

Silicon Photonics Research at IIT Madras

Bijoy Krishna Das

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Research Profile

- ❑ **Lithium Niobate Integrated Optics (1996-2006)**

IIT KGP → Uni. of Paderborn → Osaka University → Lehigh University → University of Paderborn

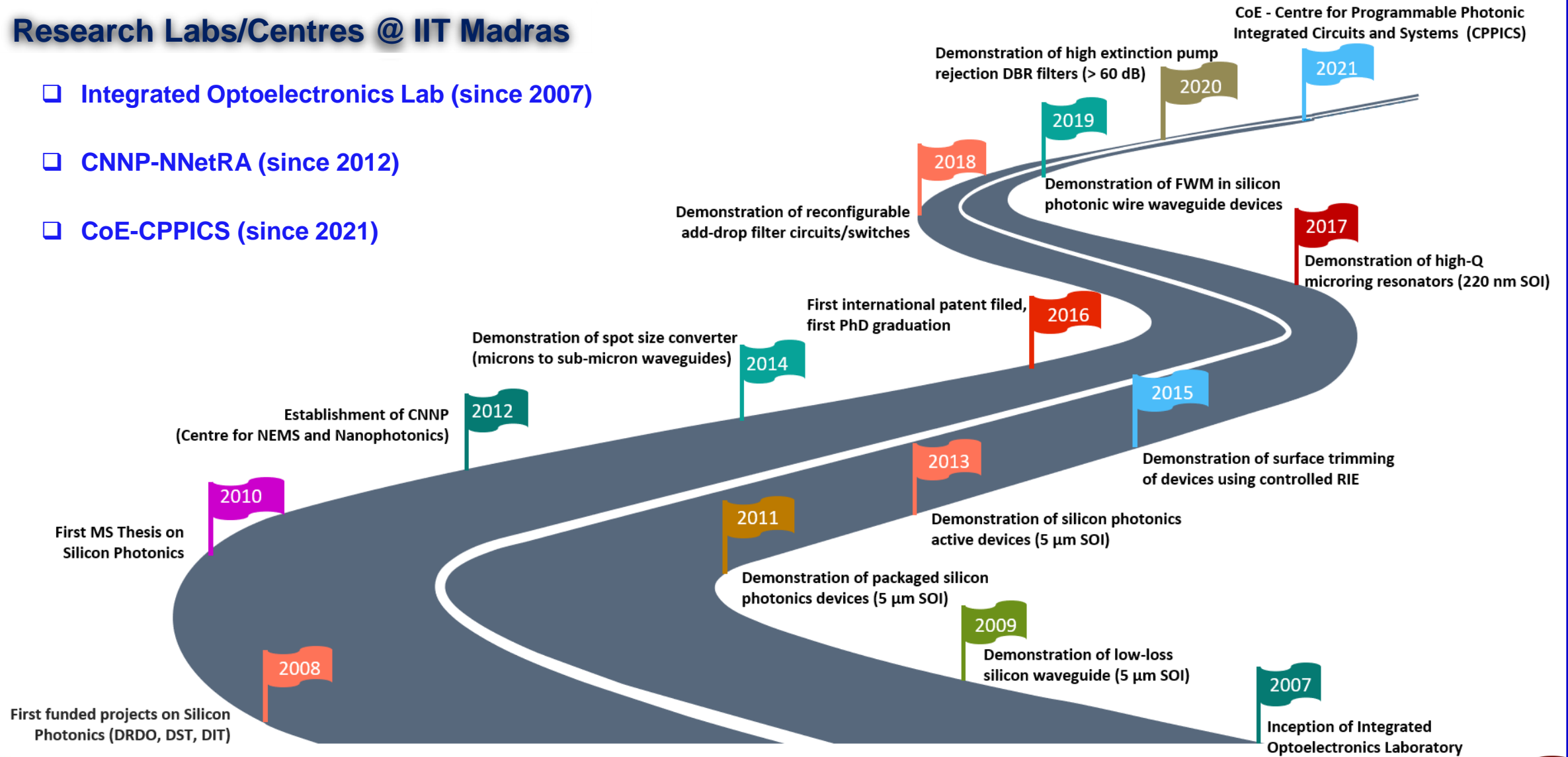
- ❑ **Silicon Integrated Photonics (2006-2021)**

Dept. of Electrical Engineering, IIT Madras



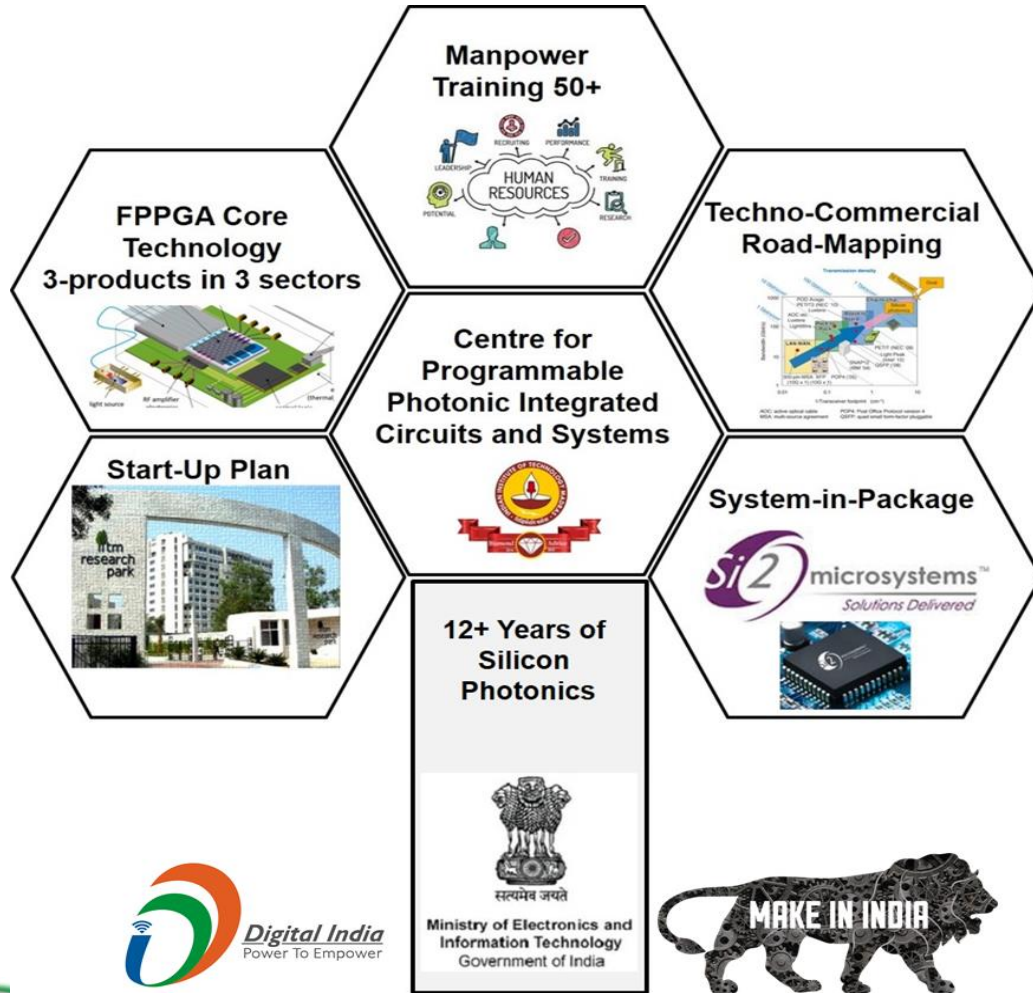
Research Labs/Centres @ IIT Madras

- ❑ Integrated Optoelectronics Lab (since 2007)
- ❑ CNNP-NNetRA (since 2012)
- ❑ CoE-CPPICS (since 2021)



Centre for Programmable Photonic Integrated Circuits and Systems

Program at a Glance



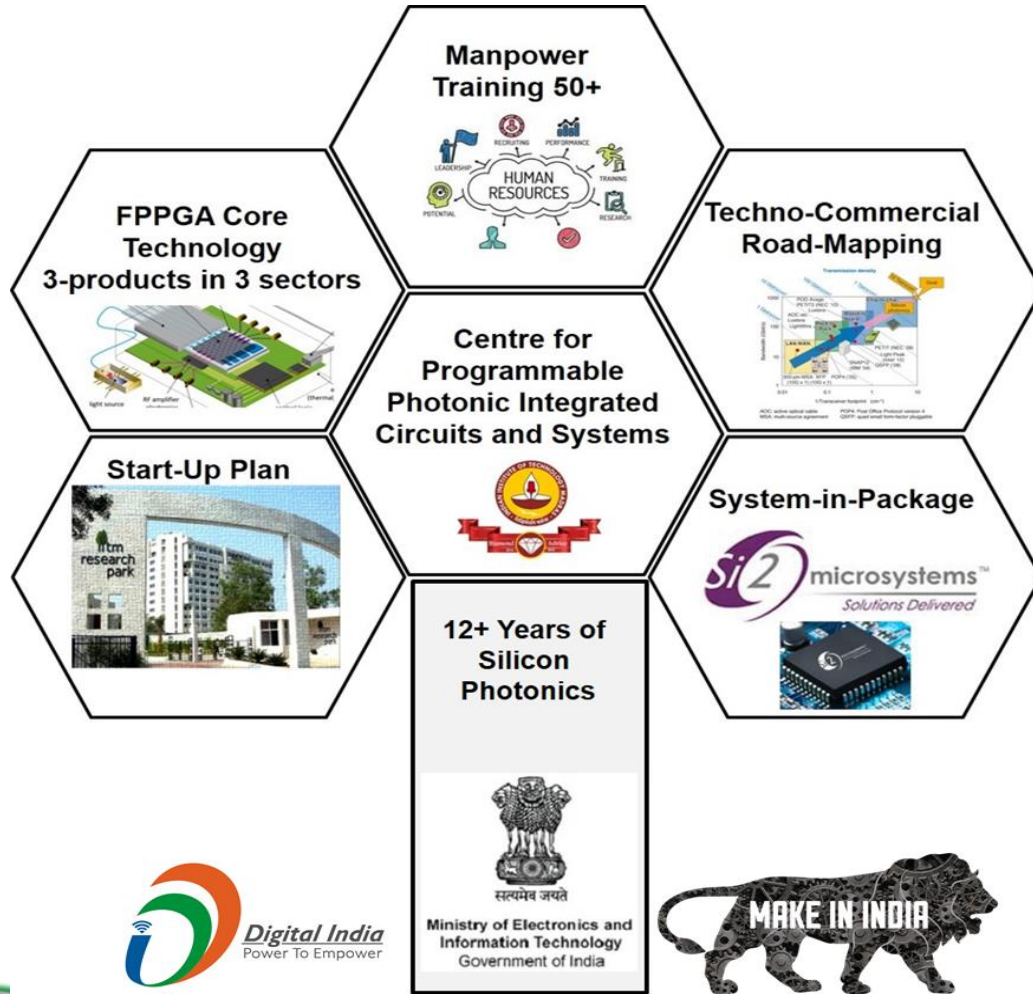
MeitY Approval	No. GG-11/15/2020-EMCD, dated 30 th Dec 2020	
Total Budget	Approved Total Budget	Rs 2,990.80 Lakh
	MeitY Contribution	Rs 2,665.80 Lakh
	Si2 Microsystems (in kind)	Rs 325.00 Lakh
Date of Starting	30th December 2020	
Date of Completion	29th December 2025	
Project Location	Dept. of EE, IIT Madras, Chennai - 600036, India.	

Focus Area

- Microwave Photonic Signal Processing
- Linear Optical Quantum Computing
- Nonlinear Photonic Quantum Key Distribution

Centre for Programmable Photonic Integrated Circuits and Systems

Program at a Glance



Prof. Bijoy Krishna Das

Silicon Photonics Chip Design, Fabrication, and Testing



Prof. Enakshi Bhattacharya

Si/SiN/SiO2 / Metallization Process Evaluation



Prof. Janakiraman Viraraghavan

Electronics Chip Design, PCB Interfacing and Testing



Prof. Deepa Venkitesh

RF/Microwave Photonics System Level Application and Evaluation

Prof. Anil Prabhakar

Quantum Photonics System Level Application and Evaluation



Prof. S. Christopher

Industry Interfacing and Field Tests



Prof. Nandita DasGupta



Prof. Amitava DasGupta



Mr. Dinanath Shoni (ED, Si2 Microsystems)



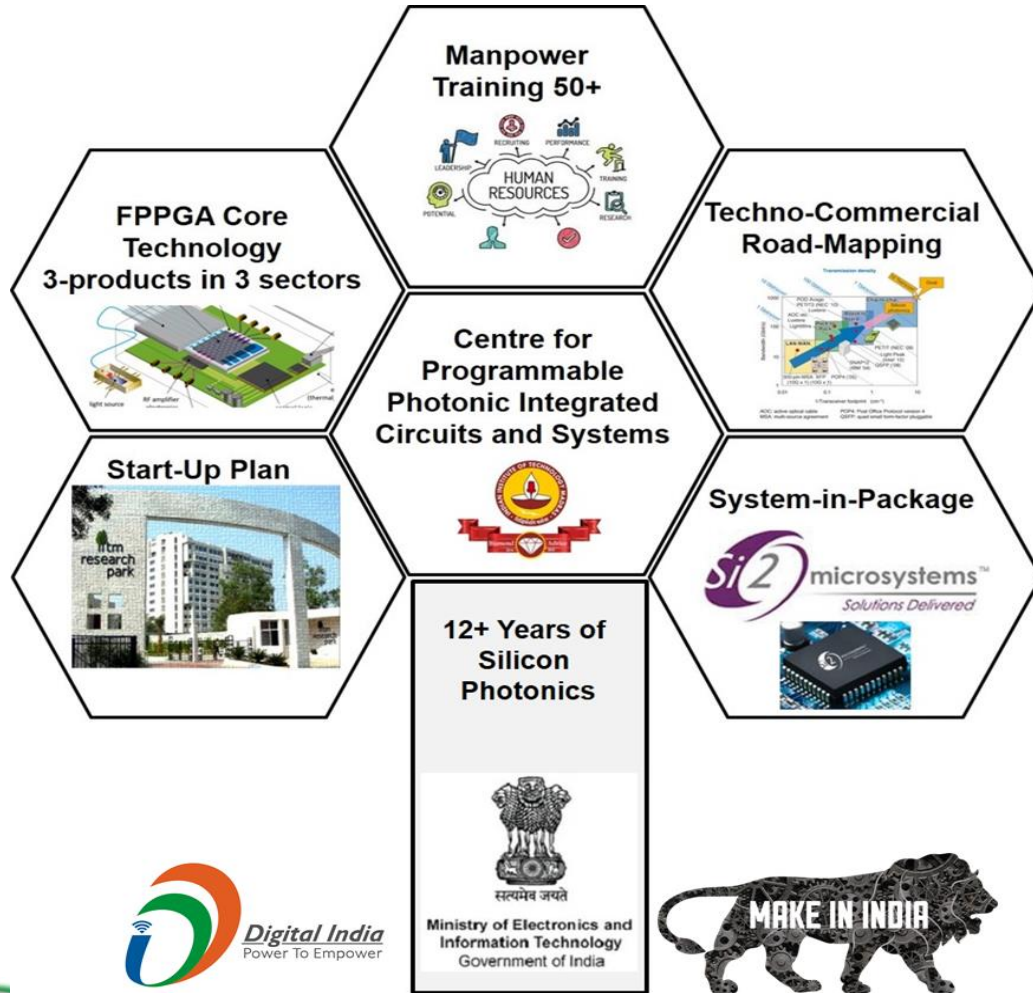
Mr. Solomon (CTO, CPPICS)

Team CPPICS



Centre for Programmable Photonic Integrated Circuits and Systems

Program at a Glance

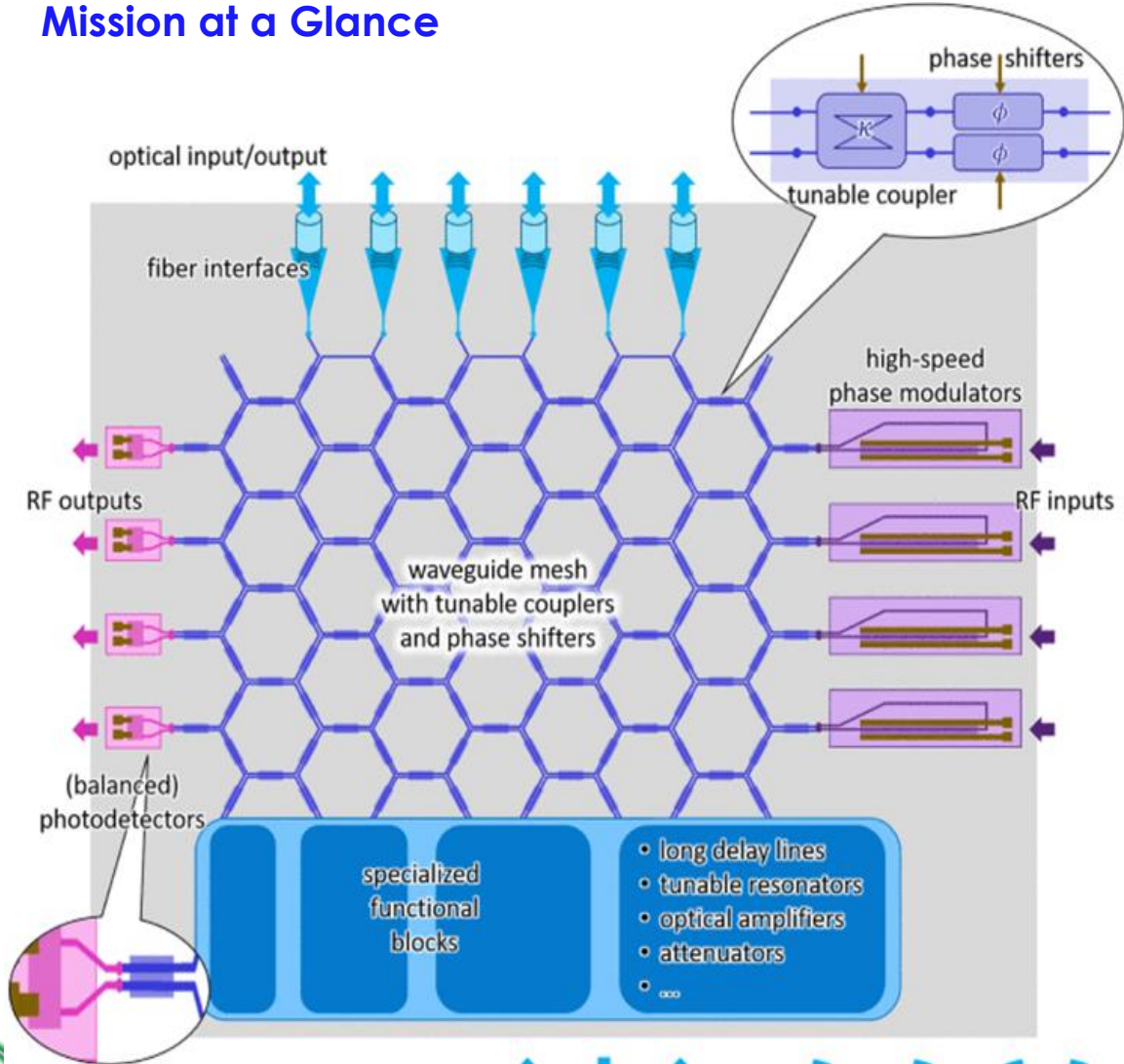


Team CPPICS

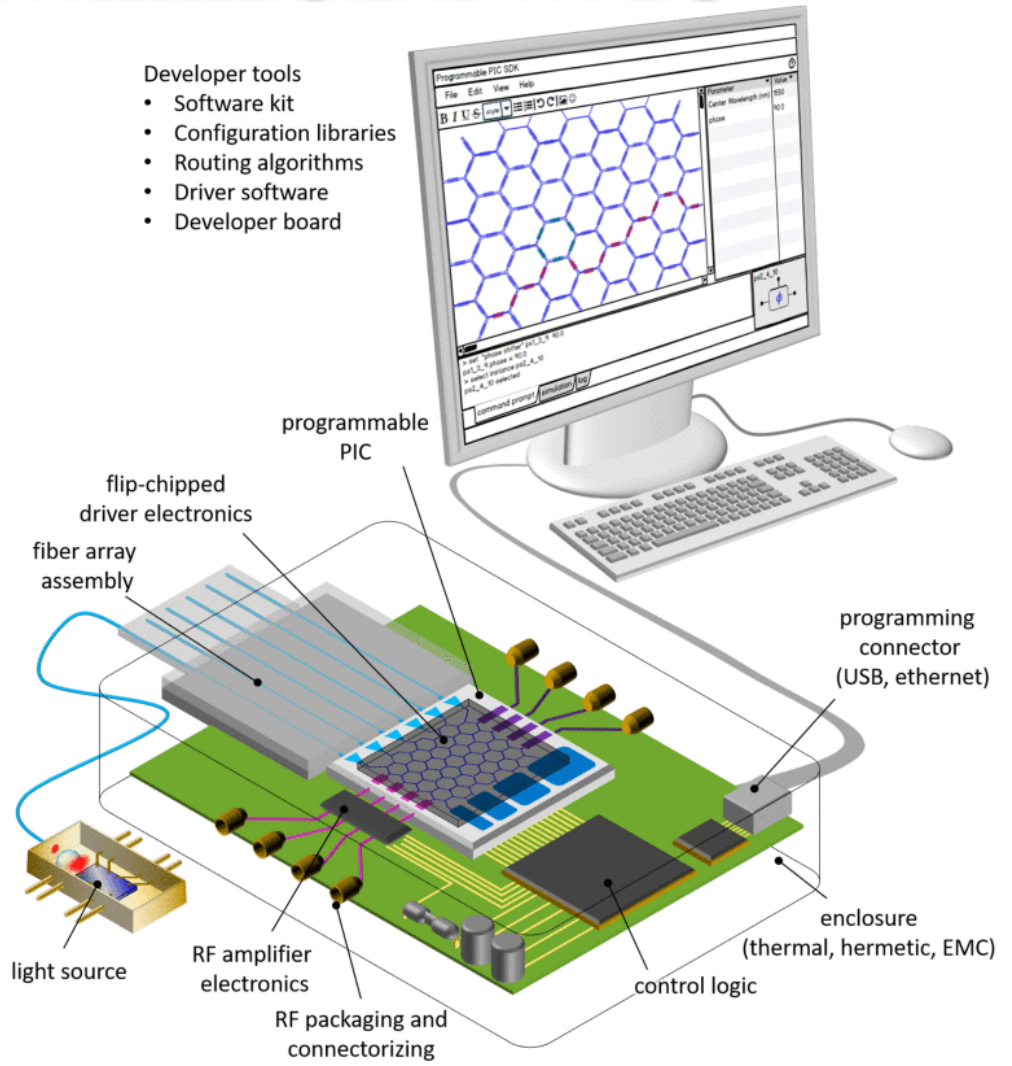


Multipurpose Programmable Photonic Processor (ASPIC+FPPGA)

Mission at a Glance



- Developer tools
- Software kit
 - Configuration libraries
 - Routing algorithms
 - Driver software
 - Developer board

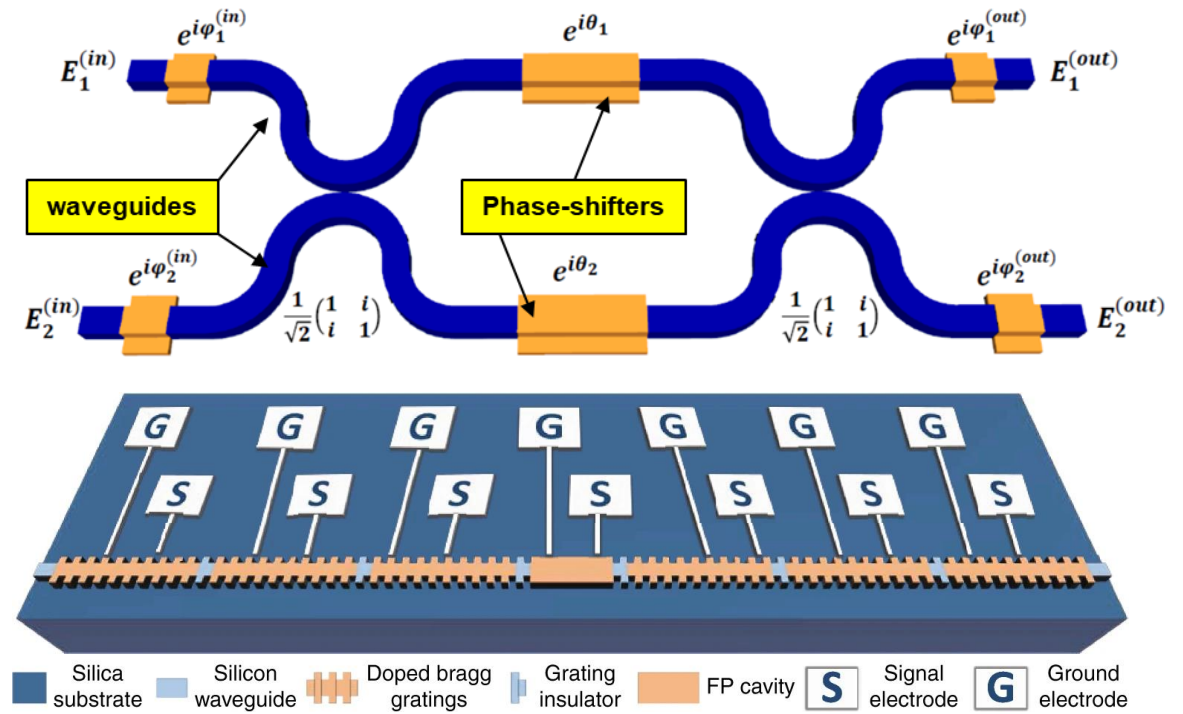
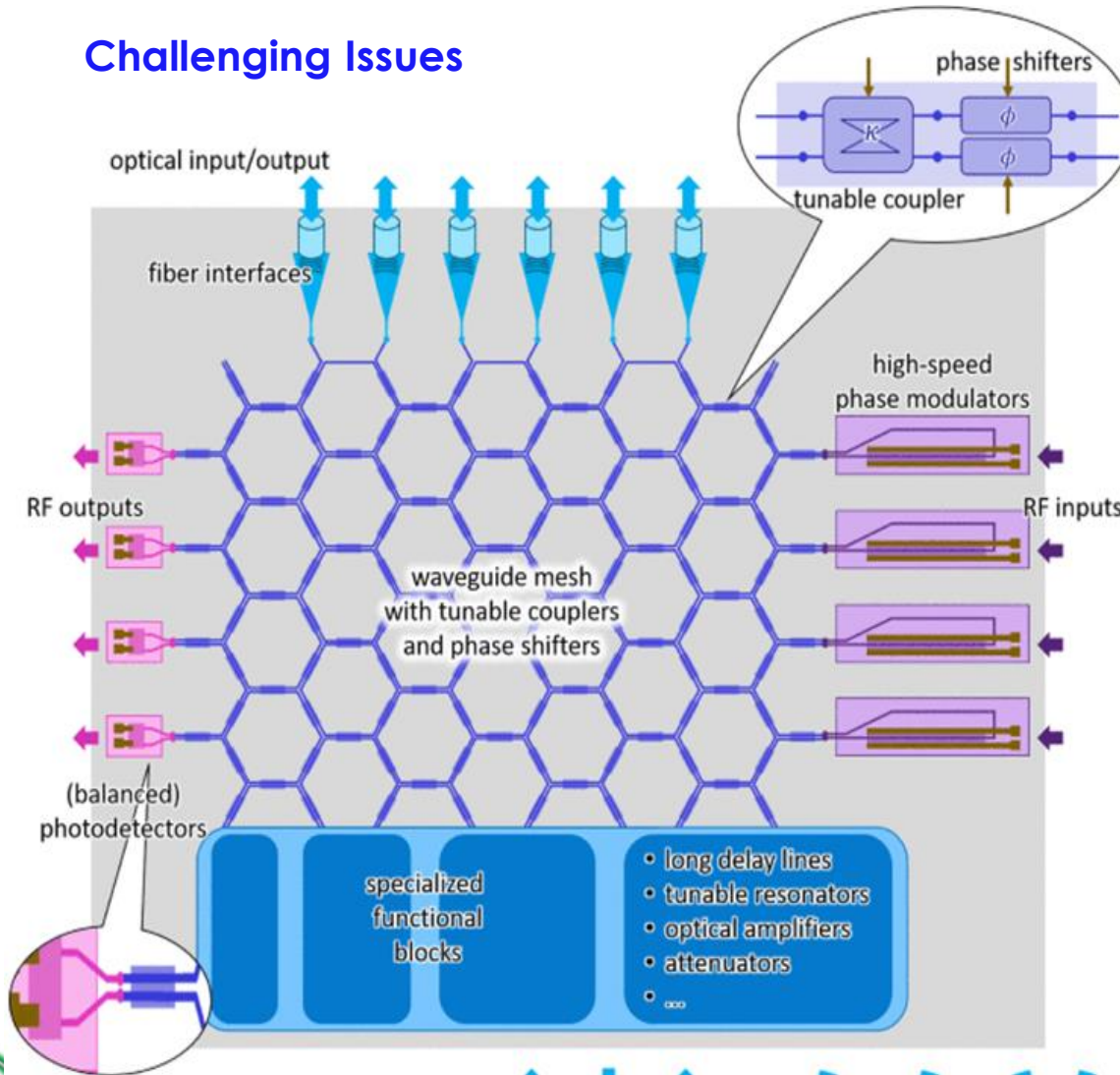


Bogaerts, Wim, and Abdul Rahim. *IEEE JSTQE*, vol. 26, pp. 1-17, 2020



Multipurpose Programmable Photonic Processor (ASPIC+FPPGA)

Challenging Issues



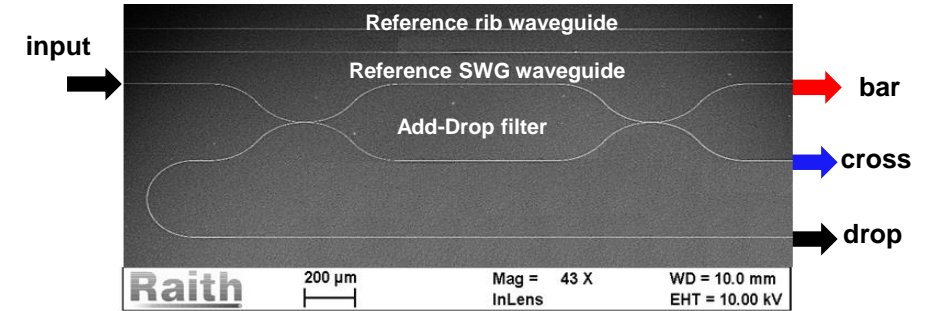
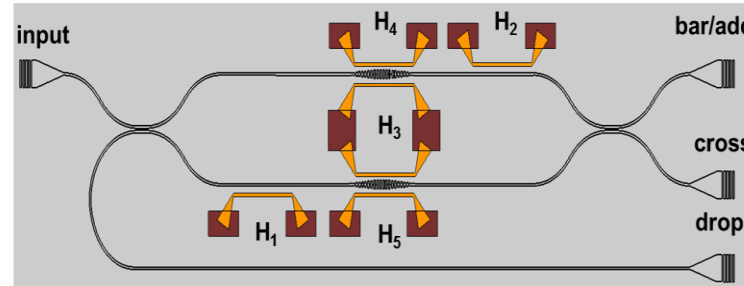
Weifeng Zhang and Jianping Yao, *Nature Comm.*, vol. 9, Art. No. 1396, 2018

- Compactness and scaling-up
- Minimizing number of programmable fields
- Minimizing number of contact pads
- Minimizing power-response ($P_{\pi}\tau$) figure of merit
- Wideband operating wavelengths

IIT Madras Research Towards Field Programmable Photonic Gate Array (FPPGA)

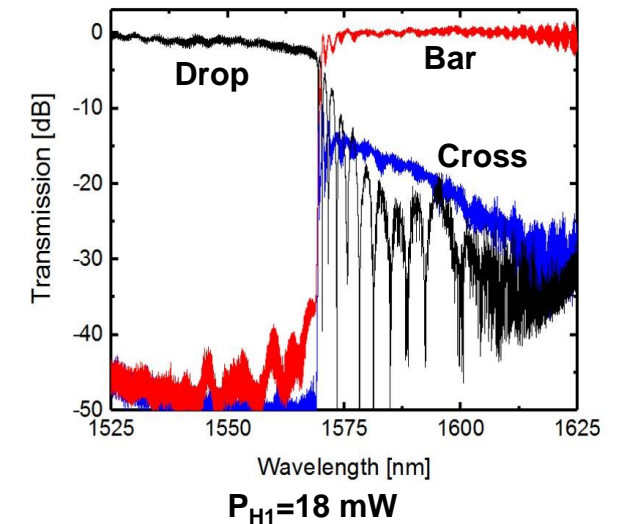
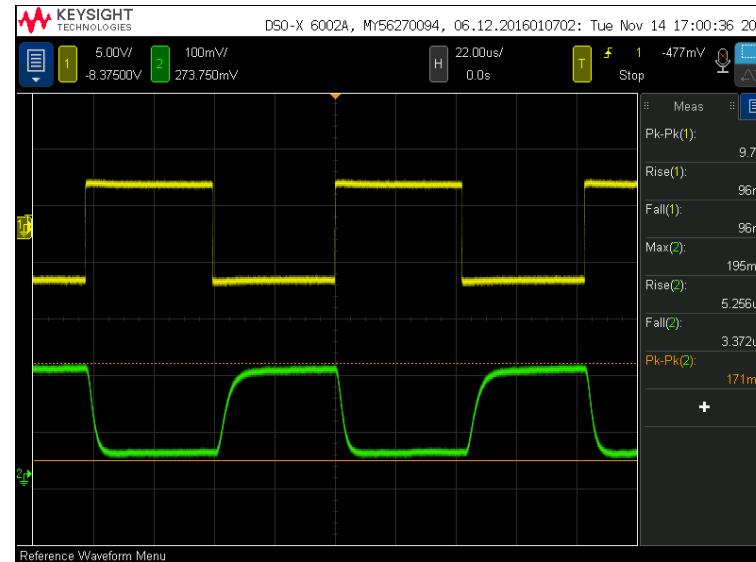
Demonstration of an ultra broadband Programmable add-drop filter circuit in MZI configuration by integrating:

- Two SWG waveguides
- Two 3-dB power splitters
- Six microheaters
- Four grating couplers



Characteristics

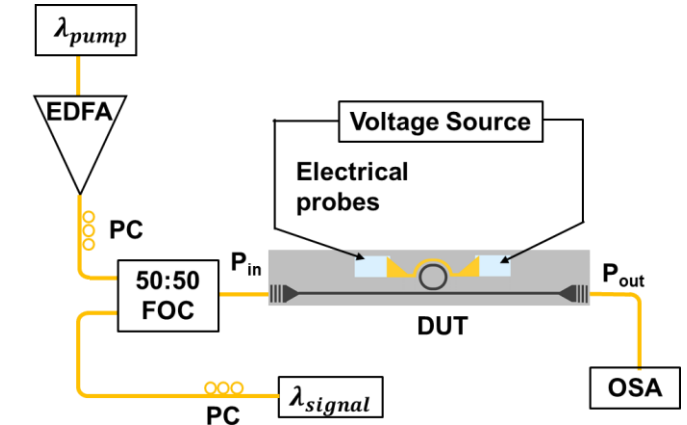
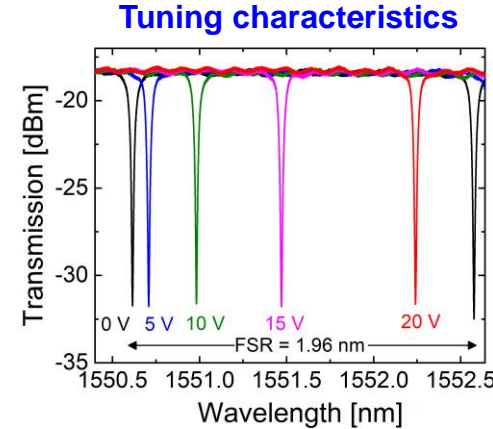
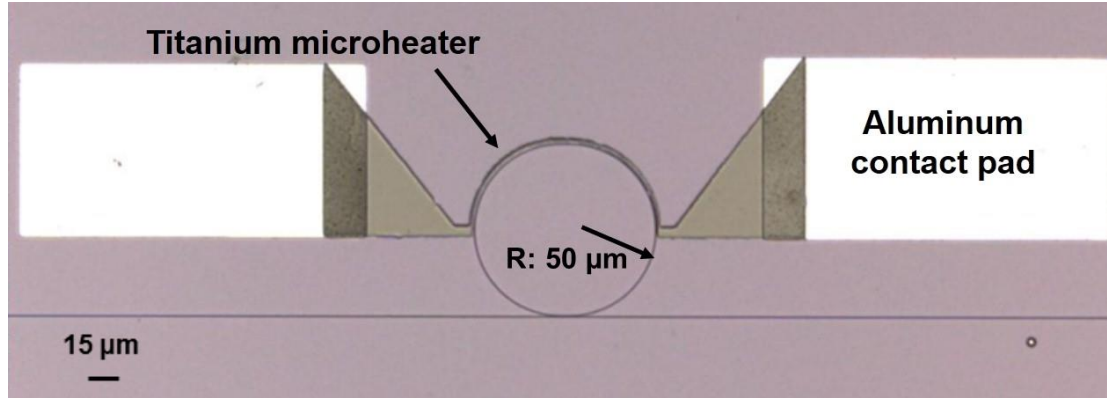
Operating wavelength range	C+L band
Polarization	TE
Insertion loss (Passband)	~ 2 dB
Insertion loss (Reflection band)	~ 2 dB
Band extinction ratio	> 35 dB
Band-edge roll off	70 dB/nm
Switching power for π phase shift	54 mW
Thermo-optic tuning efficiency	22 pm/mW
Switching time	5 μ s



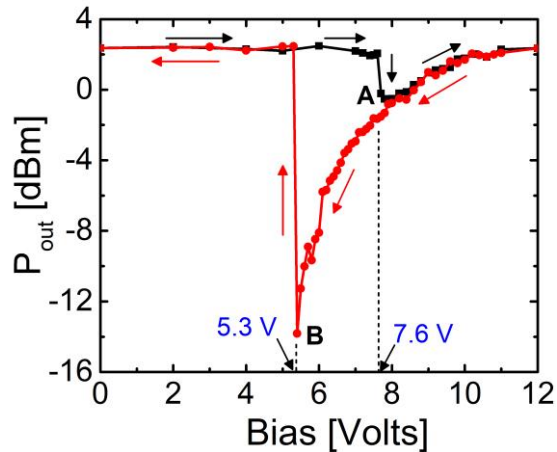
Sumi R, Ramesh K, N. DasGupta and B.K. Das, "Ultra-Broadband Add-Drop Filter/Switch Circuit Using Subwavelength Grating Waveguides" IEEE JSTQE, vol. 25, no. 3, pp. 1-11, 2019

IIT Madras Research Towards Field Programmable Photonic Gate Array (FPPGA)

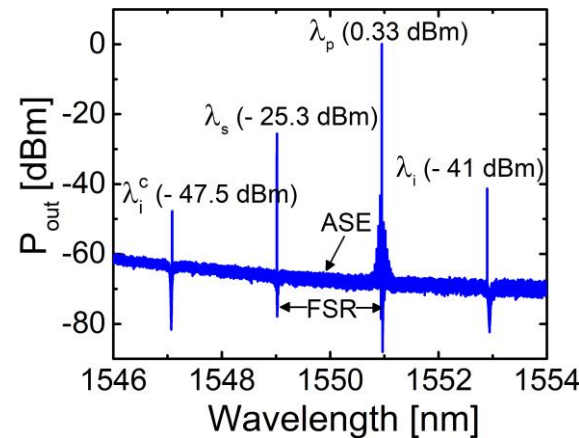
Demonstration of a programmable microring resonator (MRR) for Bistable Memory and Nonlinear Photonic Applications



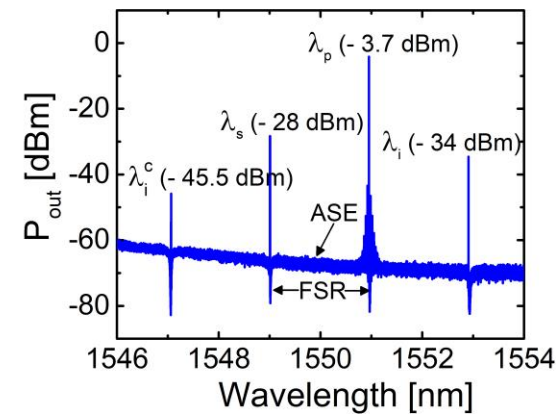
Voltage Controlled Hysteresis



FWM: operating point 'A'



FWM: operating point 'B'

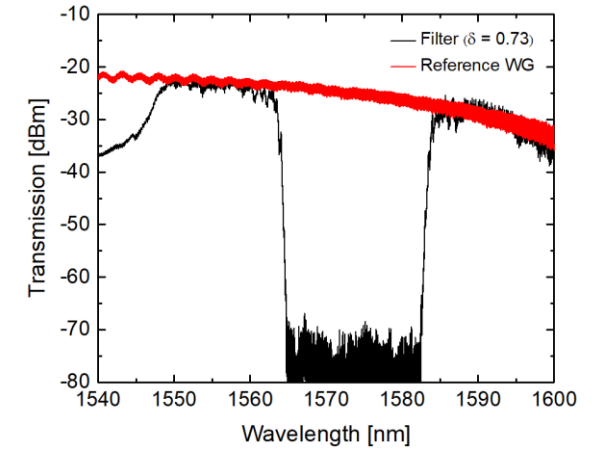
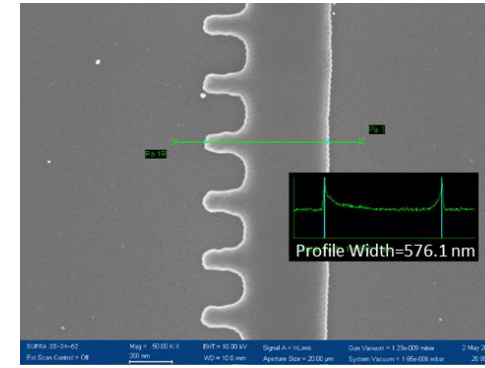
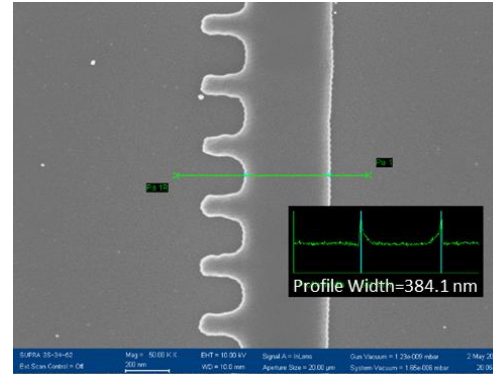
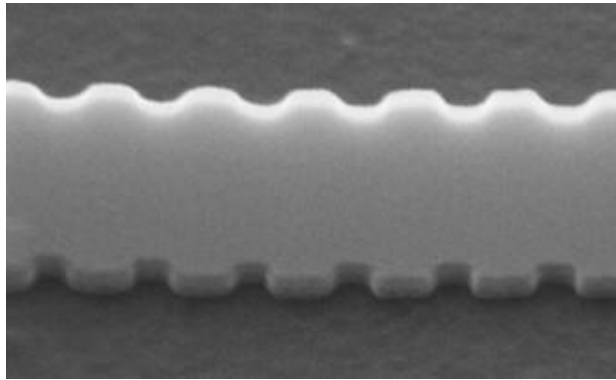


- All-pass MRR with integrated microheater is fabricated and electrically controlled bistability is studied which leads to efficient FWM by enhancing the field enhancement factor.
- It will be useful for efficient photon pair generation in quantum photonics circuits.

Riddhi Nandi, Arnab Goswami and B.K. Das, "Phase Controlled Bistability in Silicon Microring Resonators for Nonlinear Photonics", IEEE JSTQE, vol. 27, no. 2, pp. 1-9, 2021

IIT Madras Research Towards Field Programmable Photonic Gate Array (FPPGA)

Demonstration of high extinction distributed Bragg reflector (DBR) as pump rejection filter



Experimental Results of Fabricated DBR Filter :

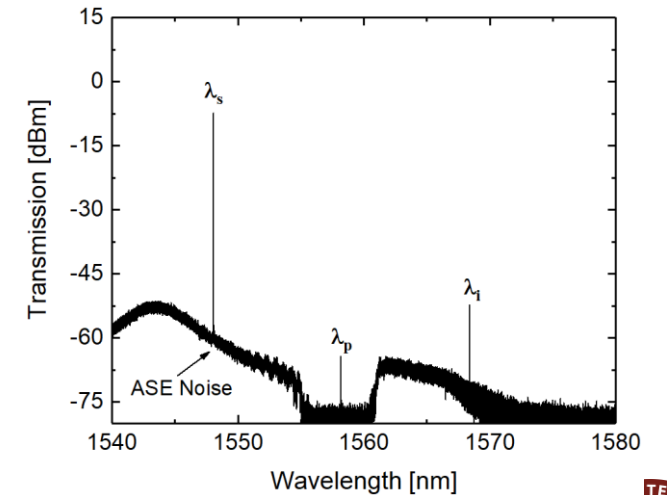
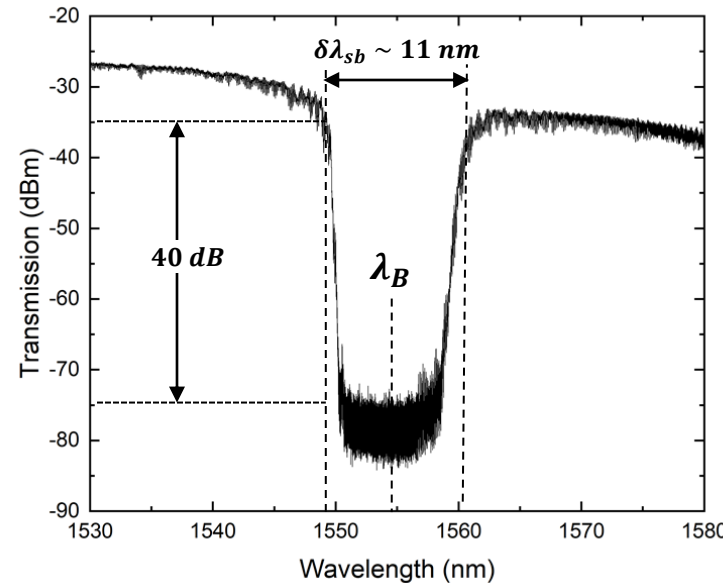
$W = 575 \text{ nm}; H = 220 \text{ nm}; h = 160 \text{ nm}$
 $\Delta W = 190 \text{ nm}; L = 450 \mu\text{m}; \Lambda = 290 \text{ nm}$

$$\delta\omega_{sb} = \frac{2c}{n_g} \sqrt{\kappa^2 + \left(\frac{\pi}{L}\right)^2} \quad \delta\lambda_{sb} = \frac{\lambda_B^2}{\pi n_g} \sqrt{\kappa^2 + \left(\frac{\pi}{L}\right)^2}$$

For $\Delta\beta = 0$ $\lambda_B = 2n_{eff}\Lambda$ $R_{max} = \tanh^2(\kappa L)$

Extracted Parameters

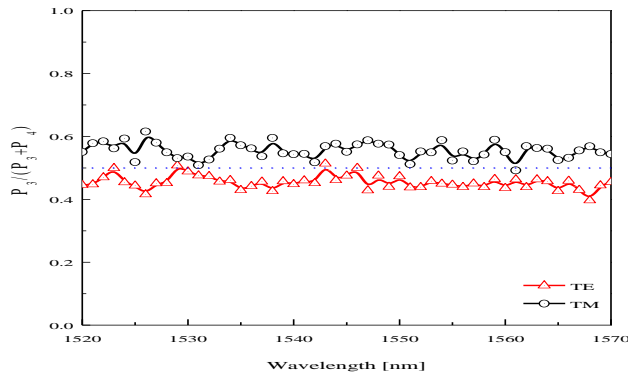
$T = 0.0001$ $R = 0.9999$ $\delta\lambda_{sb} = 11 \text{ nm}$
 $\lambda_B = 1554 \text{ nm}$ $\kappa = 0.012 \mu\text{m}^{-1}$ $n_{eff} = 2.8254$
 $n_g = 0.9690$



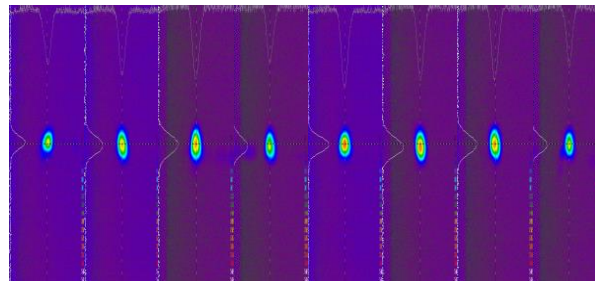
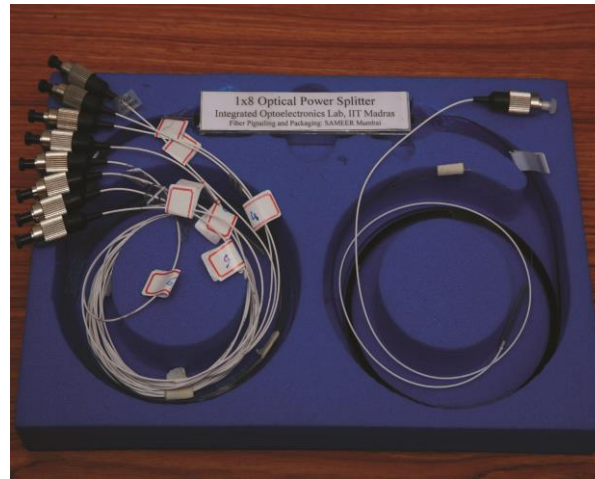
Towards Field Programmable Photonic Gate Array (FPPGA)

Fiber Pigtailed and Packaged Devices (Collaboration: SAMEER, Mumbai)
 Funded by Department of Information Technology, Govt. of India (2008-2011)

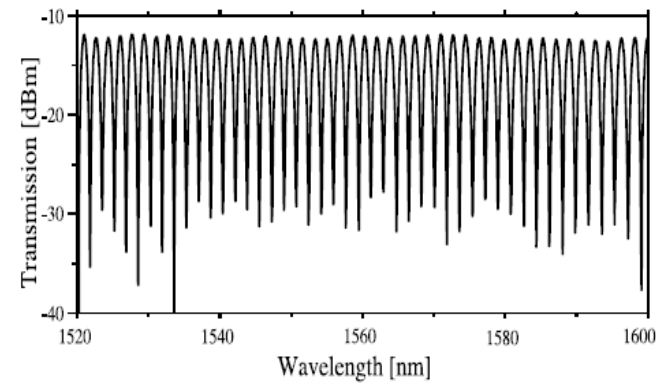
2X2 Directional Coupler



1X8 Power Splitter



2X2 DWDM Channel Interleaver



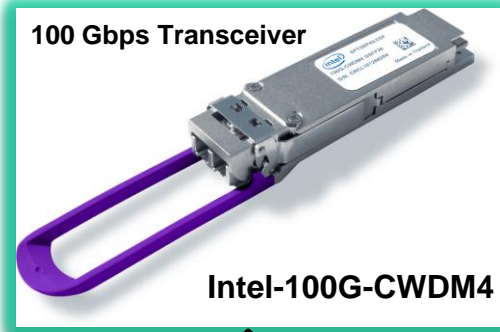
G. R. Bhatt, R. Sharma, U. Karthik and B. K. Das, "Dispersion-Free SOI Interleaver for DWDM Applications," *IEEE J. Lightwave Technol*, vol. 30, no. 1, pp. 140-146, 2012

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Integrated Photonics and Communication

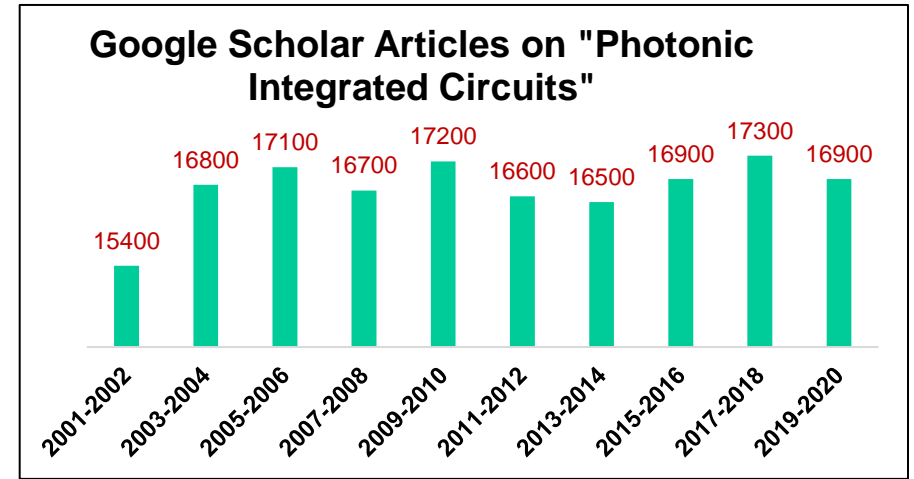
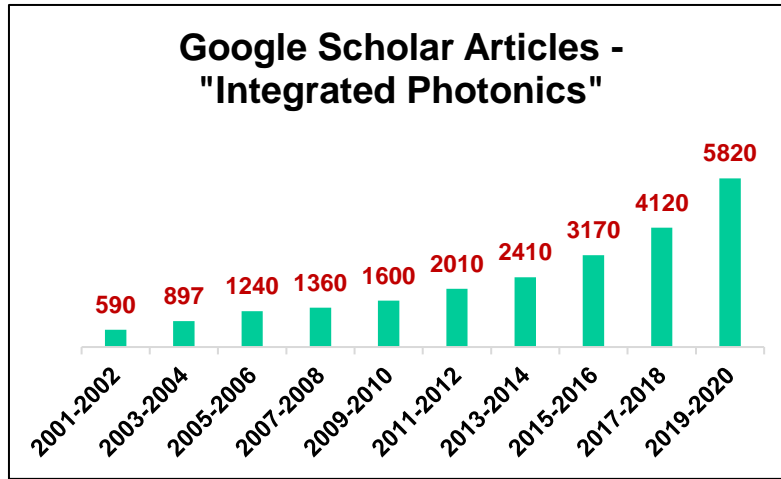
Background : State-of-the-art

Industrial Success (since 2000)

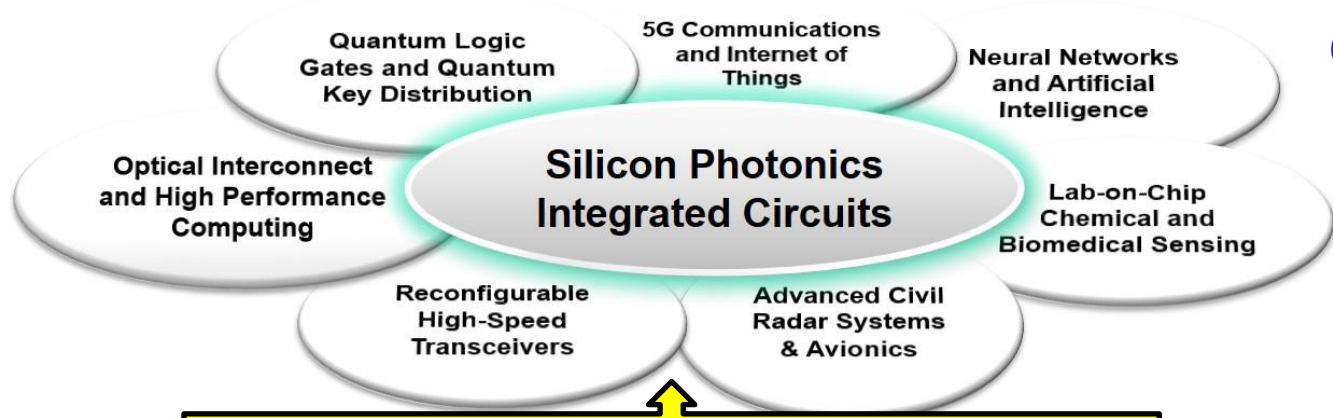


16 years of research to launch its first product

Recognition: One of the Enabling Technologies for the 21st Century



Acquired silicon photonics chip maker Luxtera for \$660 million



Predicted silicon photonics market worth \$3.0 billion by 2025

Other Technology Platforms

- InP based Integrated Photonics/optoelectronics
- Lithium Niobate on Insulator based Integrated Optics

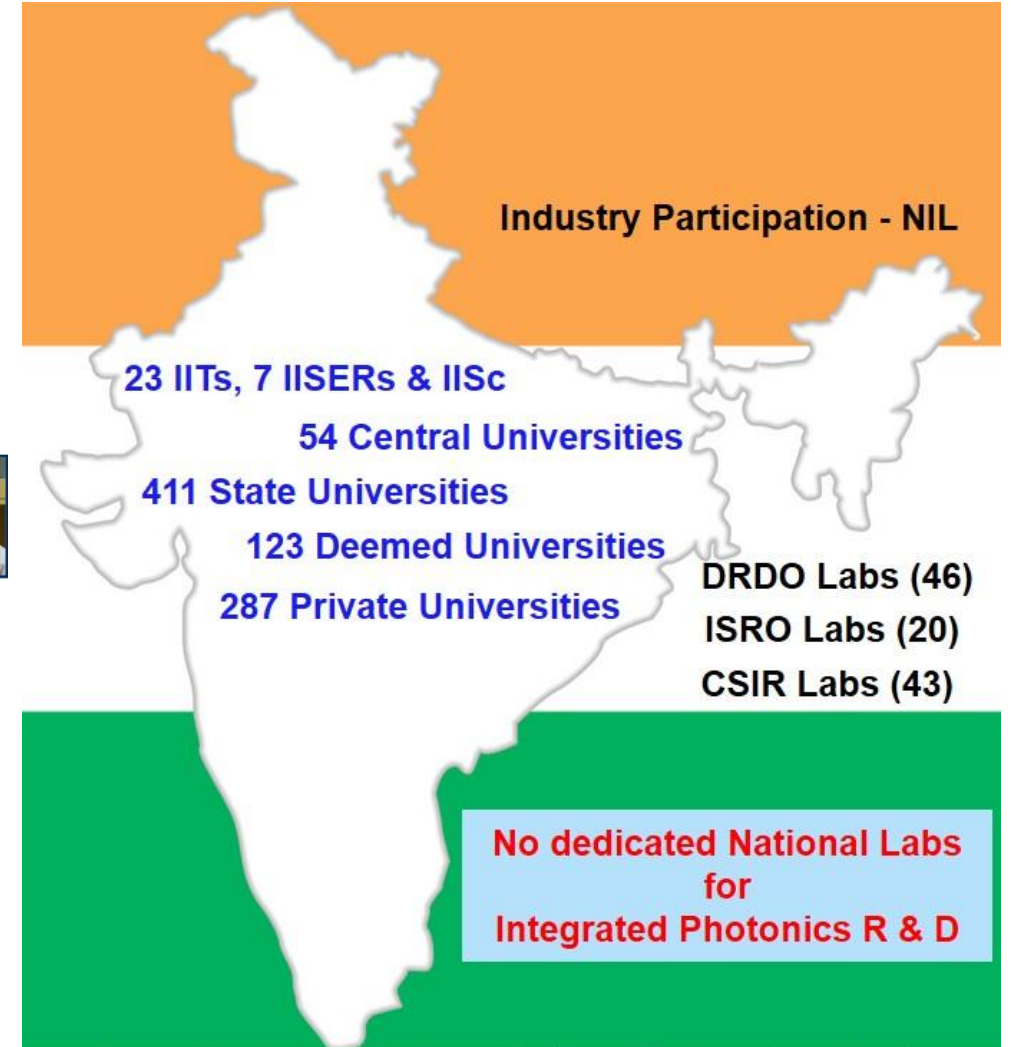
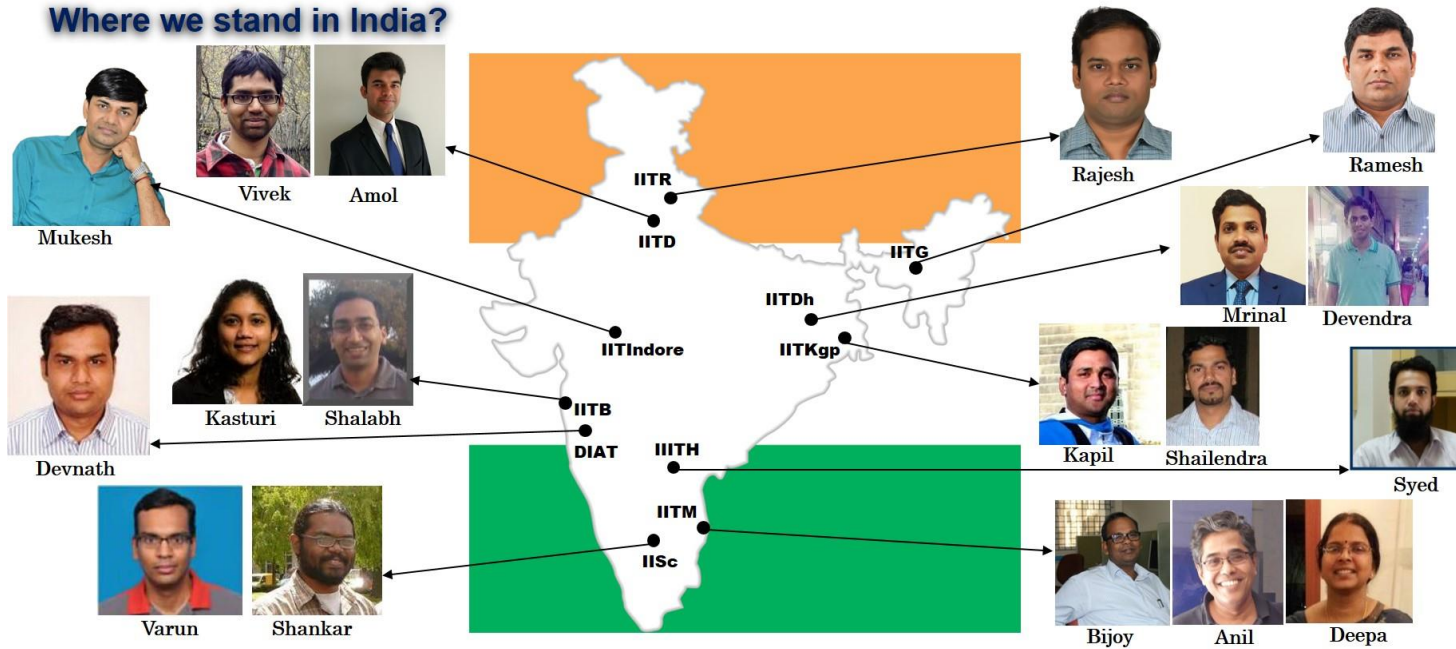
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Integrated Photonics and Communication

Where we stand in India

Only a few research groups in academic institutes in India

Where we stand in India?



- Clean rooms facilities for experimental integrated photonics research available only at IISc (CeNSE) and IIT Madras (CNNP)
- Other research groups have started their journey during last 5 years

Thank You

