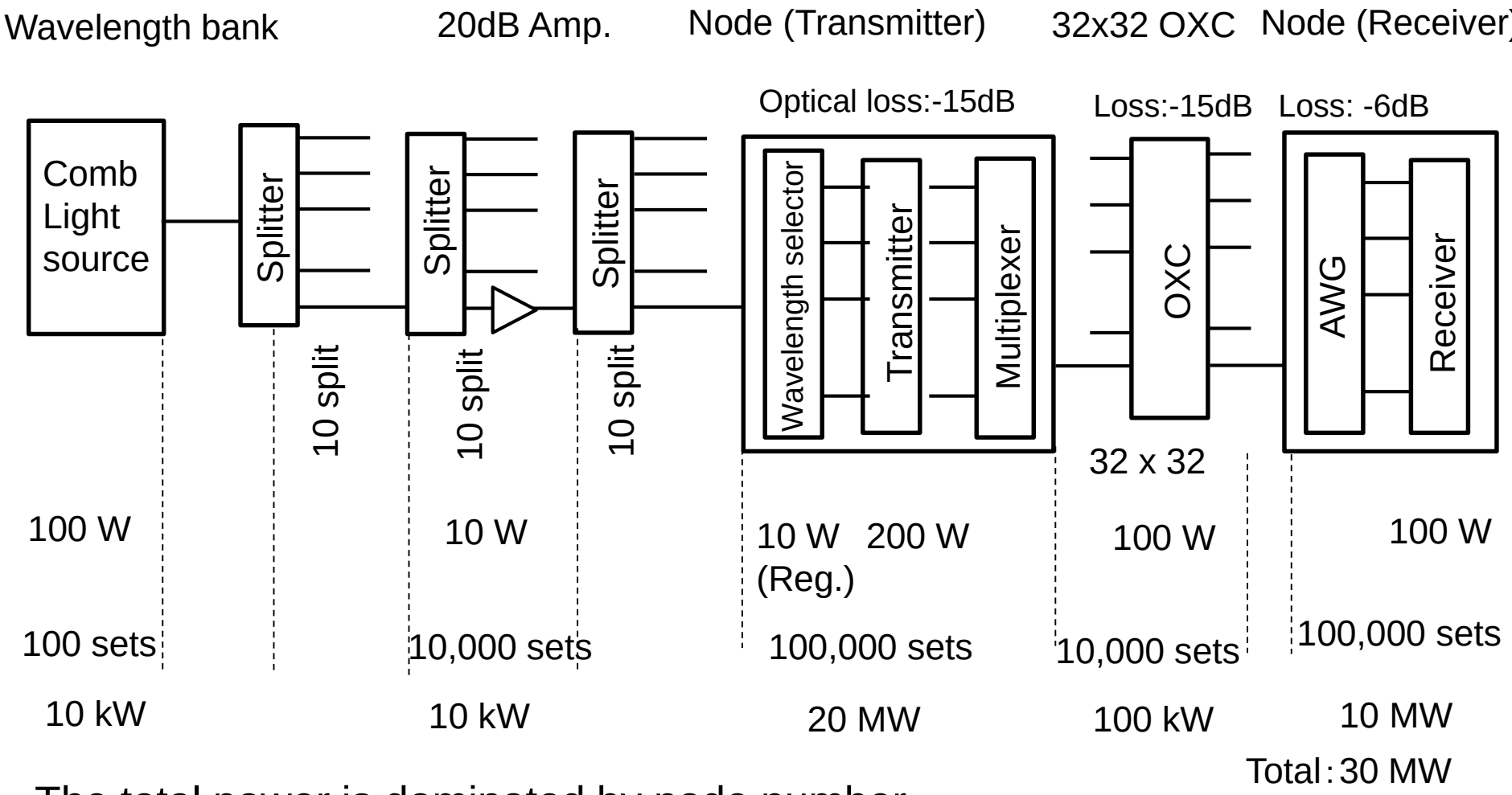
32x32 OXC
10,000 sets

Node (Receiver)
100,000 sets



The bandwidth of 10Tbps can be realized with realistic optical power.

Power consumption of wavelength bank systems



- The total power is dominated by node number.
- The switching power is negligible compared with that of electric routers of 200 MW for Exa-bps.

Summary

- Light waves in information systems
  - Optical fibers
- Advanced technologies in optical communication systems
  - Modulation format
  - DWDM
  - ROADM
  - Light sources for DWDM
- Dynamic Optical Photonic Network (VICTORIES Project)
  - OXC switches
- Wavelength bank and distribution systems for data center
  - 10Tbps transceiver
  - Optical power diagram
  - Power consumption

The development of low cost, low power-consumption and highly integrated optical devices by using new technologies such as Si photonics is indispensable for the systems.