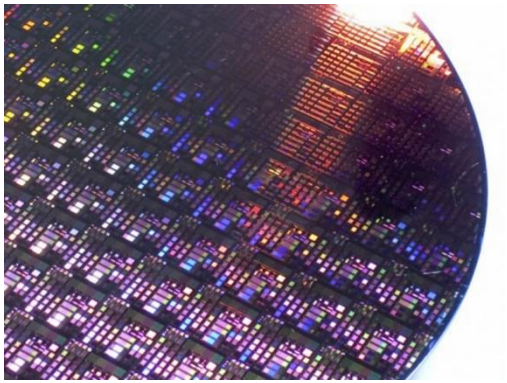
Optical Interconnects with Silicon Photonics

Photonics

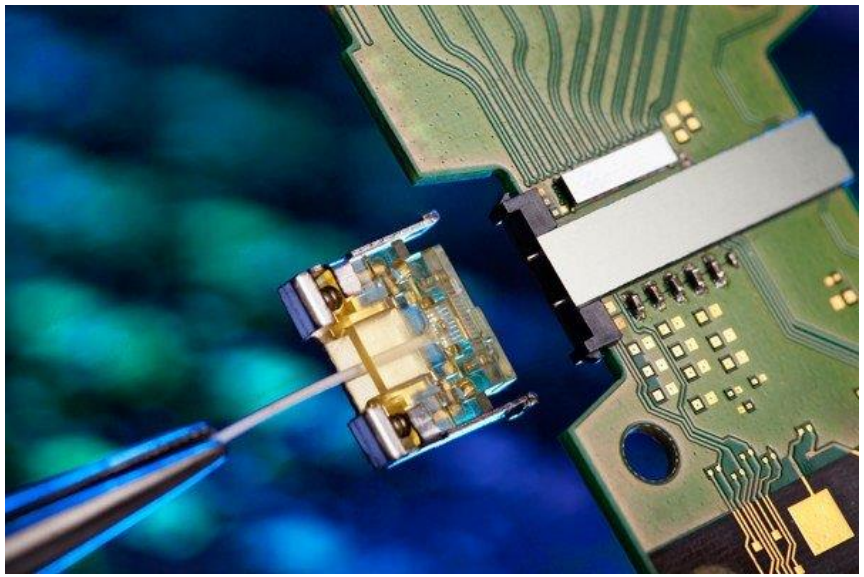
No BW limit in fiber ➔ High-speed

Si Electronics



Mature technology ➔ High-volume w/ low-cost

Si Photonics



Intel

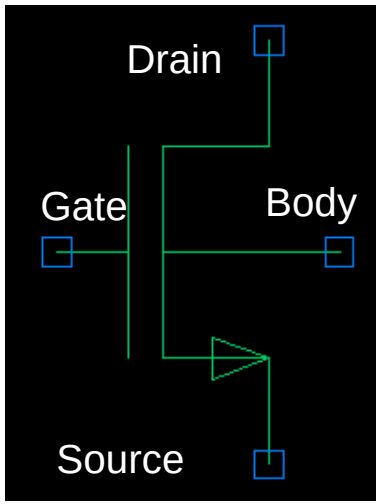
High-speed & cost-efficient technology

Equivalent Circuit Model for Photonic Devices

Layout Information

PDK

N-MOSFET in 28nm CMOS



115 Model Parameters

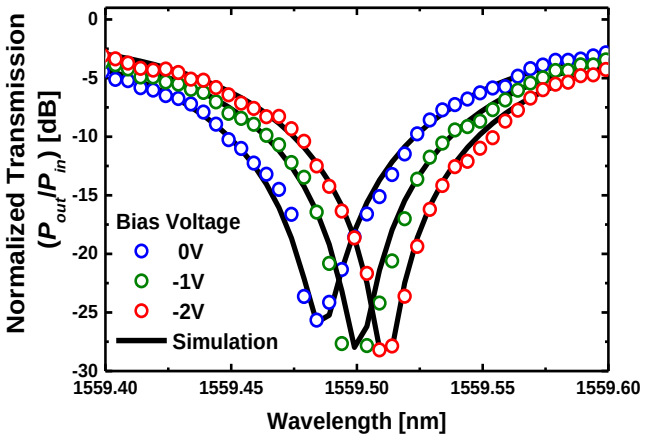
```
********** nfet **********
.model  nfet  nmos level=69 version=103.1
+ agidlw=2.18e-006          alpl2=3.008677          alpllexp=0.4904
+ alp2l2=1.506e-005         alp2lexp=0.6779         alplexp=0.018
+ alpw=0.05                 axl=0.1442              axo=5.953
+ bgidlo=12.5               cbbtbot=0               cbbtgat=1e-016
+ cbbtsti=0                 cfbo=0.35               cfw=-0.023919
+ cgidlo=0.7538             chibo=3.192             csl=1.122
+ cslexp=0.02076            cso=1.0967              csrhbot=110400
+ csrhgat=0.0509            csrhsti=0.02466         csw=-2e-012
+ ctatbot=0                 ctatgat=0.005012        ctatsti=0
+ ctlw=-0.0002              cto=0.11                dphibl=-2.9708e-009
+ dphiblexp=3.9715          dphibo=-0.042261        dvsbnudo=0.39
+ efo=1.9                   epsroxo=5               fbbtrgat=7.439e008
+ fbetl=7.95                fbet2=-3.011            fetao=1.8508
+ fol1=0.016081             fol2=2.1312e-005        gc2o=1.167
+ gc3o=3.287e-005           gcoo=1.897              gfacnudl=-0.00185
+ gfacnudlexp=1.6           gfacnudlw=0.00075       gfacnudw=-0.018
+ idsatrbot=3.6e-007        idsatrgat=1e-015        kuo=-4.5e-008
+ kvtho=-7.5e-008           lintnoi=-7e-009         lkuo=5e-007
+ lkvtho=0.2                llodkuo=1               llodvth=0.3
+ lp1=1.1481e-008           lp2=2.4e-008            lpck=1.5839e-009
+ meffatgat=0.1             mueo=0.01691            novo=7.5e026
+ npck=4.64e022             npckw=0.1649            npo=1e028
+ nsubo=9.53626023          nsubw=6.778e-5          pbot=0.4878
+ pgat=0.5597               phigbot=1.12            phiggat=0.8598
+ phigsti=0.8815            psti=0.9                saref=1.5e-006
+ sbref=1.5e-006            scref=2.5e-006          stbetl=-0.015
+ stbeto=1.189              stbgidlo=-0.0018        stigo=0
+ strso=0                   stthemuo=0              stthesatl=0.0106
+ stthesatlw=-0.0001        stthesato=0             stvfbi=3.3e-006
+ stvfblw=1e-7              stvfbo=0.0003           swgidl=1
+ swigate=1                 swjuncap=5              swjunexp=1
+ swnud=2                   themuo=1.6281           thesatbo=1.5
+ thesatgo=0.4              thesatl=0.46            thesatlexp=0.84
+ thesato=0.3               tr=25                   trj=25
+ vbirbot=0.8019            vbirgat=0.719           vbirsti=0.68
+ vfbo=-0.951               vpo=0.008551            web=3000000
+ wec=1000000               wkvtho=2.5e-005         wlodvth=1
+ wot=-7e-009               wsegp=8e-009            xcorl=-0.0208
+ xcoro=0.099774
```

- Device models very important
- Model for electronics is accurate ➔ But, no model for photonics devices

Large-signal Equiv. Circuit Model for Ring Modulator

2018 OFC, 2019 PR

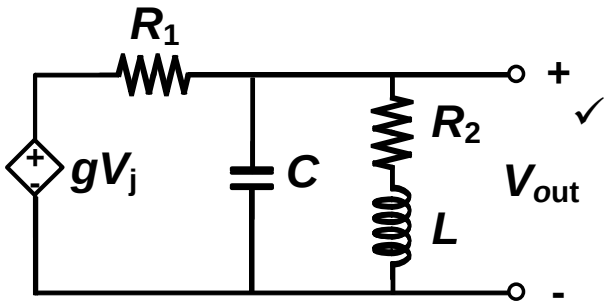
<Measured Transmission Curve>



✓ n_{eff}, τ_l, τ extracted

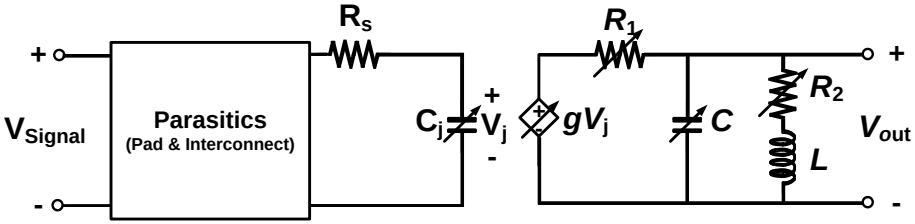
+ D
(Detuning)

<Small-signal Equivalent Circuit>



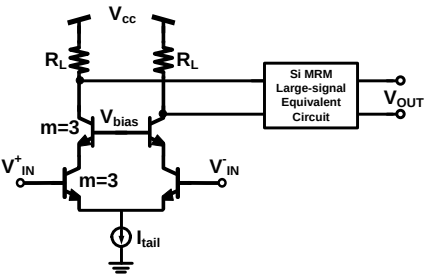
✓ n_{eff}, τ_l, τ, D determine RLC values

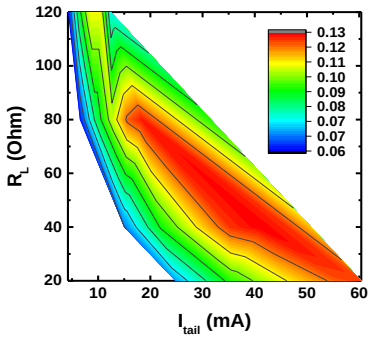
<Large-signal Equivalent Circuit>



✓ Non-linear voltage-dependent elements achieved with SPICE model

<Large-signal Equivalent Circuit>

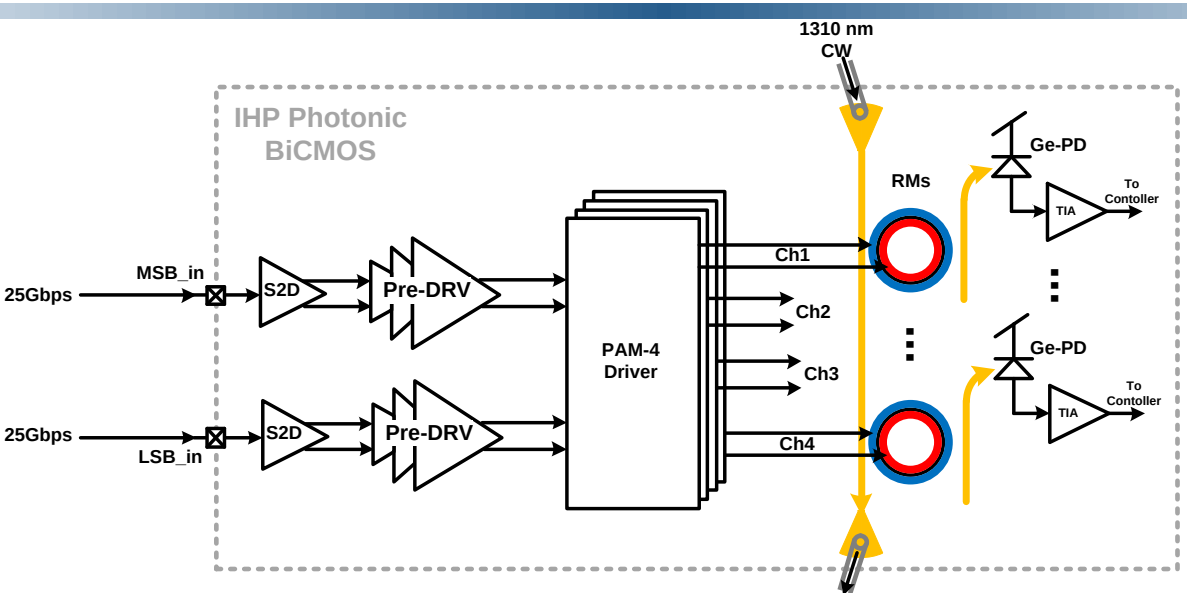




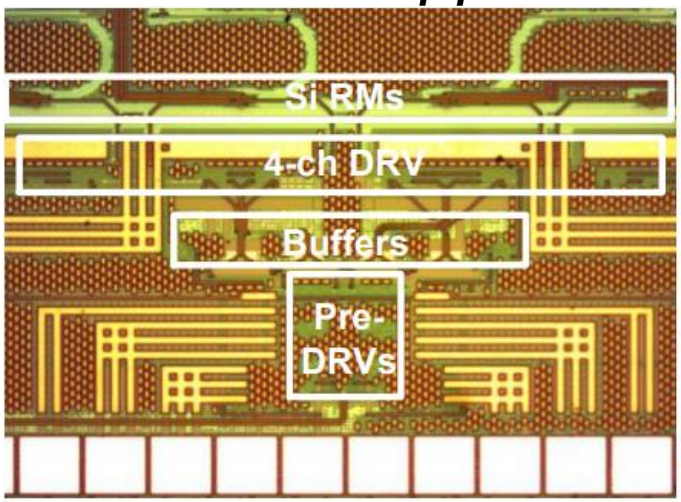
✓ Co-simulation & design optimization

Photonic BiCMOS WDM Transmitter

2019 OIC



Fabricated chip photo



Measured 4x25Gbps Eye-diagram