Will photonics penetrate into inter-chip and intra-chip communications?

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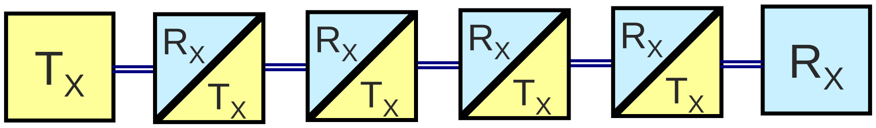
Where innovation starts

On-chip interconnect networks



Electronic on-chip interconnect network

- Interconnect needs repeaters
- Each repeater receive, buffers and re-transmits every bit
- Higher clock frequencies: more power per repeater and more repeaters

Optical on-chip interconnect network

- No repeaters
- Power independent of distance/ no cross talk, etc

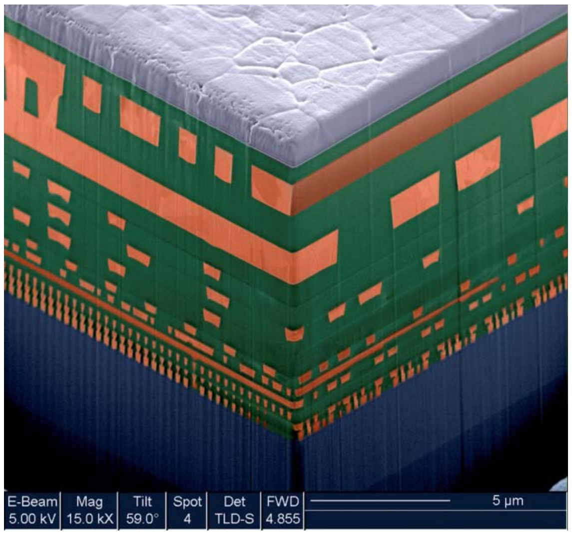
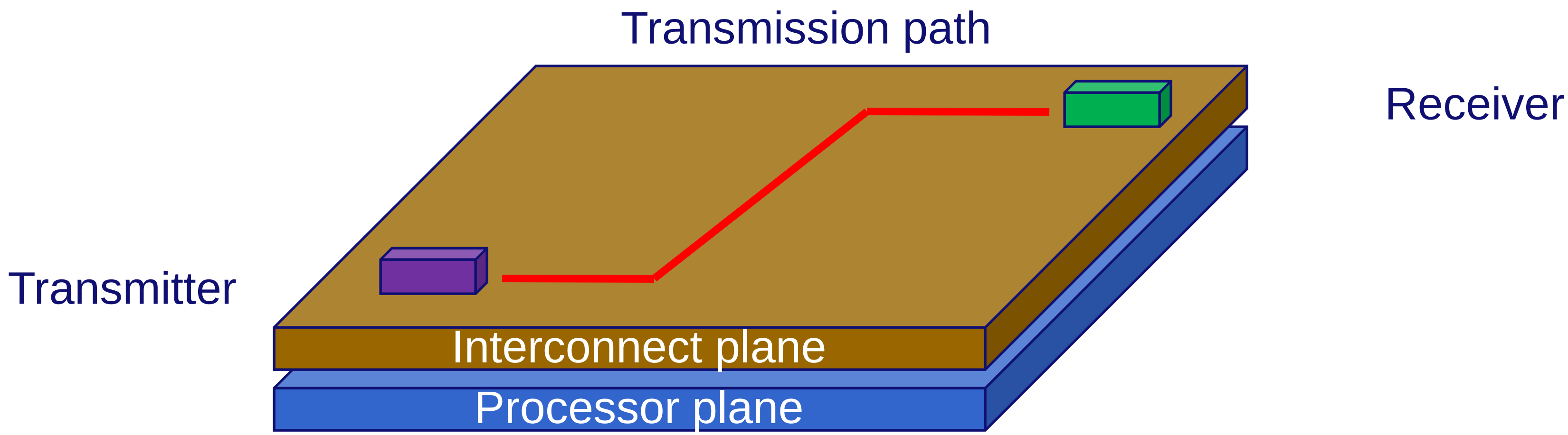


Photo by IBM

Forecast for 2020

- 10 TFLOP processors
- On-chip I/O ~ 1 byte per flop (Amdahl)
- Power electronic network 10 TFLOPs chip ~ 500 Watts
- ~ 7 pJ/bit or 7 mW/Gb/s

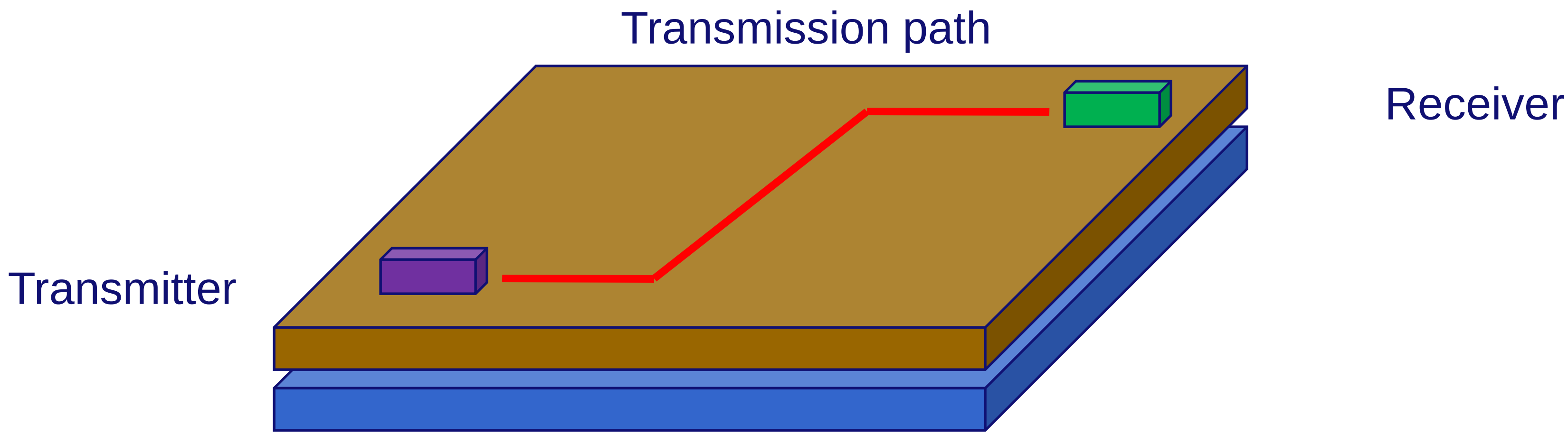
Photonic interconnect network:
Receiver



Typical receiver sensitivity at BER 10^{-9}

	PIN	APD	Power (TIA)
40 Gb/s	-10 dBm	-	~ 250 mW
10 Gb/s	-20 dBm	- 25 dBm	~200 mW
2.5 Gb/s	-25 dBm	-30 dBm	~75 mW

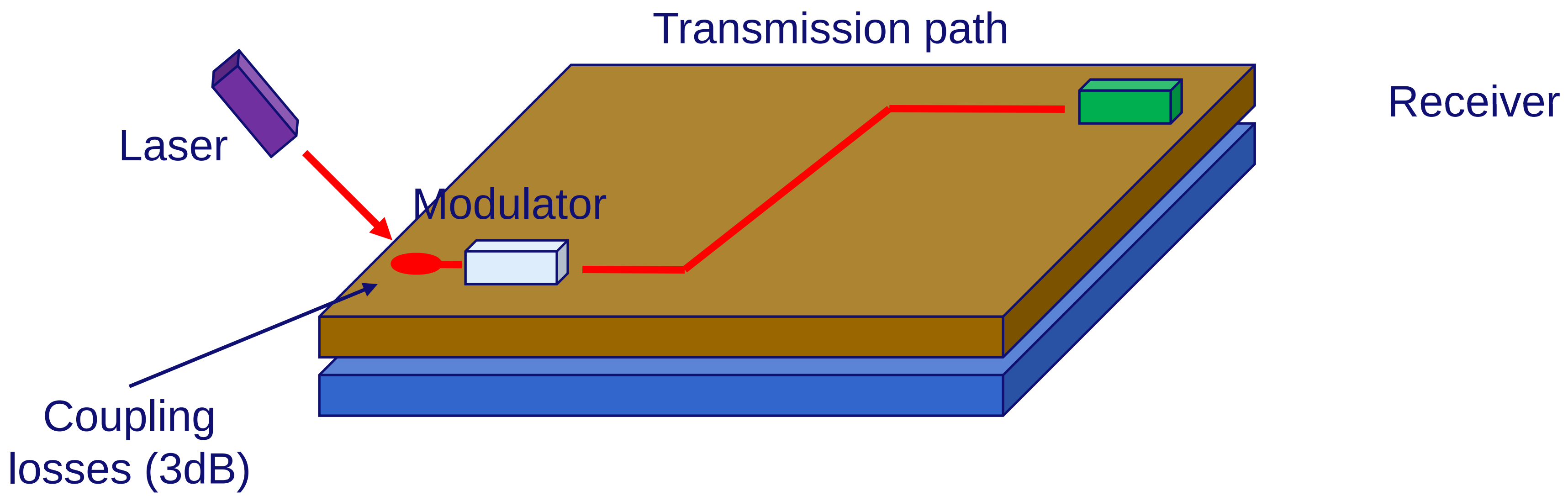
Photonic interconnect network
Transmission path



Typical waveguide losses

	Typical losses	Bending radius
Silica	0.01 dB/cm	500 micrometer
Etchless silicon	0.3 dB/cm	50 micrometer
SOI	2.4 dB/cm	5 micrometer
InP membranes	*3 dB/cm*	*5 micrometer*

Photonic Interconnect network:
Option 1: *Off-chip laser and transmitter*

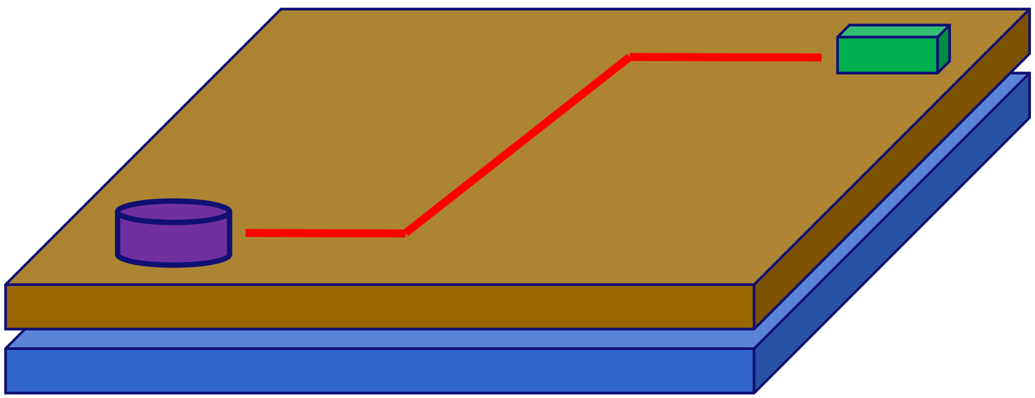


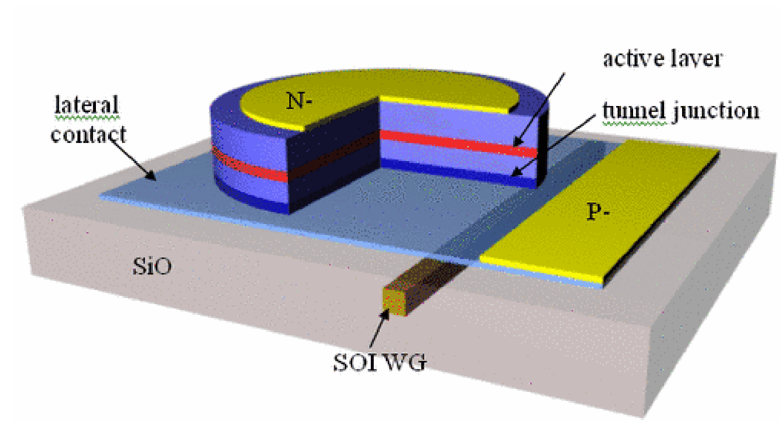
	Power laser	Power modulator	Power modulator driver	Insertion losses
40 Gb/s	150 mW	60 mW	5.85 W	8 dB
10 Gb/s	150 mW	< 50 mW	3.6 W	8 dB
2.5 Gb/s	150 mW	< 50 mW	1~2 W	8 dB

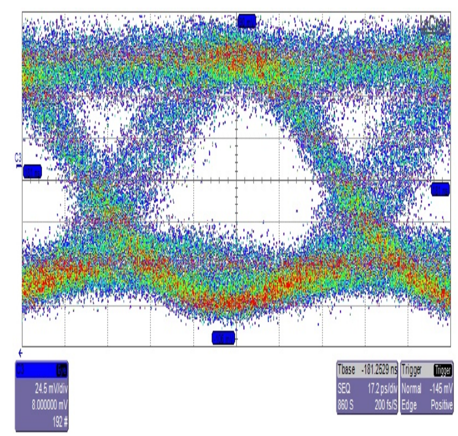
Silicon modulators, MZI or Ring resonator, limited data available, but high losses, and high power!

See Ding and Pan, SLIP 09

Direct modulation







Use microdisk laser (diameter 7.5 micrometer)
Threshold current is ~ 0.1 mA
Power 5 mW (2V, 2.5mAmps)
Optical power in waveguide ~ 50 mW
10 Gb/s wavelength conversion is possible but

direct modulation at high speed never been demonstrated

Devices made by IMEC/Gent (FP7 project HISTORC)

Link and power budget
40 Gb/s (off-chip laser)

Receiver sensitivity (PIN):	-10 dbm
Waveguide losses:	5 dB
Insertion losses modulator:	8 dB
Coupling losses	3 dB
Required laser power	6 dbm (4mW)

Power laser	150 mW
Power modulator	60 mW
	210 mW (5.25 mW/Gb/s)

Power modulator driver	*5850 mW*
Power TIA Receiver:	*250 mW*
	6100 mW (153 mW/Gb/s)

Link and power budget
10 Gb/s (off-chip laser)

Receiver sensitivity (APD):	- 25 dBm
Waveguide losses:	5 dB
Insertion losses modulator:	8 dB
Coupling losses	3 dB
Required laser power	-9 dbm (0.13 mW)

Power laser	150 mW
Power modulator	50 mW
	200 mW (20 mW/Gb/s)

Power modulator driver	*3600 mW*
Power TIA Receiver:	*200 mW*
	3800 mW (380 mW/Gb/s)

Link and power budget
2.5 *Gb/s (off-chip laser)*

Receiver sensitivity (APD):	- 30 dBm
Waveguide losses:	5 dB
Insertion losses modulator:	8 dB
Coupling losses	3 dB
Required laser power	-14 dbm (0.04 mW)

Power laser	150 mW
Power modulator	50 mW
	200 mW (80 mW/Gb/s)

Power modulator driver	*1000 mW*
Power TIA Receiver:	*75 mW*
	1075 mW (430 mW/Gb/s)

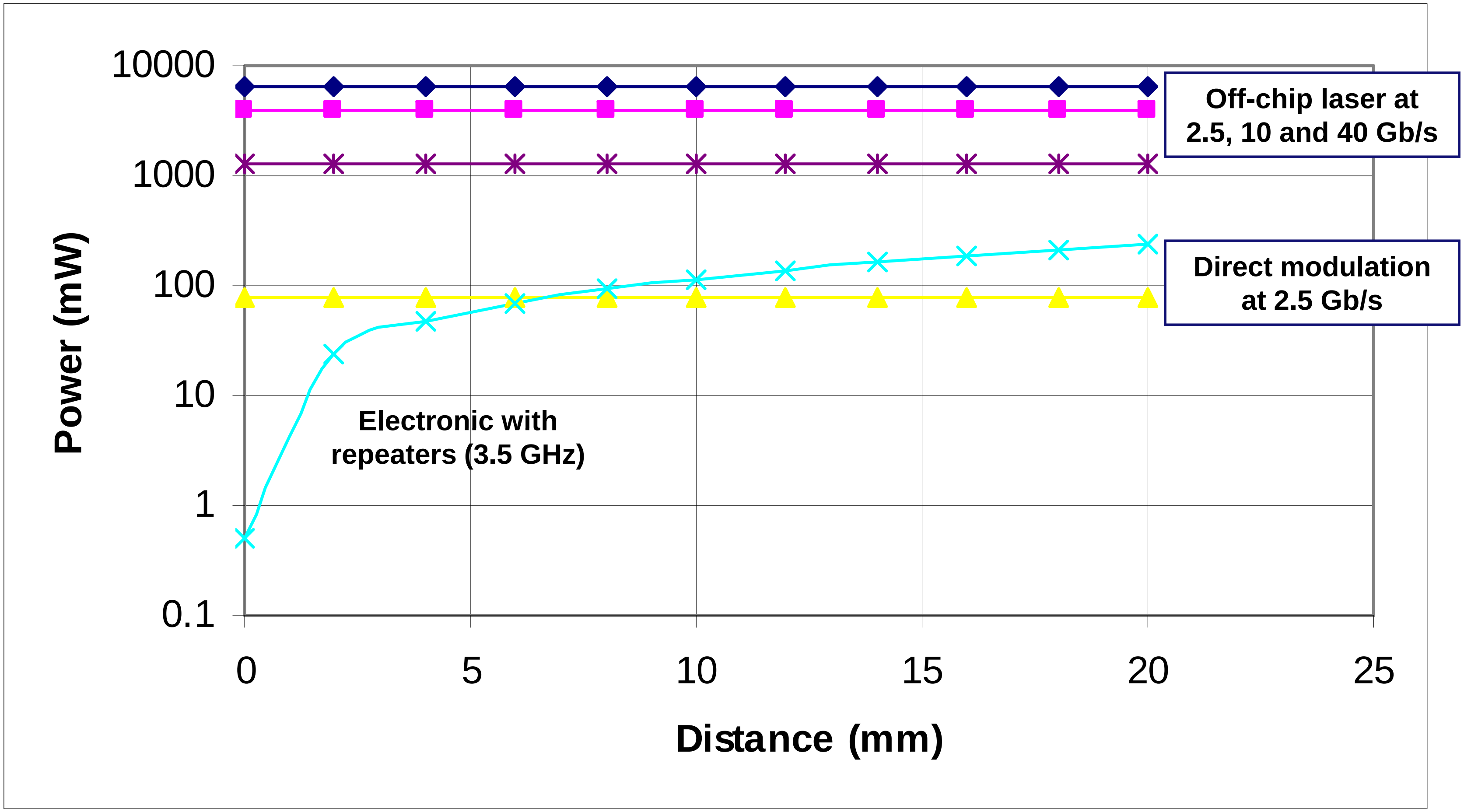
Link and power budget
2.5 Gb/s (direct modulation)

Receiver sensitivity (APD):	- 30 dbm
Waveguide losses:	5 dB
Insertion losses modulator:	8 dB
Coupling losses	3 dB
Required laser power	-14 dbm (0.04 mW)

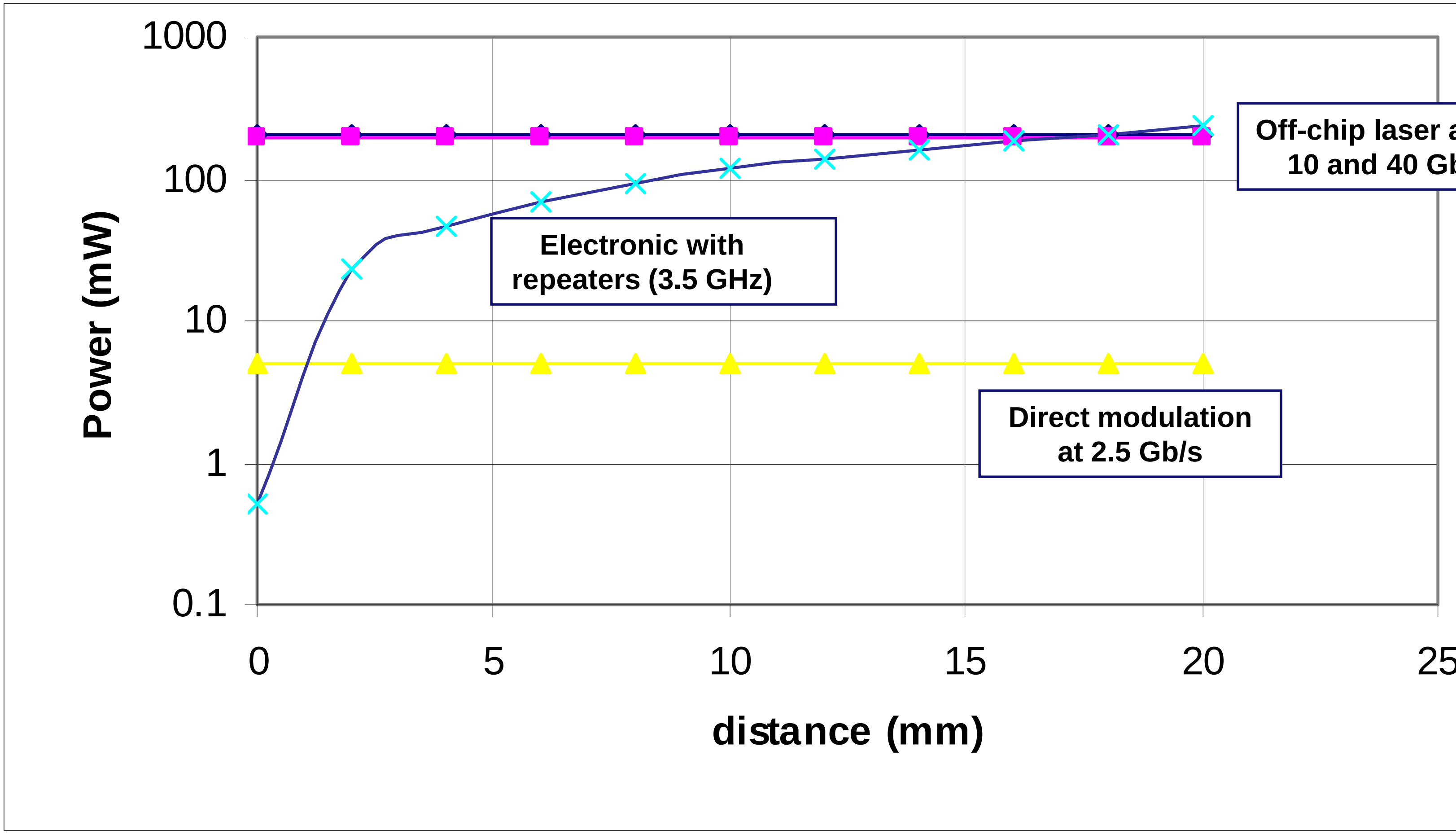
Power laser	5 mW
Power modulator	0 mW
	5 mW (2 mW/Gb/s)

Power modulator driver	*0 mW*
Power TIA Receiver:	*75 mW*
	75 mW (30 mW/Gb/s

Bandwidth distance product
including driver power



Bandwidth distance product
without *driver power*



Conclusions (1)

Off-chip laser

- Sufficient link budget to allow some networking, but, ….. high power dominated by drivers

On-chip laser

- Sufficient power for a single link, but, …. insufficient link budget for a network on a chip

Conclusions (2)

Photonics gives an improved bandwidth distance product:

Bandwidth is limited by electronics, thus photonics only gives distance!!!

Need applications with “distance”