Photonic Integrated Circuits and VCSELs for Communication and Sensing

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UC SANTA BARBARA engineering

Optical Frequency Synthesizer Using Heterodyne Optical Phase-locked Loop

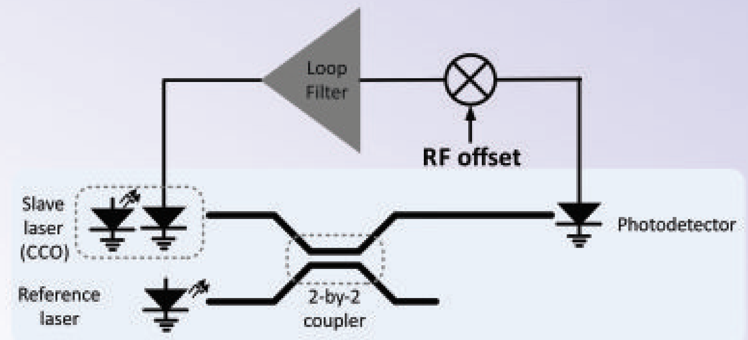
Why OPLL?

→ Solves laser linewidth problem

→ Sub-Hz-level accuracy wavelength synthesis possible

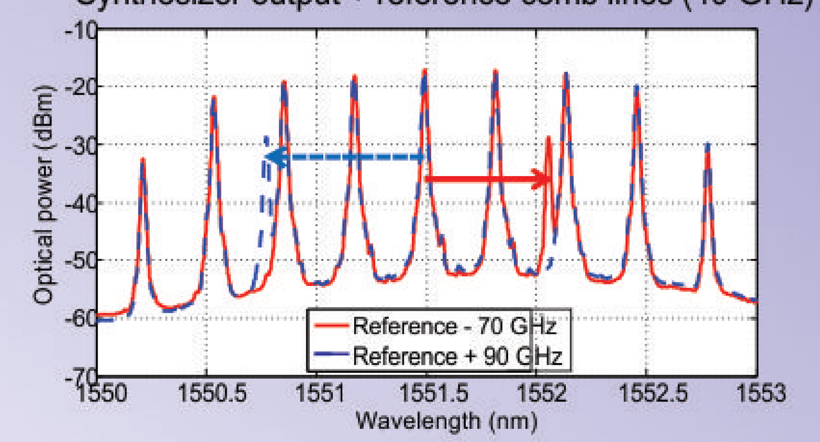
→ Homodyne or heterodyne coherent receiver

→ Advanced sensing and imaging system



Schematic of heterodyne OPLLs with a electronic mixer at the electronics part to introduce the frequency offset.

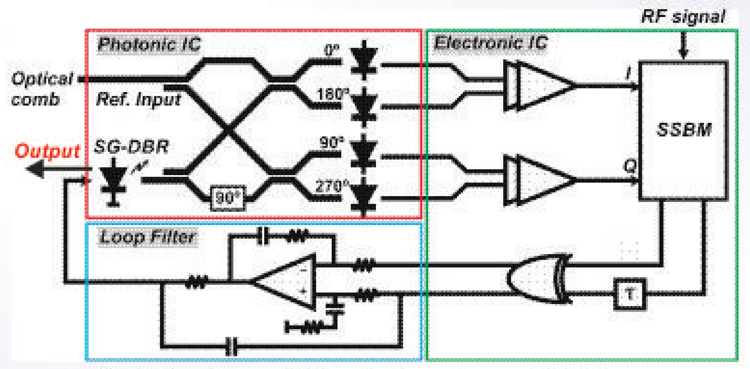
Synthesizer output + reference comb lines (40 GHz)



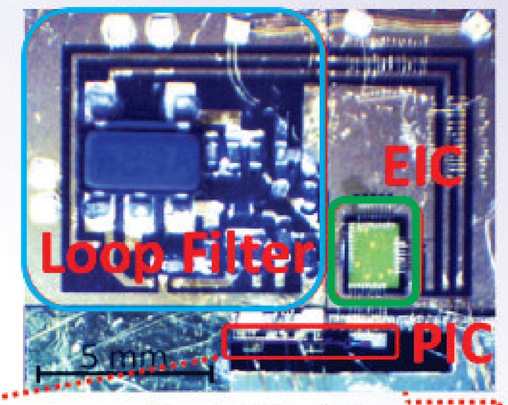
Output tuned relative to central comb line

Prior OPLLs
→ bulky bench-top systems,
→ non-application suited

Photonic integration provides
revolutionary systems improvements and simplifications
- small footprint
- low cost
- low power consumption
- improved reliability

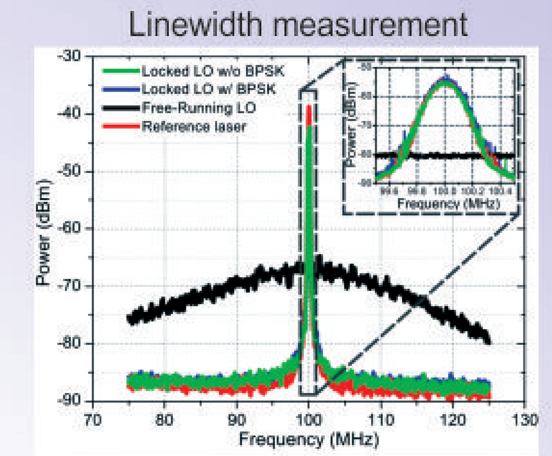


Architecture of the heterodyne OPLL



A microscope picture of the heterodyne OPLL device, showing PIC, EIC and loop filter

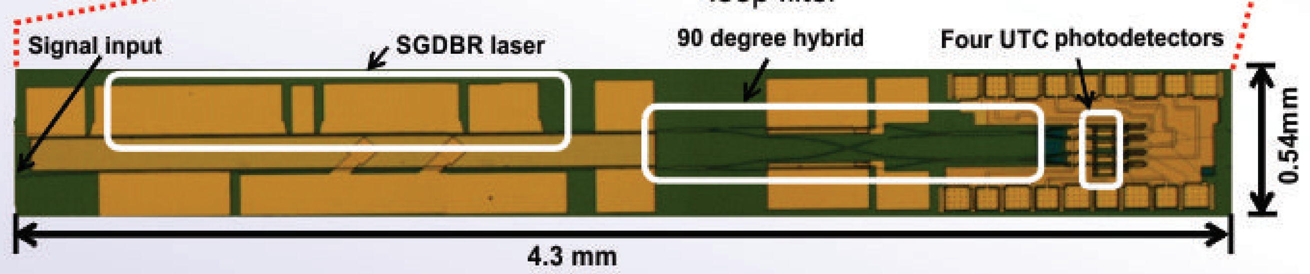
Linewidth measurement



Linewidth of input comb line duplicated

Potential applications of Optical Frequency Synthesizer (OFS)

→ Multiple optical coherent sources
→ Coherent sensing, and LIDAR
→ Optical instrumentation



Microscope image of the fabricated PIC used for optical synthesizer

→ Very low phase noise : < 0.03 rad² - phase error variance
→ ~ 500 MHz loop bandwidth
→ ± 25 GHz offset-locking capture range
→ 160 GHz output frequency sweep range demonstrated
- Hz level relative accuracy

Phase Sensitive Amplifier

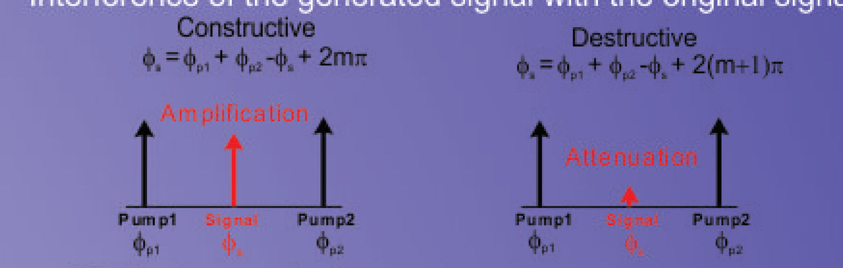
Phase sensitive amplifier (PSA) :
→ Provides <3 dB noise figure
→ Theoretically possible:
- noise free amplification
- noise figure of 0 dB
→ Significant improvement of the performance of optical links

→ Previously demonstrated PSAs
- bulky bench-top systems,
- non-application suited

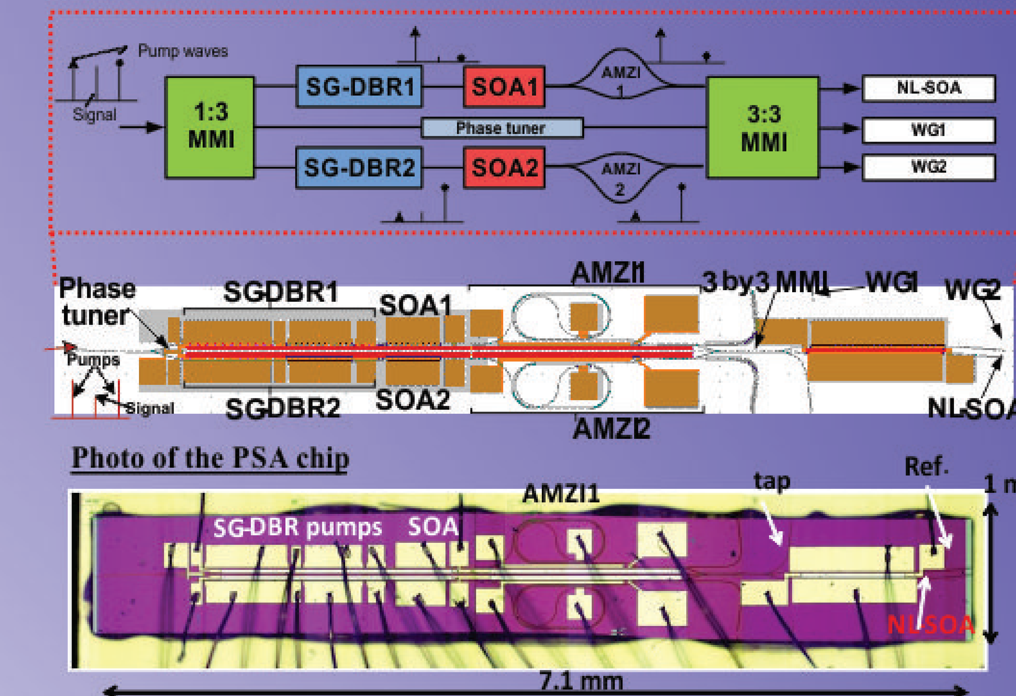
Bench-top system

→ Photonic integration for PSAs
- Smaller size, weight, lower power consumption
- Improved power & phase stability
- Reduced coupling losses
- Less susceptible to environmental influences
- Batch fabrication economies
- Improved reliability
- Improved optical alignment, immunity to vibration

Interference of the generated signal with the original signal:

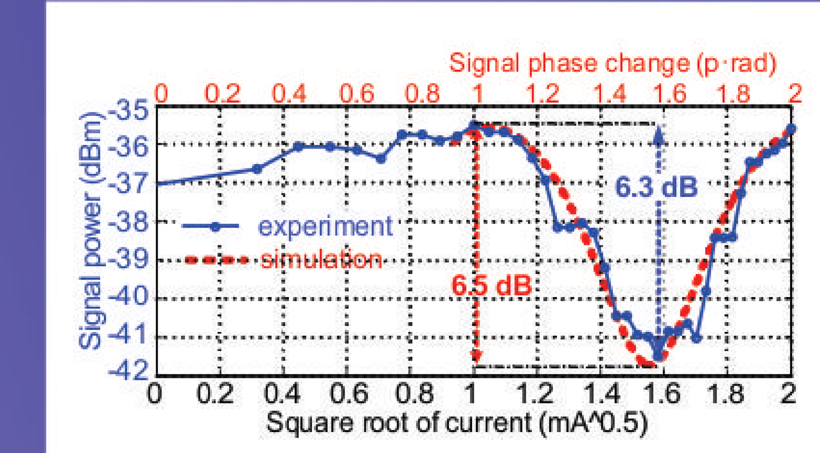


→ PSA gain π periodic
→ Amplifies one of the two quadrature phase components and attenuates the other

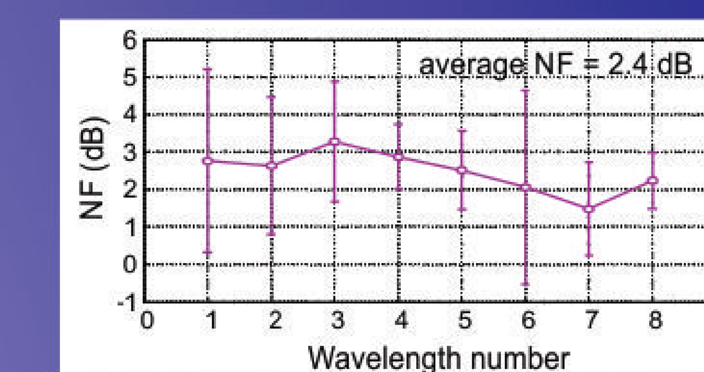


Schematic, mask layout and fabricated dual-pumped PSA chip.

→ PSA chip on InP/InGaAsP platform
→ Generation of two tunable laser pumps coherently injection-locked from sidebands of an external modulated tone
→ Dual-pumped phase-sensitive amplification in a highly saturated semiconductor optical amplifier



Comparisons between measured PSA gain curve and the theoretical simulation



Calculated noise figure

→ Results are in good agreement with the theory
→ Phase-sensitive amplification experimentally achieved
→ Measured phase-sensitive on-chip gain ~6.3 dB
→ Measured averaged noise figures ~ 2.4 dB

Two-Dimensional Optical Beam Steering

Electronically controlled optical beam steering potentially useful for:

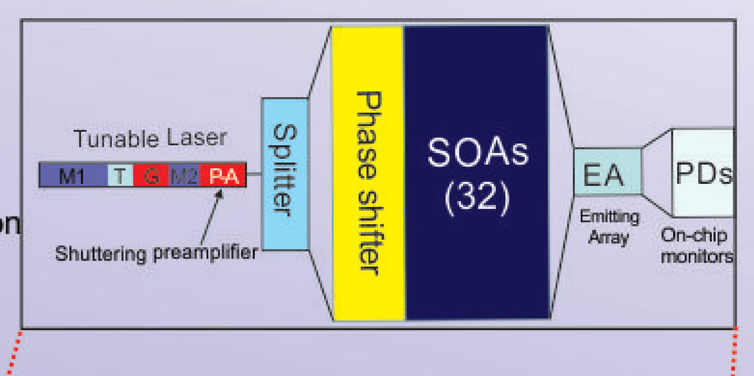
→ Laser secure communication
- Tracking and high speed communication at the same time

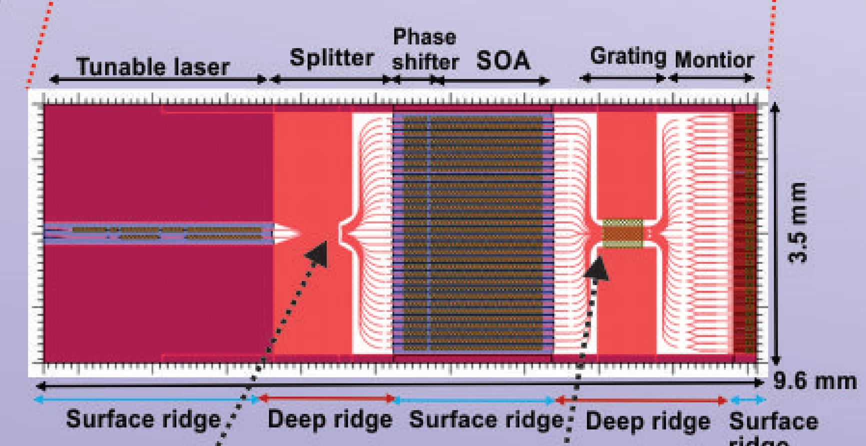
→ LIDAR (RADAR with light)
- Active Electronically Scanned Array
- 3D imaging

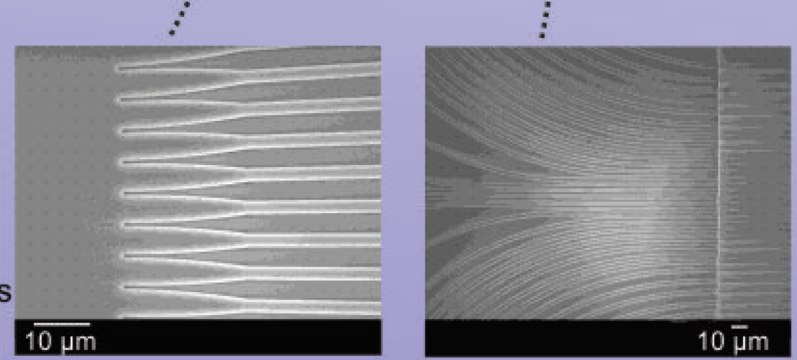
Our approach: 1D array + grating
→ Lateral beam-steering via phase-shifter array

→ Longitudinal beam-steering via wavelength-tuned grating diffraction

InP PIC with:
→ on-chip widely tunable laser
→ 1D optical phased array
→ grating surface emitters
→ larger scale of integration, 32 channels
→ simple layout: star coupler splitter; unequally spaced grating emitters







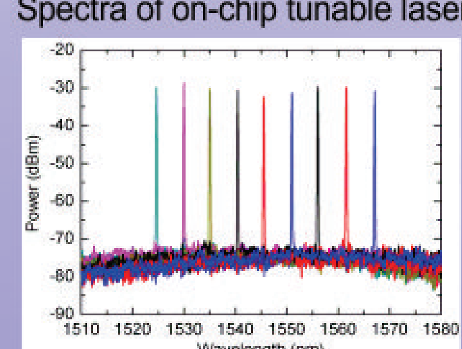
Schematic (top) and mask layout (middle) of the PIC. SEM images of waveguide feeds from splitter and into grating arrays (bottom)

Google driverless car

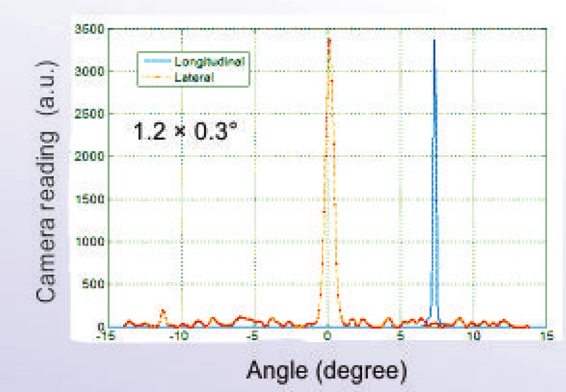
F22

Google car uses rotating laser; arrays with no moving parts needed

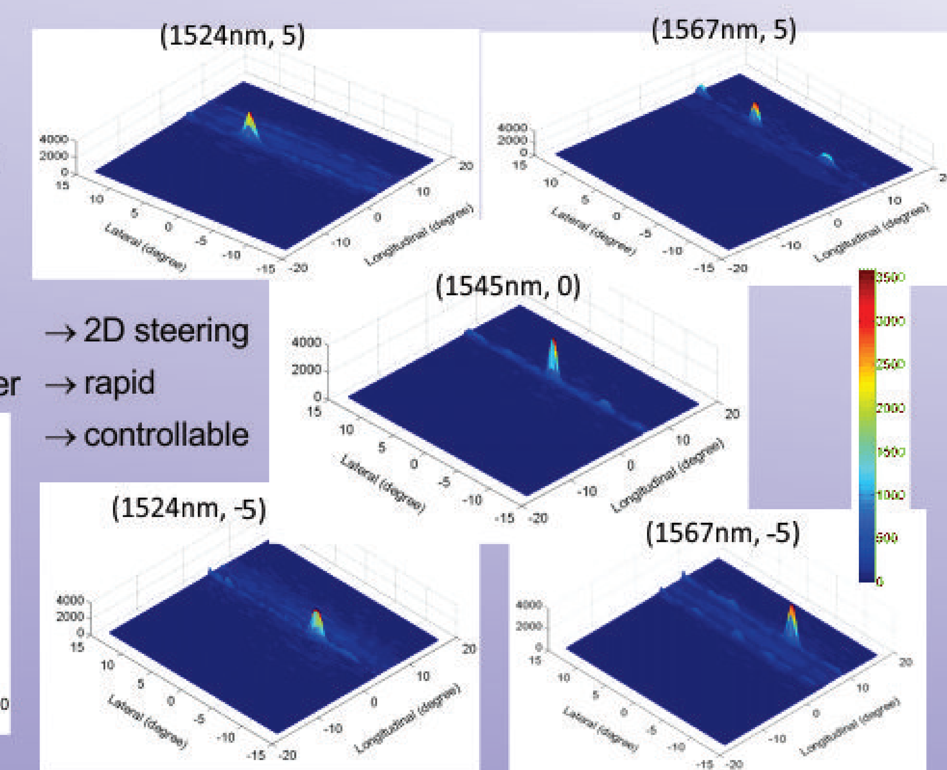
Spectra of on-chip tunable laser



→ Super modes of tunable laser
→ Tuning range >40 nm



Far-field distribution in the lateral and longitudinal direction



→ 2D steering
→ rapid
→ controllable

Three-dimensional plot of the far-field patterns for some critical angles in the 2D plane.

Polarization Modulation of VCSELs

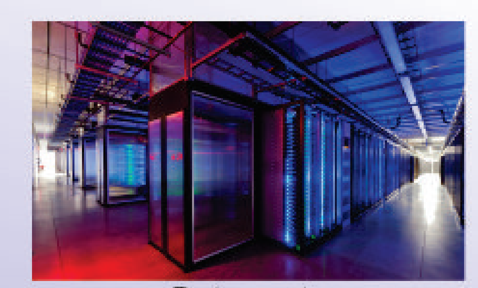
→ Study of a novel technique for high-speed polarization modulation in VCSELs

→ Effectively doubles the data rate through polarization modulation

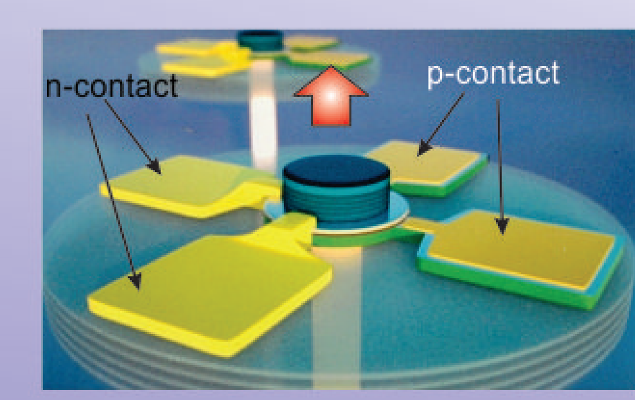
→ Electrical RF frequency applied for such modulation

→ Direction of lateral current injection determines polarization mode

→ Suitable for optical data communication

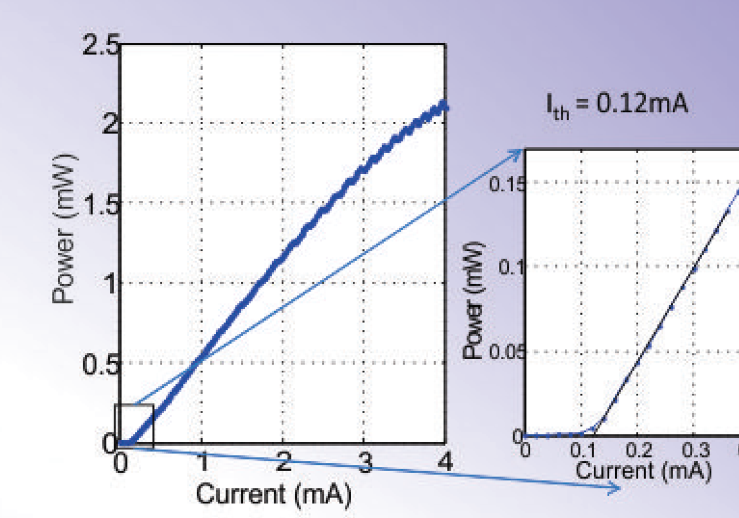


Data center

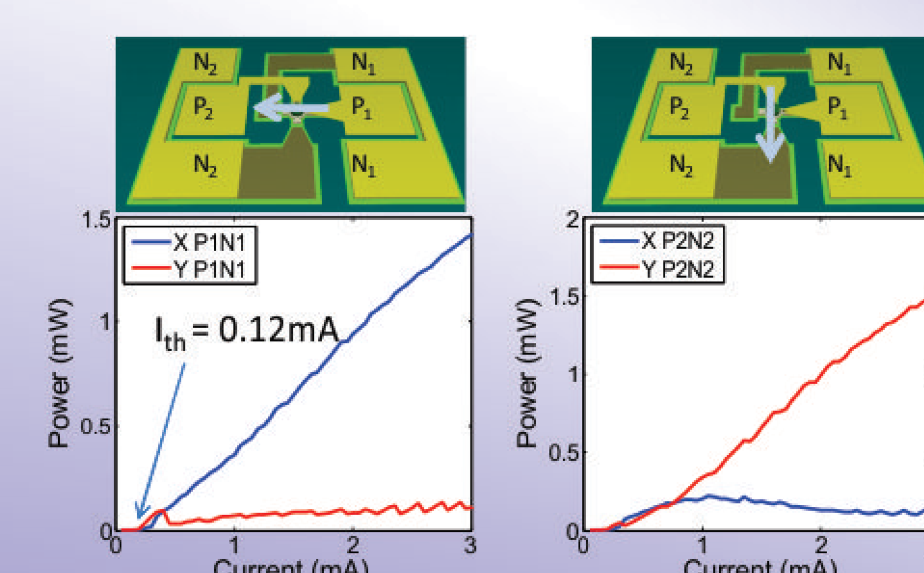


Schematic view of VCSELs with asymmetric current injection for electrically-controlled polarization modulation

Static characteristics

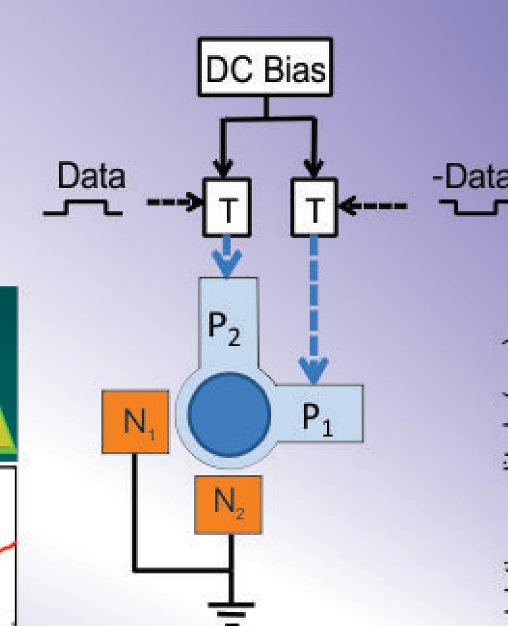


Light-current (*L-I*) characteristics



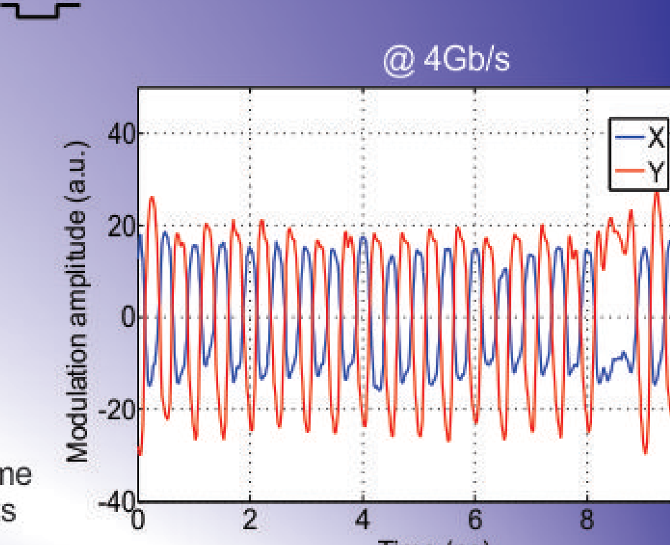
→ Polarized *L-I* characteristics for two paths
→ Static extinction ratio >14 dB

High speed polarization modulation techniques demonstrated
→ efficient as the DC power is shared
→ double data rate without using higher modulation formats
→ New record for polarization modulation frequency
→ -3 dB bandwidth 5.5 GHz (parasitically limited)



Biasing scheme for time domain measurements

Dynamic characteristics



High Speed Polarization Modulation (Time domain results)

These works were financially supported by DARPA-MTO; DARPA-DSO; and NSF