

제21회 광인터넷 워크숍 (Optical Internet Workshop 2021)

저탄소 디지털 경제에서 광네트워크의 역할
- Role of optical network in the low-carbon digital economy -



- 일 자 2021년 10월 20일(수) ~ 10월 22일(금)
- 장 소 메종글래드제주 2층 크리스탈 홀
- 주 최 광인터넷포럼, 한국광학회
- 형 식 온라인/오프라인 병행
- 웹사이트 <https://www.osk.or.kr/conference/event/index.php?cfid=19>
- 후 원 과학기술정보통신부, ETRI, IITP, NIA, KAIST, 한국광기술원, 한국광산업진흥회, 케이티, SKT/SKB, LGU+
- 협 찬 넷비전텔레콤, 라이트론, 비아비솔루션스코리아, 에치에프알, 오이솔루션, 옵티코어, 우리넷, 우리로, 캠옵틱스, 코워버, 텔레다인르크로이, 텔레필드, 팬옵틱스, 포인투테크놀로지, 피피아이

제21회 광인터넷 워크숍(OIW 2021) 프로그램 안내

첫째 날(Day 1) 10월 20일 수요일		
시간	내용	좌장 / 발표자
13:00-13:30	등록	
Tutorial 세션		최준균/KAIST
13:30-14:50 (40분 발표)	디지털 트랜스포메이션과 Telco의 비즈니스 트랜스포메이션	모순래/ KT경제경영연구소
	광대역, 저전력화를 위한 실리콘 포토닉스 기술	정석환/수원대
14:50-15:00	휴식	
세션 1-1: 광통신 소자/부품 기술		이원기/오이솔루션
15:00-16:30 (30분 발표)	유무선통합형 광트랜시버 개발 및 실증	정소기/SKB
	IOT 및 특화망을 위한 국산 5G 모듈 기술 및 Eco-system	이성규/ 에이엠티솔루션즈
	FOWLP 기반 고집적 웨이퍼레벨 All-in-One Hybrid 광패키징 기술	최성욱/라이텍
16:30-16:50	휴식	
세션 1-2: 광통신 소자/부품 기술		백용순/ETRI
16:50-18:20 (30분 발표)	5G 프론트홀 광부품 기술	임동성/레진저스
	데이터 센터용 광트랜시버 개발을 위한 실리콘 포토닉스 소자 및 집적 기술	박성봉/삼성전자
	저전력 초고속 실리콘 링 변조기	최우영/연세대
둘째 날(Day 2) 10월 21일 목요일()		
시간	내용	좌장 / 발표자
세션 2: 광통신 장비 기술		김선미/ETRI
09:00-10:30 (30분 발표)	WiFi6E 인더어 빅데이터 처리 기술	이주연/올래디오
	커버리지 확대와 속도증대를 위한 PON 리피터 기술	김광욱/ETRI
	미래 네트워크 구축을 위한 차세대 광통신 장비 기술과 역할	이원희/코위버
10:30-10:50	휴식	
세션 3: 미래 광대역 서비스		최성호/IITP
10:50-12:30 (25분 발표)	메타버스 확산동향 및 발전방향	이남경/ETRI
	5G MEC 기반 융복합서비스 적용사례	고선경/LGU+
	5G 특화망 동향과 유스케이스	박동주/에릭슨LG
12:30-14:00	6G 서비스와 통신기술 전망	고영조/ETRI
	중식	

셋째 날(Day 2) 10월 21일 목요일()		
시간	내용	좌장 / 발표자
개회식		이준기/ETRI
14:00-14:30	개회사	광인터넷포럼의장
	환영사	한국광학회장
	축사	조직위원장
	격려사	과기정통부
Plenary 세션		신종윤/SKT
14:30-16:10 (50분 발표)	근거리 광통신 기술	정윤철/KAIST
	공공분야 디지털전환 정책	박덕수/행정안전부
16:10-16:30	휴식	
세션 4: 포토닉스 응용 기술		박경현/ETRI
16:30-18:00 (30분 발표)	Photonics 응용 국내외 레이다 개발 동향	장성훈/ADD
	Perspectives on silicon optical phased array for wireless data transmission and image sensor applications	박효훈/KAIST
	포토닉스 기반 THz 근거리 통신을 위한 핵심 부품 기술 개발	이일민/ETRI
넷째 날(Day 3) 10월 22일 금요일		
시간	내용	좌장 / 발표자
세션 5: 탄소중립을 위한 광통신		김장선/편유티스
09:00-10:15 (25분 발표)	A new Electrical Dispersion Compensation methodology for 25Gbps data-rate and beyond	박진호/ Point2 Technology
	반도체 기반 광스위치	한상윤/DGIST
	데이터센터의 탄소발자국 줄이기	김주환/NHIN
10:15-10:30	휴식	
세션 6: 양자, 국방 및 공공 인프라		양종한/NIA
10:30-12:10 (25분 발표)	1 테라를 지향하는 초연결 지능형 연구개발망 (KOREN) 의의	김형우/KT
	국방정보통신망을 위한 다매체 다중경로 네트워크 최적화 기술	정병철/ 경상국립대학교
	양자 ICT 산업화 사례와 양자암호통신 테스트베드 실증 현황	나성욱/NIA
	QKD 및 기관리 시스템 구축 기술과 출연(연) 적용 사례	이원혁/KISTI

* 본 프로그램은 사정에 따라 변경될 수 있습니다.

* 정부의 코로나 방역지침에 따라 단체 중식은 제공하지 않음을 양지하여 주시기 바랍니다.

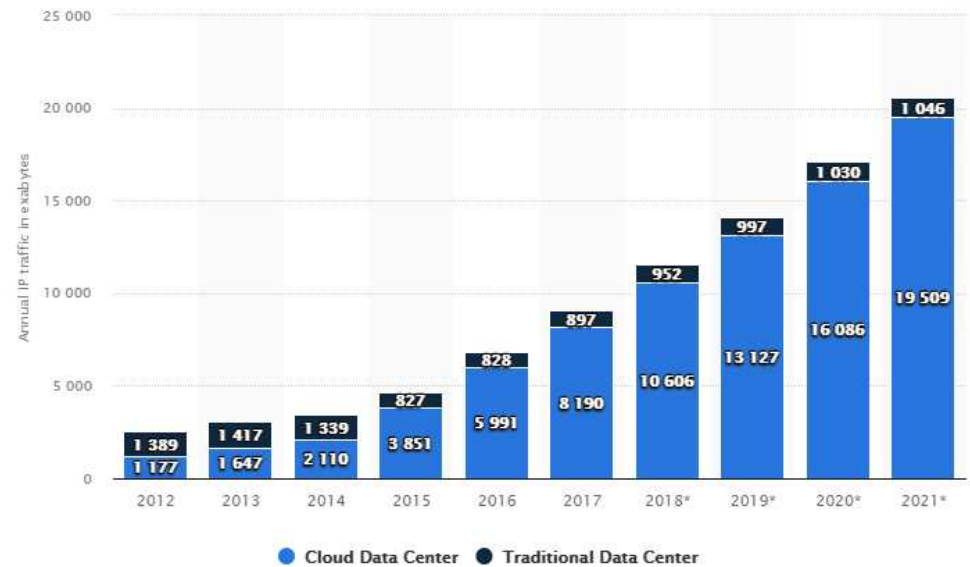
저전력 초고속 실리콘 링 변조기

연세대학교 전기전자공학과
High-Speed Circuits and Systems Lab
최우영

Data Centers



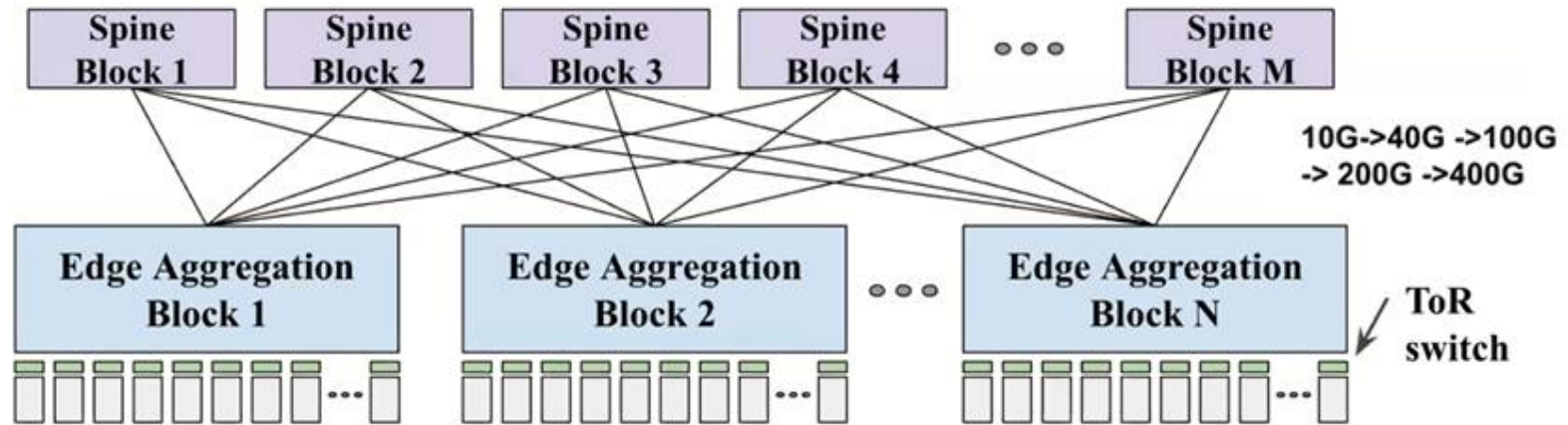
Global DC IP Traffic
(in exabytes per year)



(Statista 2021)

Data Center Network

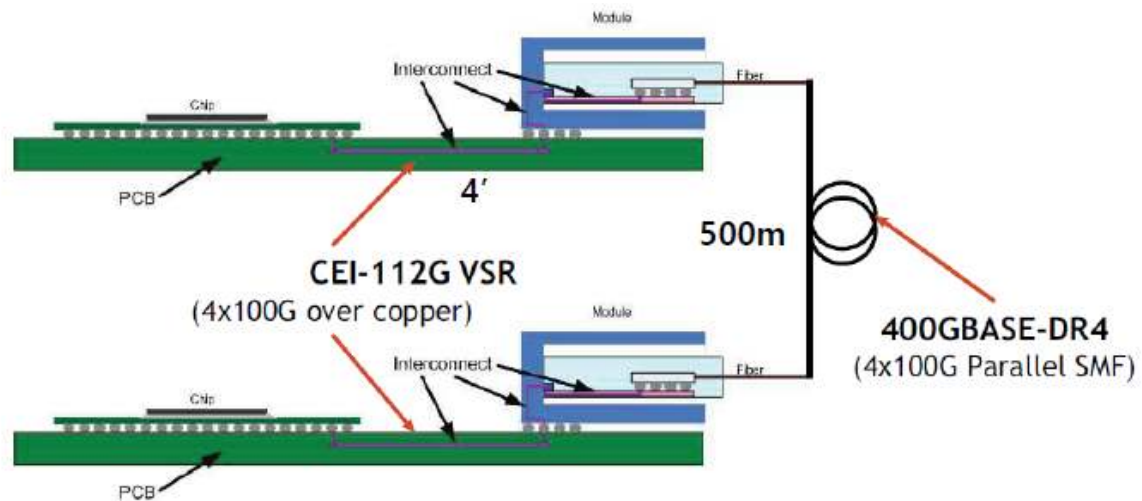
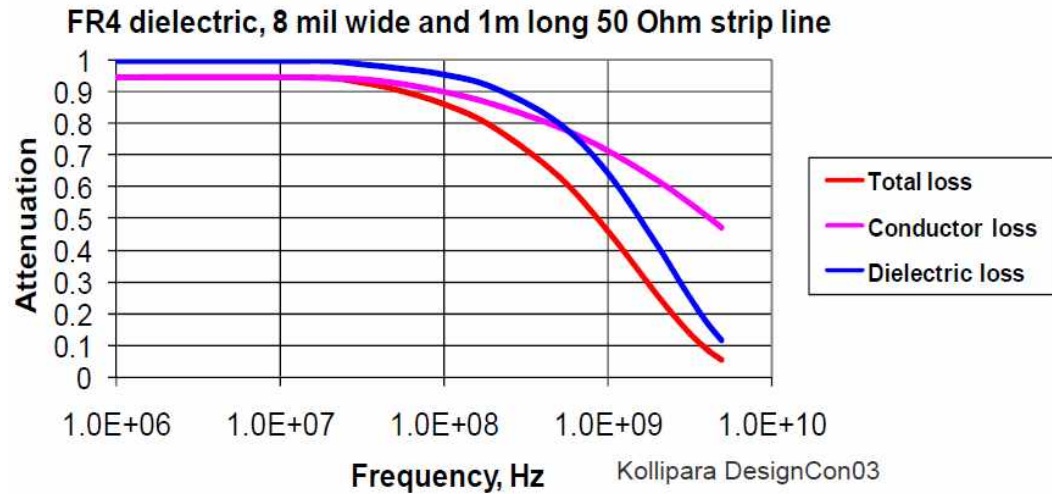
Google Data Center Network



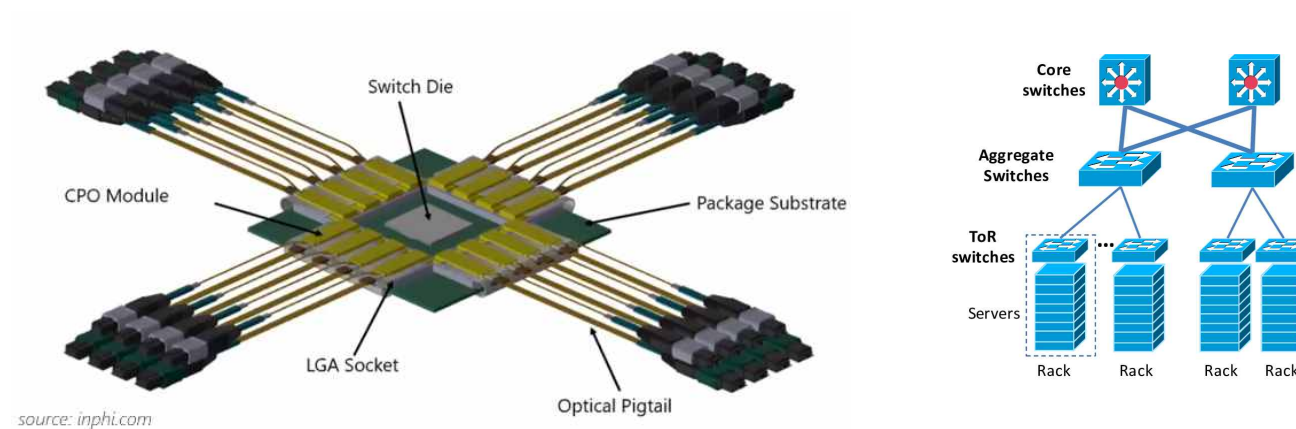
Ref: "A Decade of Clos Topologies and Centralized Control in Google's Data Center Network (Plus a Look Ahead)", Amin Vahdat, ONS 2015 Keynote

Total bandwidth: 2 Tbps → 10 Tbps → 100 Tbps → 200 Tbps → 6 Petabps

Why photonics for interconnects?



Co-Packaged Optics



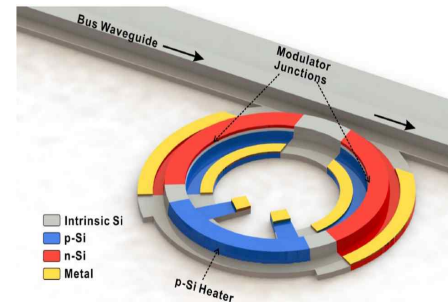
Requirements on Optical Tx

- MMF or SMF ?
- Direct or external modulation?
- Large modulation bandwidth density
- High energy efficiency (small J/bit)
- CMOS compatibility (MCM)
- Large scale integration

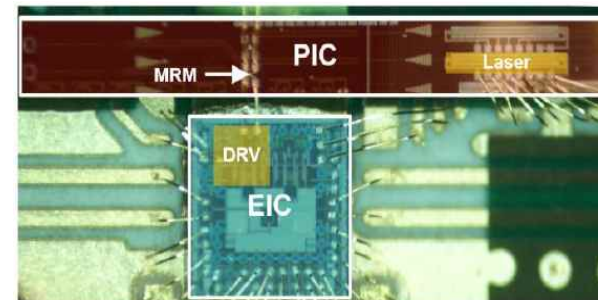
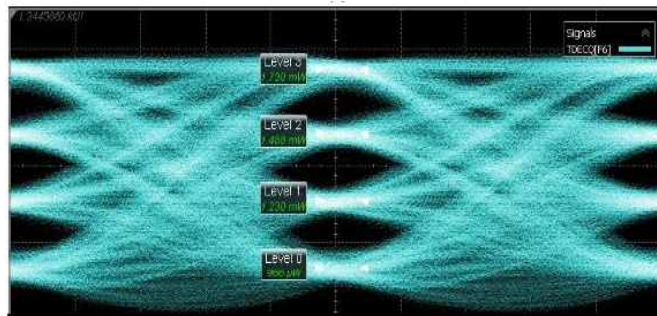
➔ Si Micro-Ring Modulator (Si MRM) for Photonic I/O

➔ Disaggregated DC Architecture

High-Performance Si MRM



<112-Gb/s PAM4 transmitter>



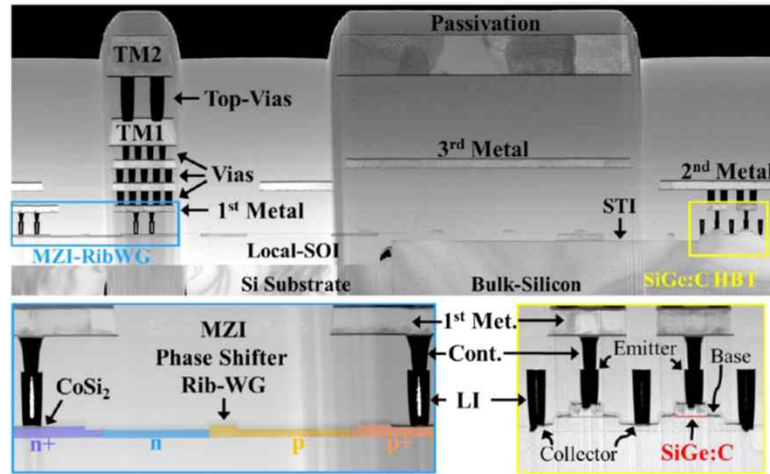
(Intel, OFC 2019)

Si Photonic I/O Research at Yonsei

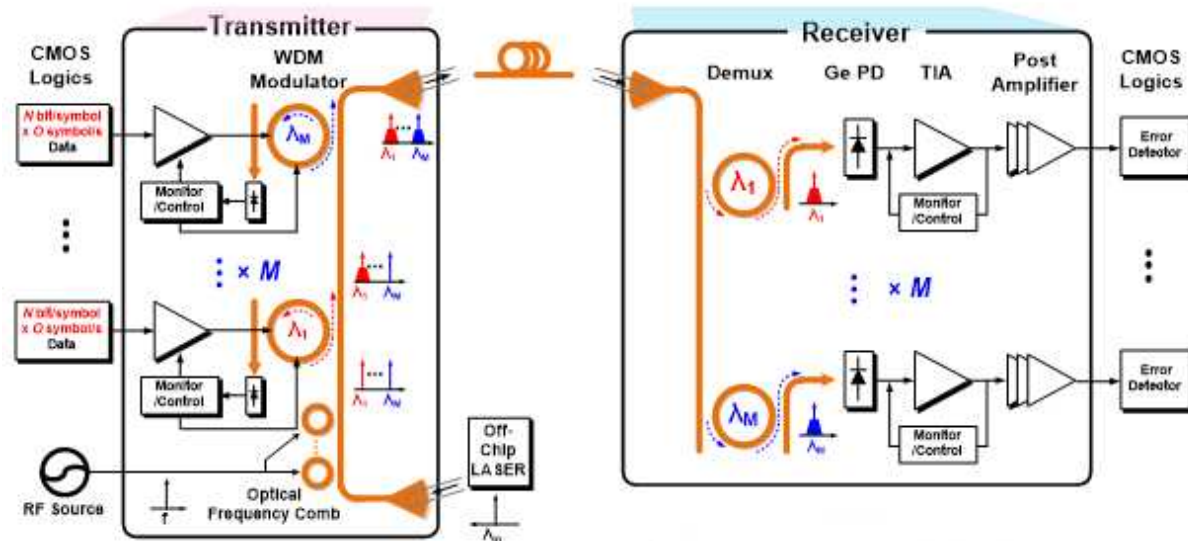
- IHP Photonic BiCMOS



innovations
for high
performance
microelectronics

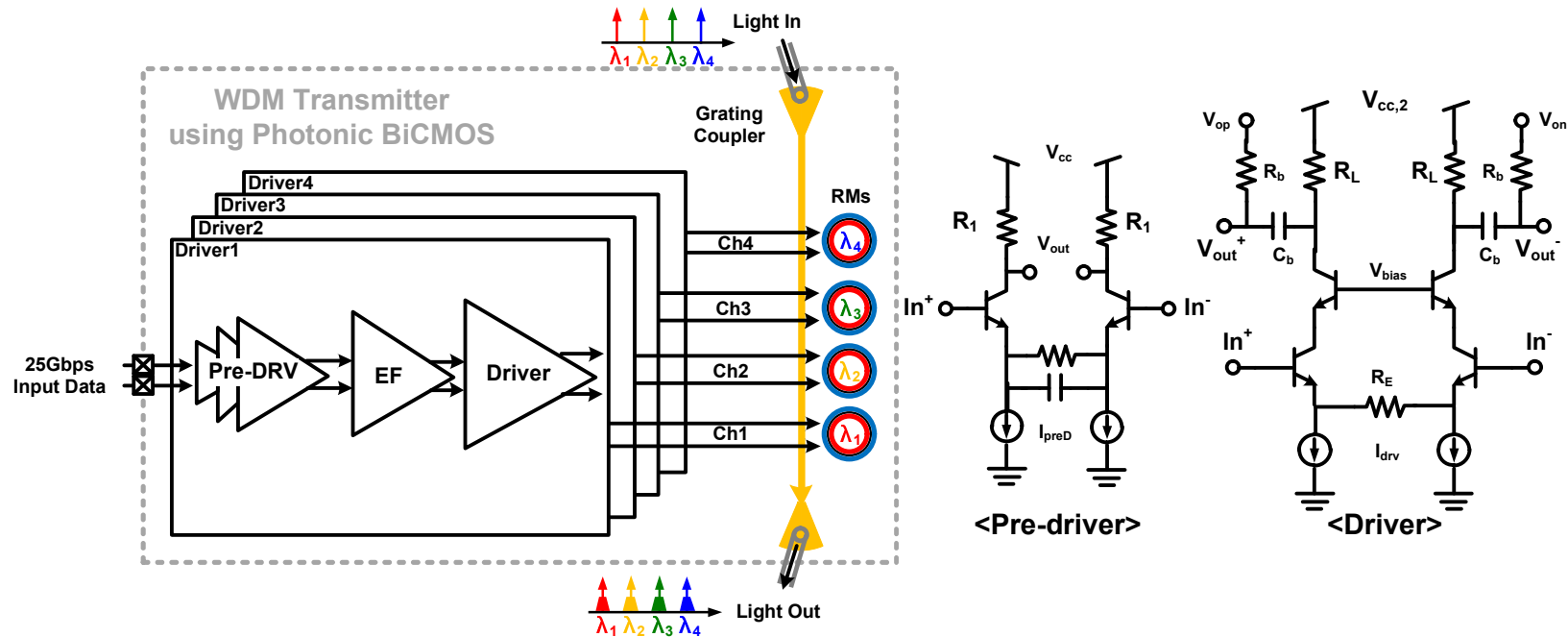


Monolithic integration of
Si photonic devices and
High-performance SiGe HBT



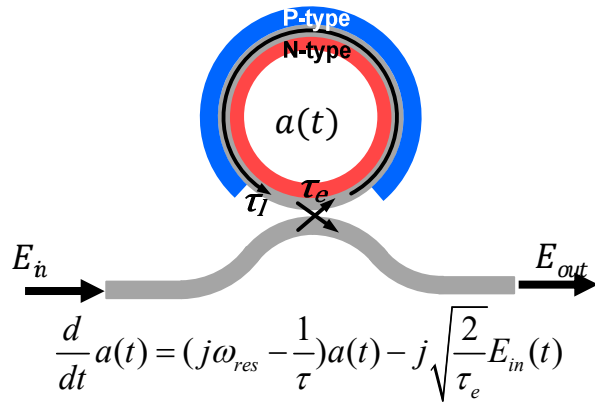
Monolithic Si Photonic WDM Transmitter

- 100Gbps (4 x 25 Gbps) Tx



- Accurate modelling of Si MRM
- Optimization of driver circuits by electronic-photonic co-simulation
- Temperature controller for Si MRM

Model Parameter Extraction



$$E_{out}(t) = E_{in}(t) - j\sqrt{\frac{2}{\tau_e}} a(t)$$

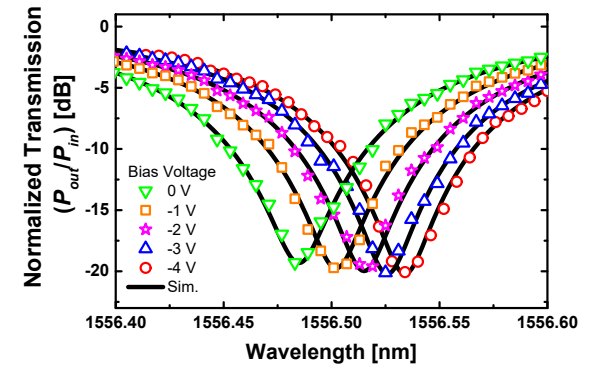
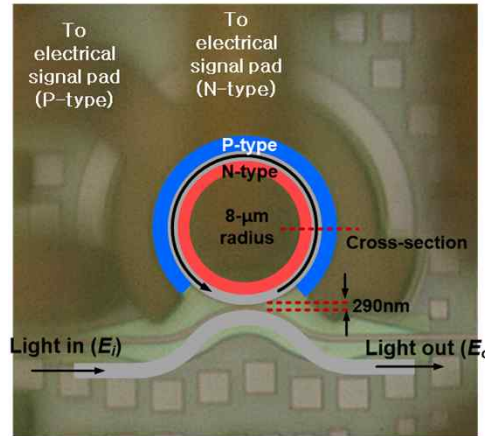
a : Optical energy amplitude in the ring

τ_l : Amplitude decay-time constant by round-trip
 τ_e : Amplitude decay-time constant by coupling

τ : Total amplitude decay-time constant ($\frac{1}{\tau} = \frac{1}{\tau_e} + \frac{1}{\tau_l}$)



$$Q_{Unloaded} = \frac{\omega_{res}\tau_l}{2}, Q_{Loaded} = \frac{\omega_{res}\tau}{2}$$



<Extracted parameters>

$$\frac{P_t}{P_i} = \left(\frac{E_t}{E_i} \right)^2 = \left(\frac{j(\omega - \omega_{res}) + \frac{2}{\tau_l} - \frac{1}{\tau}}{j(\omega - \omega_{res}) + \frac{1}{\tau}} \right)^2$$

V_{Bias} (V)	n_{eff}	τ_l (ps/rad)	τ (ps/rad)
0	2.632166	22.7239	12.8595
-1	2.632185	22.9560	12.9335
-2	2.632216	23.5576	13.1224
-3	2.632233	23.5578	13.1225
-4	2.632250	23.5579	13.1225

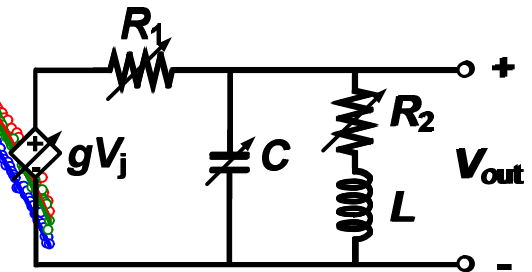
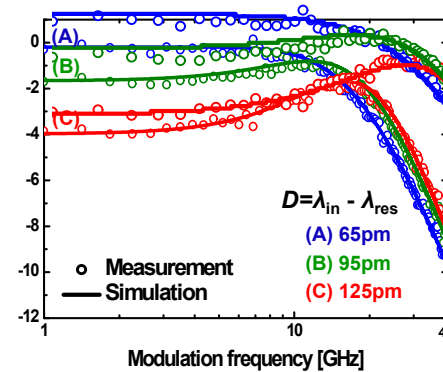
Equivalent Circuit SPICE Model for RM

$$\Delta_o(s) = \frac{P_{out}(s)}{V_j(s)} = G \cdot \frac{s + 2/\tau_1}{s^2 + (2/\tau)s + D^2 + 1/\tau^2}$$

<OIC, 2015>

$$\Rightarrow \frac{g}{C} \frac{s + \frac{R_2}{L}}{s^2 + \left(\frac{1}{CR_1} + \frac{R_2}{L}\right)s + \frac{1}{LC} \left(\frac{R_2}{R_1} + 1\right)}$$

Relative response [dB]



<Calculated RC Parameters for $D_\lambda=70\text{pm}$ >

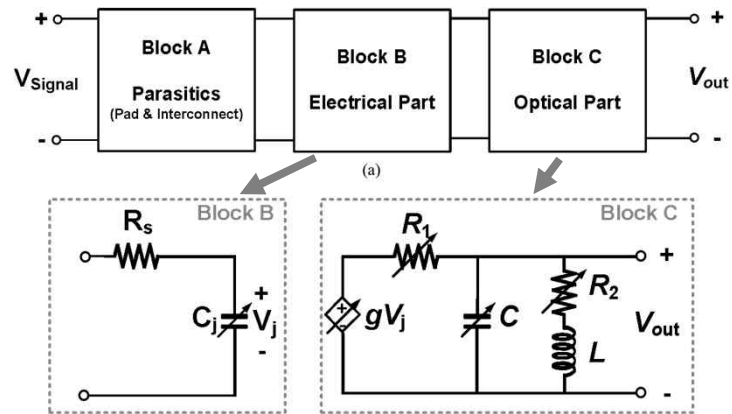
V_{Bias} (V)	R_1 (k Ω)	C (fF)	R_2 (k Ω)	L (nH)
0	2.07	7.14	10.00	114.41
-1	3.15	4.70	9.96	
-2	5.15	2.87	9.71	
-3	7.19	2.06	9.71	
-4	8.99	1.65	9.71	

```

*****Circuits*****
Evgain      mid  vss  VCVS  POLY(1) in  vss  2.91606e-1  1.46931137e-1  2.52937513e-2
Ivvar      mid  out  R='V(in)*V(in)*290 + V(in)*1569 + 3004'
Cvar       out  vss  C='V(in)*V(in)*9e-16 - V(in)*2e-15 + 4.0992e-15'  CTYPE=1
R2var      out  mid_ind R='V(in)*V(in)*50.767 + V(in)*253.93 + 10203'
Ll         mid_ind vss  114.413n

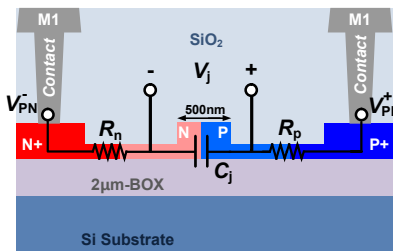
.option  finesim_deltmax=0.1p
.tran  0.1p  1u
    
```

Verification with Measurement Results

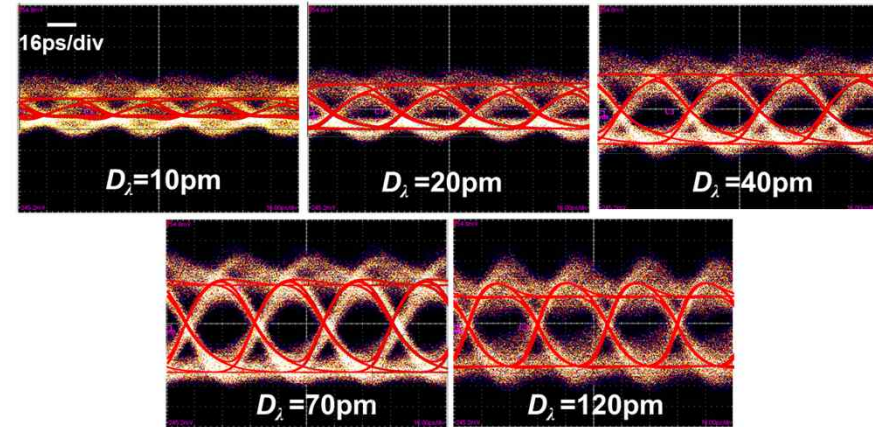


(b) <Extracted RC Parameters>

V_{Bias} (V)	R_s (Ω)	C_j (fF)
0	249	14.26
-1		10.95
-2		9.47
-3		8.55
-4		7.90



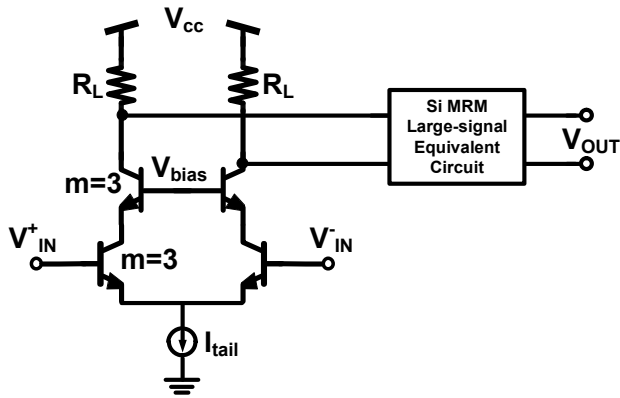
$$R_s = R_p + R_n$$



- ✓ $4V_{\text{peak-to-peak}}$ swing driving PRBS31, 25-Gbps
- ✓ Freq. response of Orx, oscilloscope included
- ✓ Simulated by Synopsys HSPICE
- ✓ Simulation time is 4.43s for 1-us transient (Verilog-A model: 980.25s)
 → 220 times faster!

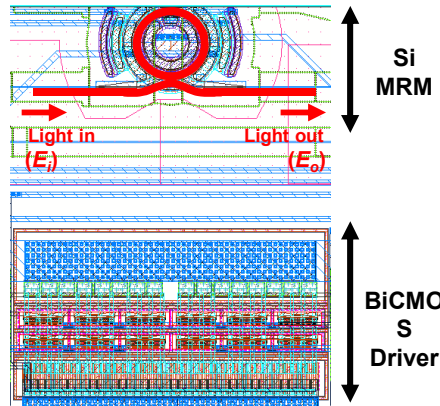
<Photonics Research, 2019>

Co-simulation with Driver IC

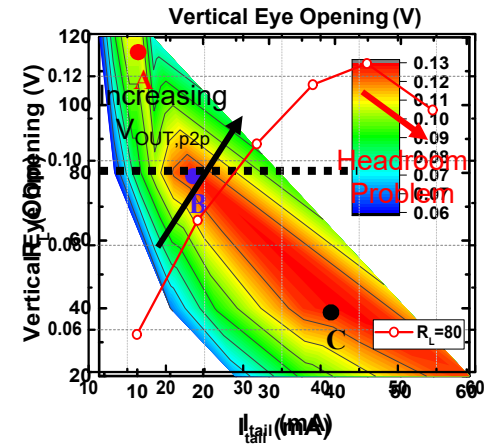


<Schematic of co-simulation>

A ($I_{tail} = 10.4mA$)

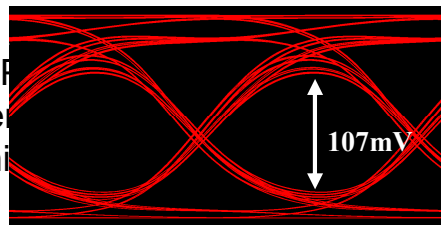


<Layout of transmitter>
B ($I_{tail} = 18.4mA$)

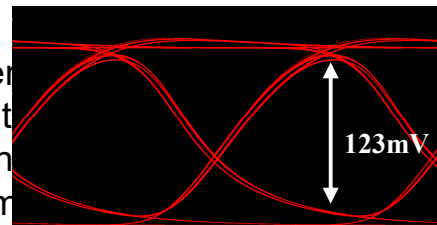


C ($I_{tail} = 41.3mA$)

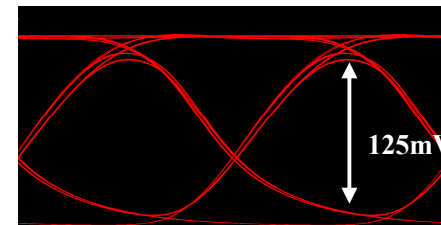
- ✓ IHP
- ✓ Differ
- for hi
- ✓ Size



Degradation due to large RC time constant



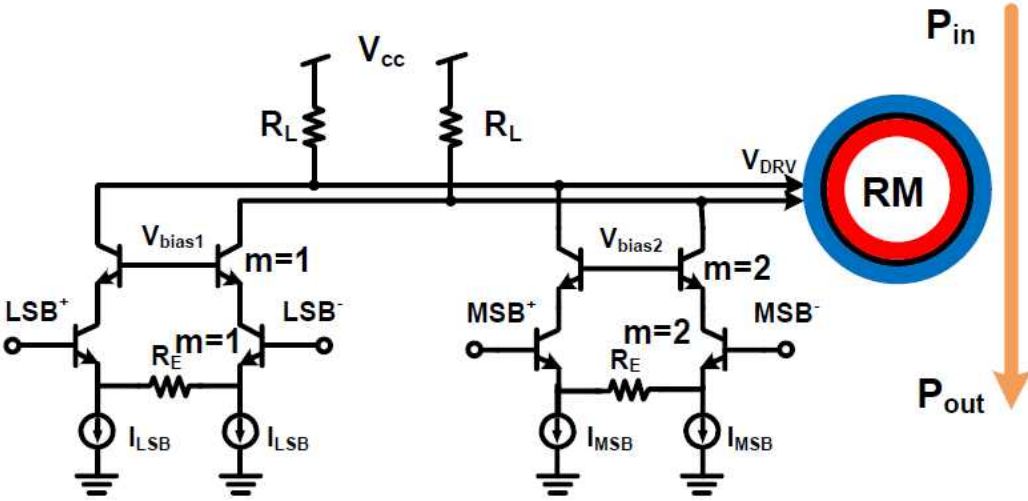
Large enough eye opening & smallest power consumption
(Optimum design)



Too much power consumption

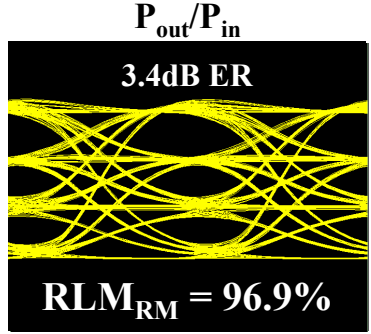
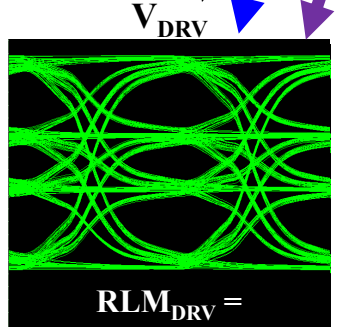
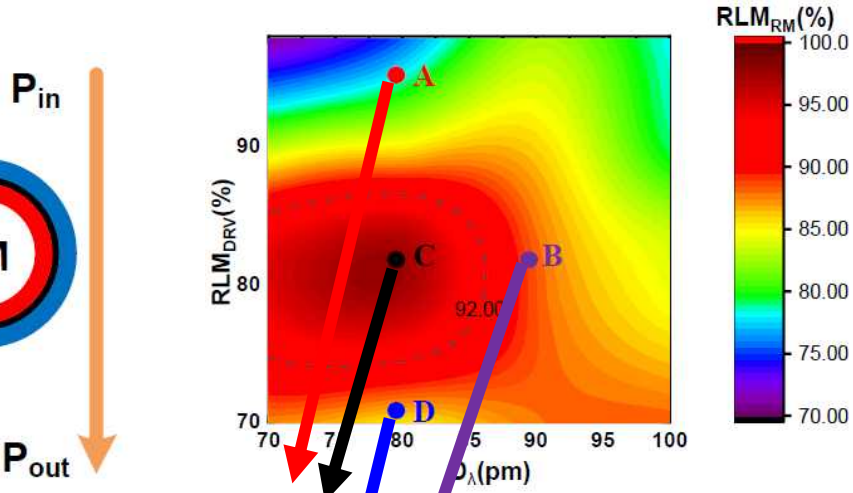
<OFC, 2018>

PAM-4 Signal Optimization with Co-simulation

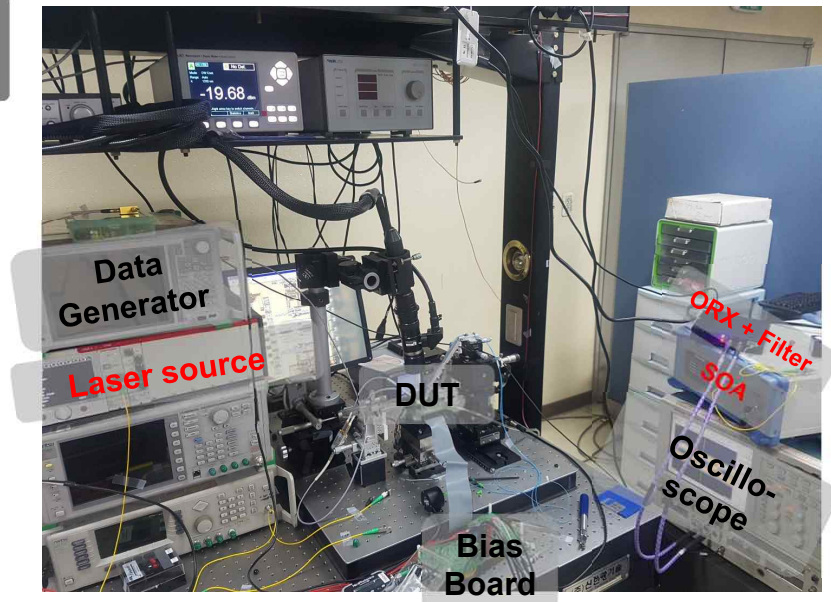
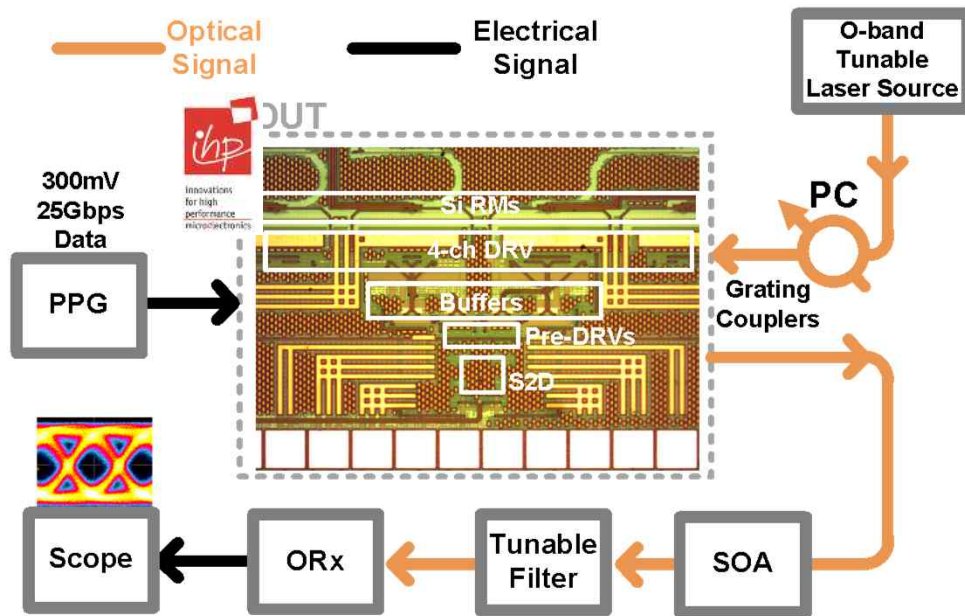


- ✓ IHP Photonic BiCMOS foundry service
- ✓ Differential cascode common-emitter structure with emitter degeneration employed
- ✓ PAM4 summation with different TR size

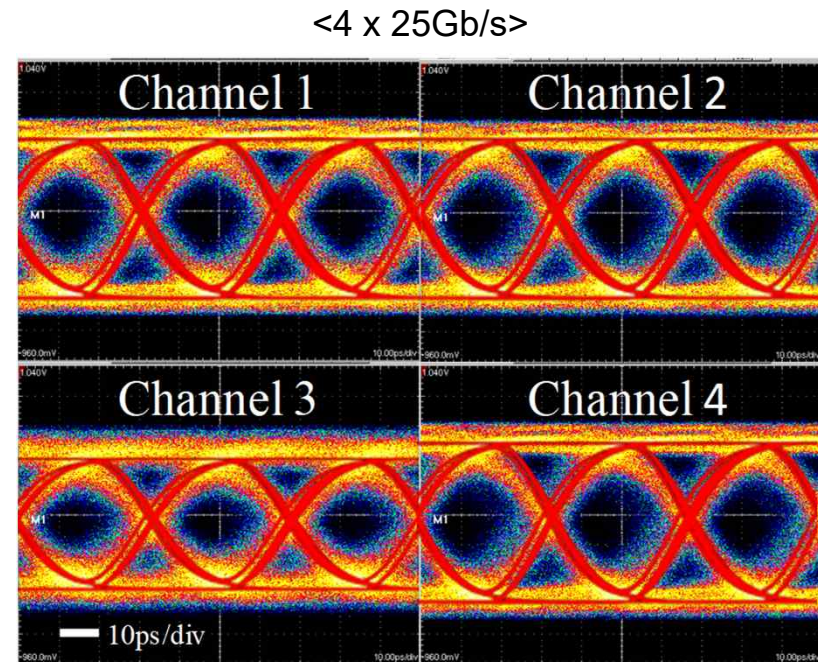
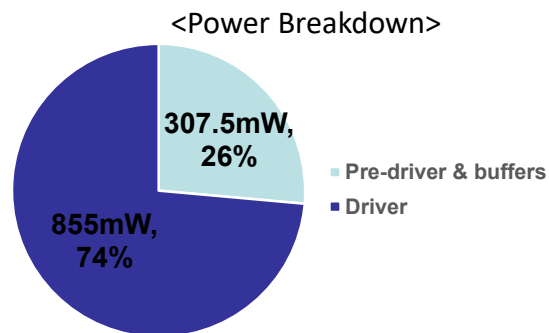
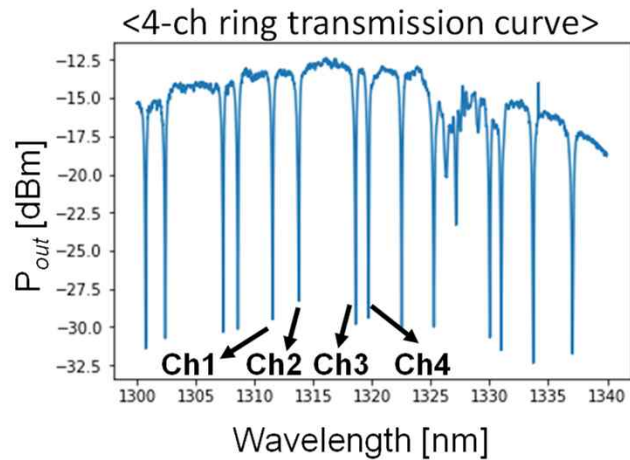
<Photonics Research, 2019>



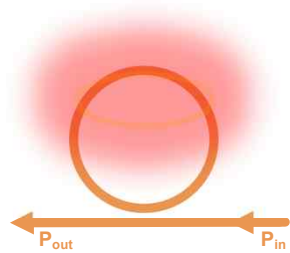
Measurement Setup



Measurement Results

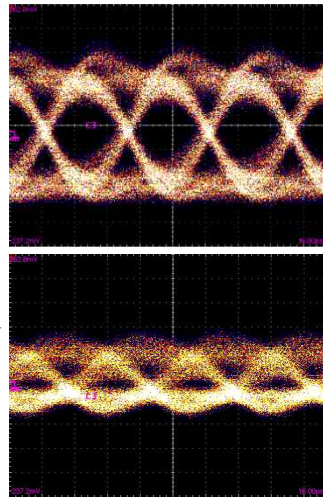
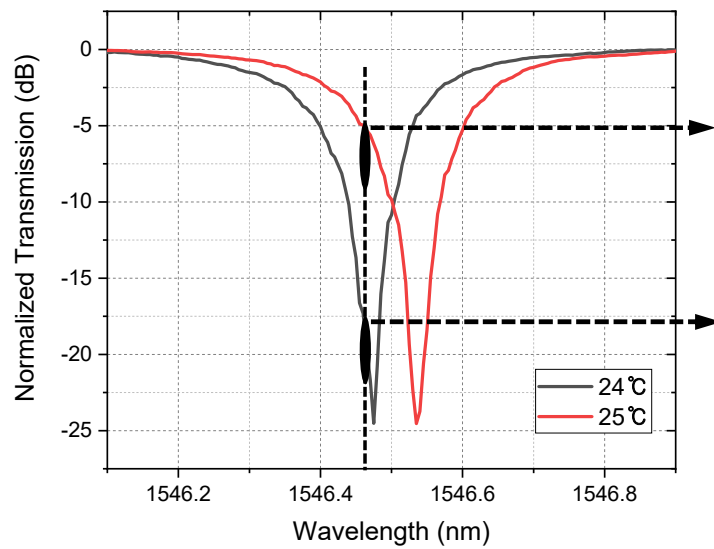


Temperature Sensitivity of Si RM

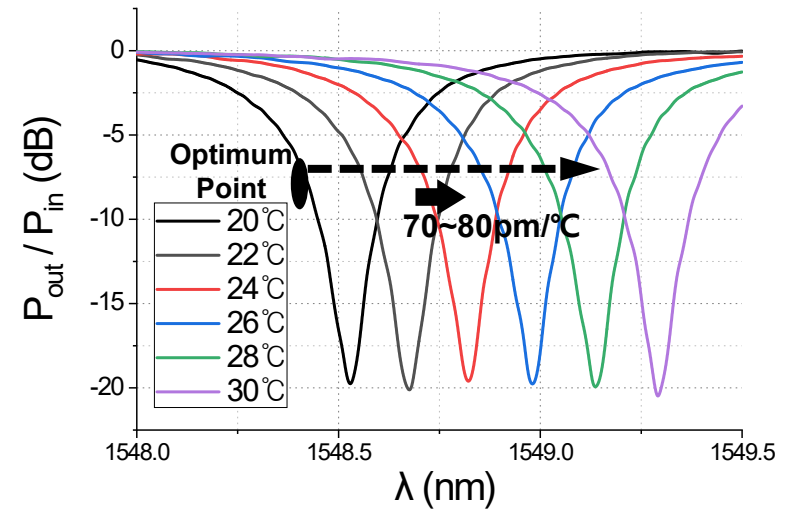


$$\lambda_{res} = \frac{2\pi r \cdot \eta}{m c}$$

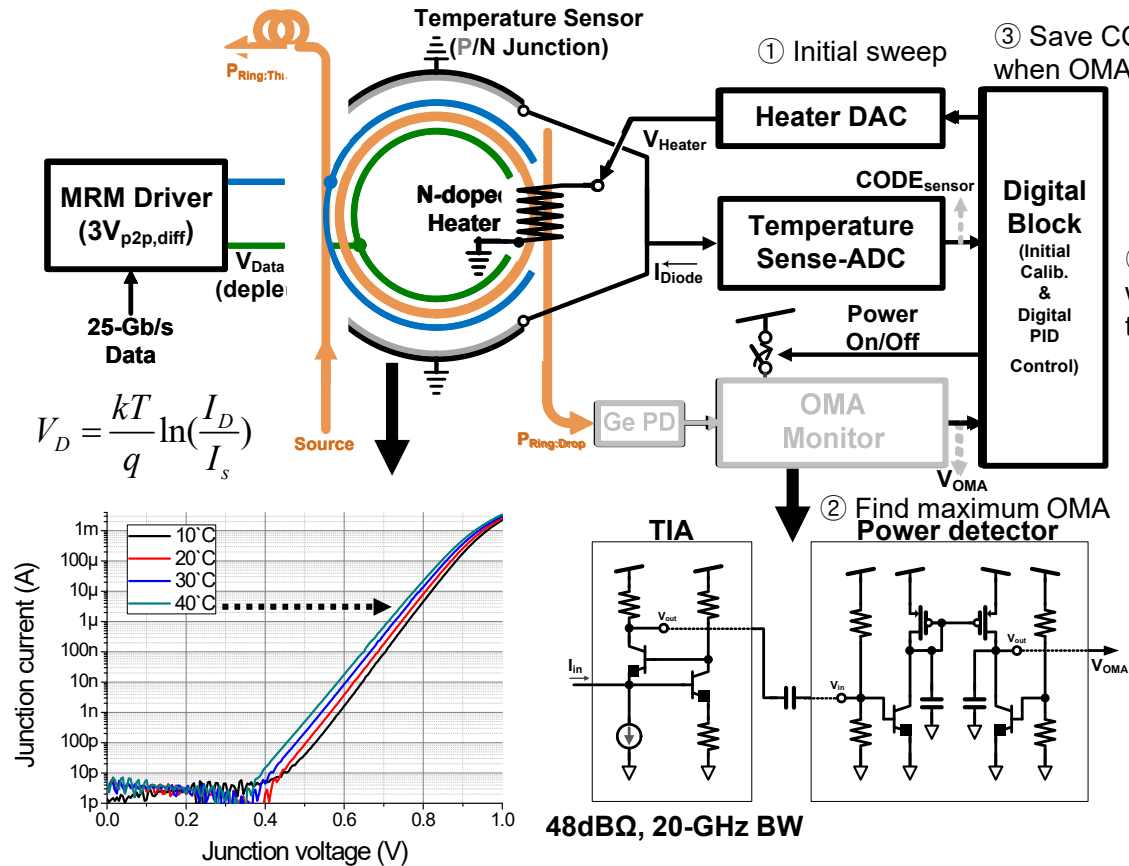
Temperature increase
 → Index increase
 → Resonance λ increase



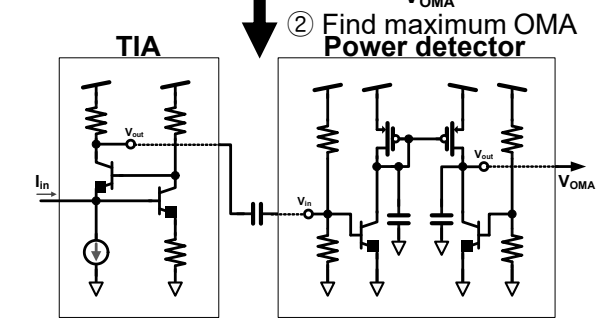
25Gb/s Modulation



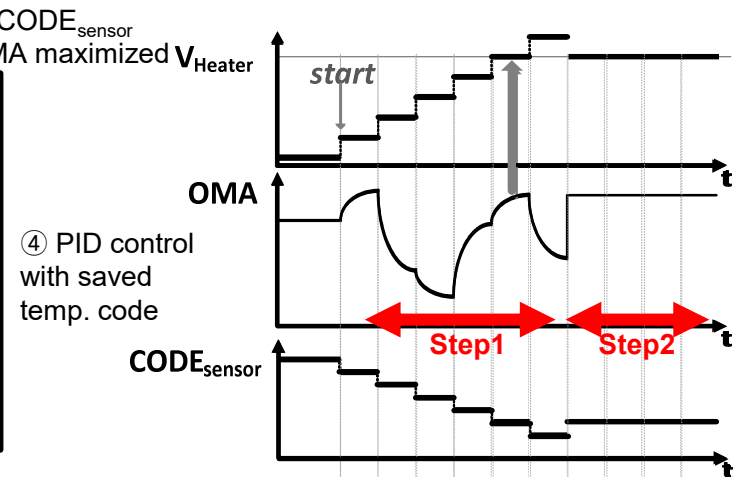
Temperature Control with Temp. Sensor



$$V_D = \frac{kT}{q} \ln\left(\frac{I_D}{I_s}\right)$$

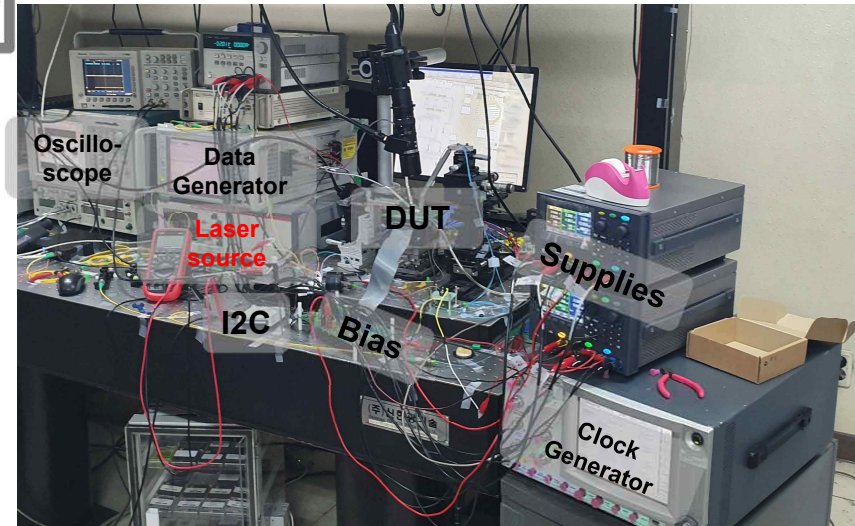
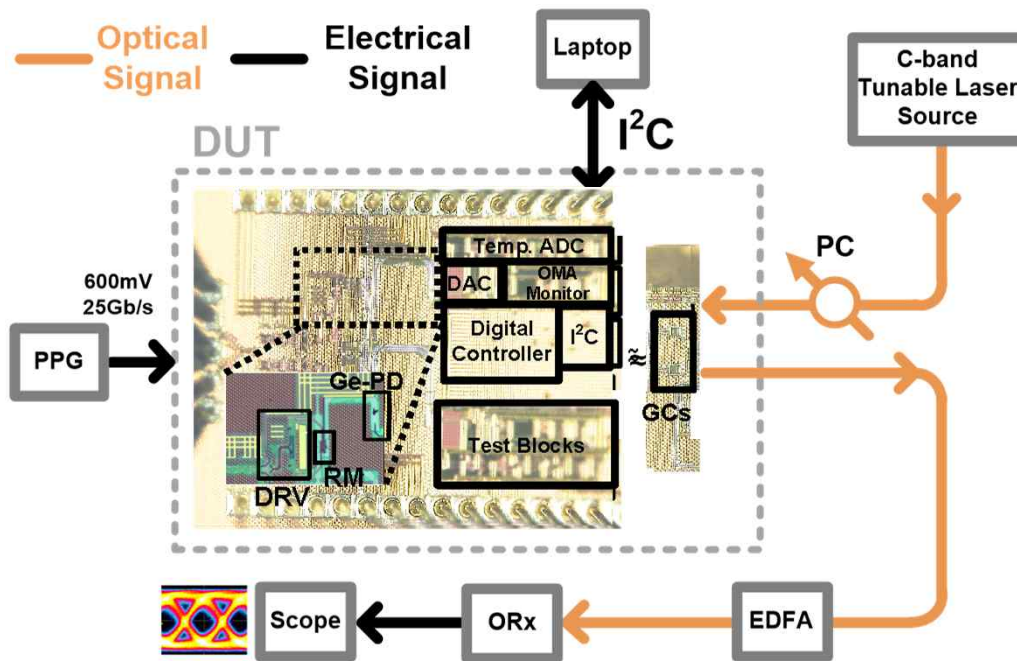


48dBΩ, 20-GHz BW

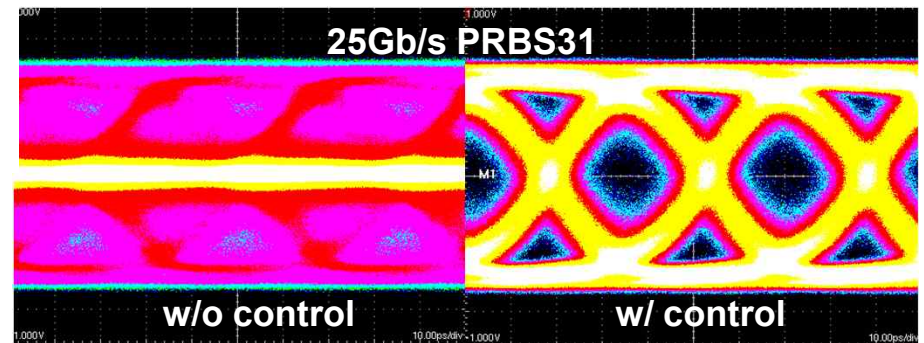
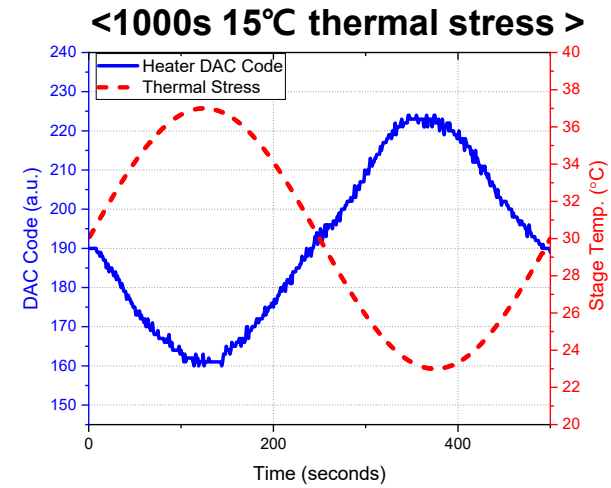
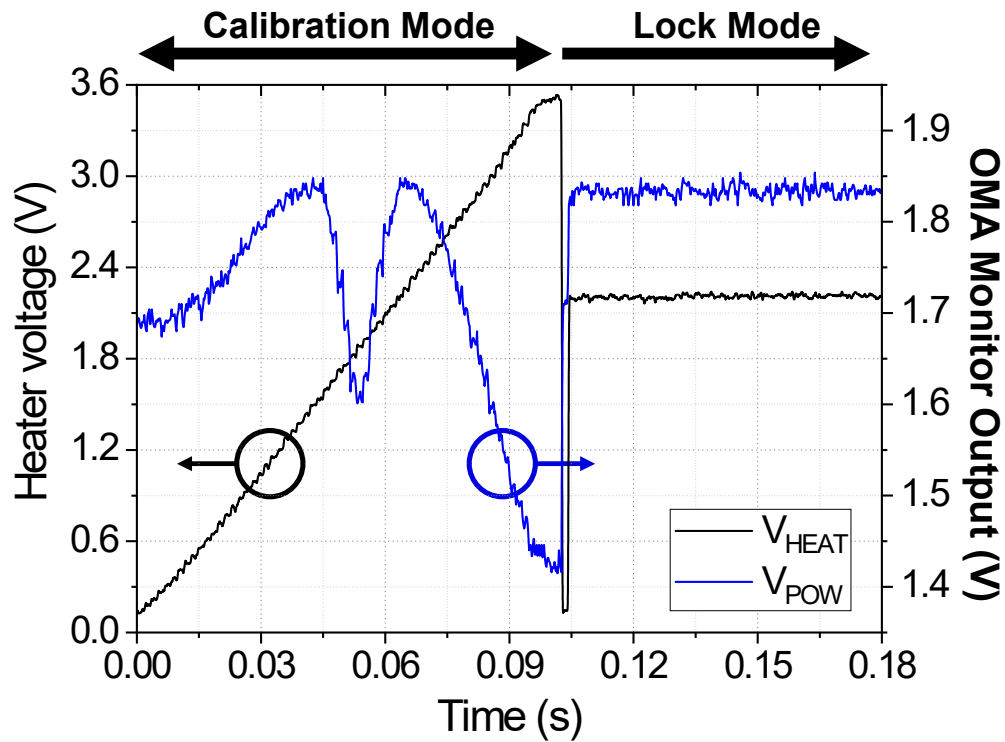


- ✓ Temp. control with two steps
 - Step1 (Calibration Mode)
 - :Initial sweep (Find optimum CODE_{sensor} and save it)
 - Step2 (Lock Mode)
 - :PID control to maintain CODE_{sensor}
- ✓ Decouple OMA monitor power when Lock Mode

Measurement Setup



Measurement Results



Performance Comparison

	15' JSSC	18' ISSCC	16' JSSC	16' JSSC	19' JLT	<i>This Work</i>
Process	130nm SOI SiPh + 65nm CMOS	100nm SOI SiPh + 65nm CMOS	130nm SOI SiPh + 40nm CMOS	45nm CMOS SOI	0.25μm BiCMOS	0.25μm Photonic BiCMOS
Wavelength	1550 nm	1310 nm	1550nm	1180 nm	1550 nm	1550nm
Demo. data-rate	25 Gb/s	10 Gb/s	2 Gb/s	5 Gb/s	25 Gb/s	25Gb/s
Driver Integration	○ (Wire-bonded)	○ (3D face-to-face)	○ (Wire-bonded)	○ (Monolithic)	X	○ (Monolithic)
Controller Integration	X (Off-chip PD)	○ (3D face-to-face)	X (Off-chip DAC)	○ (Monolithic)	X (Off-chip PD)	○ (Monolithic)
Scheme	Average Power	Analog closed-loop w/ digital reconfig.	OMA monitor w/ slope quantization	Bit-statistics	OMA monitor w/ power detector & wo-step approach	OMA monitor w/ Temp. sensing & PID control
Manual Reference Setting	○	○	X	X	X	X
Resonance wavelength tuning range	N/A	N/A	5 nm	2.5 nm	0.55 nm	3.27 nm
Controller Power	0.17 mW	0.15mW	2.9 mW	0.72 mW	3.91 mW	3.325 mW
Energy efficiency	0.0068 pJ/bit	0.015 pJ/bit	1.45 pJ/bit	0.144 pJ/bit	0.1564 pJ/bit	0.133 pJ/bit

✓ *Monolithic, high data-rate, and energy-efficient*

<OFC, 2020>

<Photonics Research, 2021>

Summary

- **Importance of Si Photonics for Data Center Connectivity**
 - Co-Packaged Optics requires
Large bandwidth, Energy efficiency, Size efficiency
 - For Tx, Si MRM is most promising
 - Lots of active R&D efforts for Si MRM based photonic integrated circuits and systems
- **At Yonsei**
 - Based on IHP's Photonic BiCMOS technology
 - 100 Gbps (25 Gbps x 4 λ') Si MRM EPIC solution with built-in temperature controller achieved
- **For successful photonic I/O R&D, expertise both in photonics and electronics needed**