BT Group

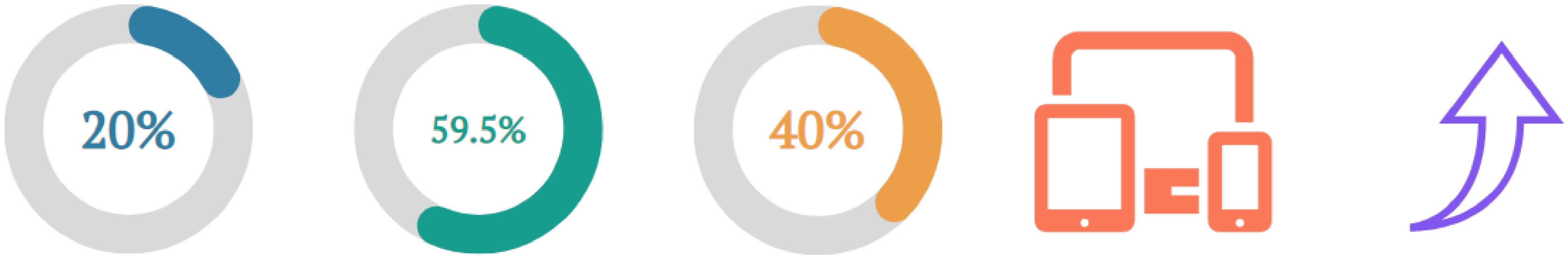
Photonic Integrated Circuits

Material, structures, and use-cases.

Dr. Zoe Davidson

Contents

Introduction and Motivation



By 2030 the internet is expected to consume 20% of the world's electricity output [1].

As of January 2021, 59.5% of the total global population were active internet users [3].

Data centres use an estimated 200TWh each year, with 40% of this being used by cooling [5,6].

By 2025 there will be more than 27 billion internet enabled devices [2].

In 2018 Cisco reported that global internet traffic had risen to 150,700GB per second, in comparison to 100GB per day in 1992 [4].

The telecommunications industry will increasingly struggle with increasing requirements in power consumption, data processing, cost, etc.

A promising technology to solve these issues is Photonic Integrated Circuits.

[1] NASA, climate.nasa.gov/vital-signs/global-temperature/ (25/10/2021).
[2] IoT-Analytics, https://iot-analytics.com/number-connected-iot-devices/ (25/10/2021)
[3] Statistica, https://www.statista.com/statistics/617136/digital-population-worldwide/ (25/10/2021)
[4] Cisco, Annual Internet Report, 2018.
[5] N. Jones, Nature, September 2018, https://www.nature.com/articles/d41586-018-06610-y
[6] X. Zhang, T. Lindberg, N. Xiong, V. Vyatkin, A. Mousavi, Energy Procedia, 105, 2017, 2047-2052

Introduction to Photonic Integrated Circuits

- Microchip containing two or more photonic components which form a functioning circuit.
- Detects, generates, transports, and processes light.
- Initial examples of photonic integrated circuits were simple 2-section DBR lasers, consisting of two independently controlled device sections – a gain section and a DBR mirror section.
- All modern monolithic tuneable lasers, widely tuneable lasers, externally modulated lasers and transmitters, integrated receivers, etc. are examples of photonic integrated circuits.
- The arrayed waveguide grating (AWG) which are commonly used as optical (de)multiplexers in WDM fibre-optic communication systems are an example of a photonic integrated circuit.
- Another example is the externally modulated laser (EML) which combines a distributed feedback laser diode with an electro-absorption modulator.

Why PICs?

Future private and public networks will be increasingly secure and low power, in addition to developing further in the classical network requirements of higher bandwidth and lower latency.

As these demands on the network grow, there will be an increasing requirement for integrated photonics and quantum technologies.

PICs will become a significant technology in the industry, ultimately appearing ubiquitously in network kit in high volumes.

As such we expect PICs to sit in many areas of our network.

What are PICs?

Key Materials and structures

Materials

InP

Si

SiN

GaAs

Ge-on-Si

Sb

GaN

SiC

Structures

Quantum Wells (QW)

Quantum Dots (QD)

Nano Wires (NW)

Quantum Dots in Nanowires (NWQD)

Micro rings/Optical rings

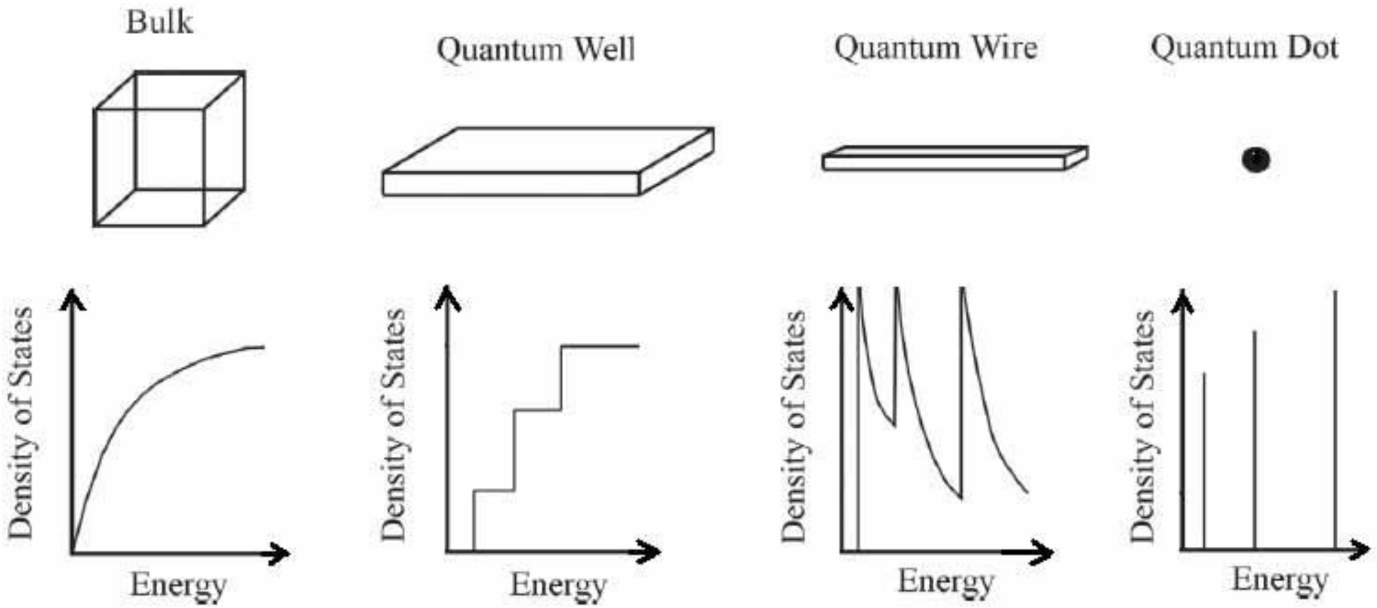
Optical frequency combs

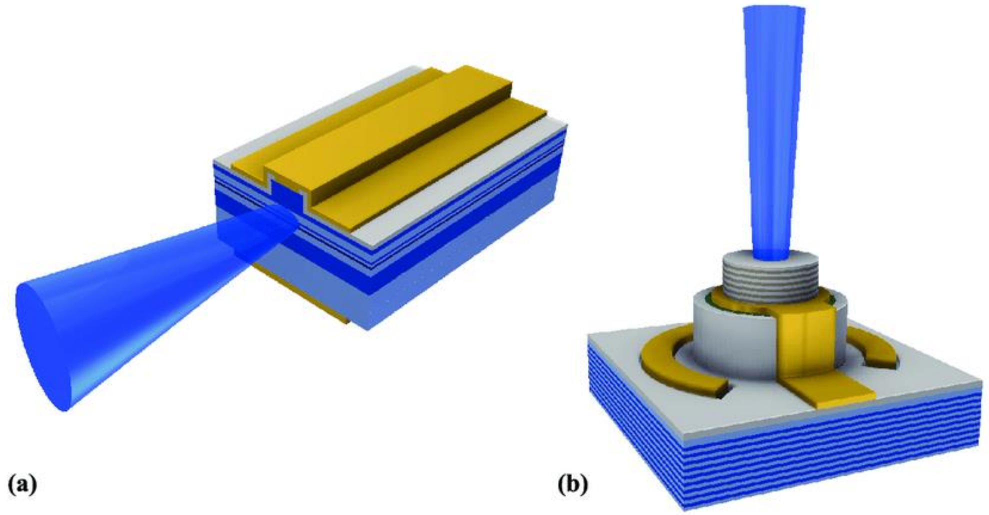
VCSELs

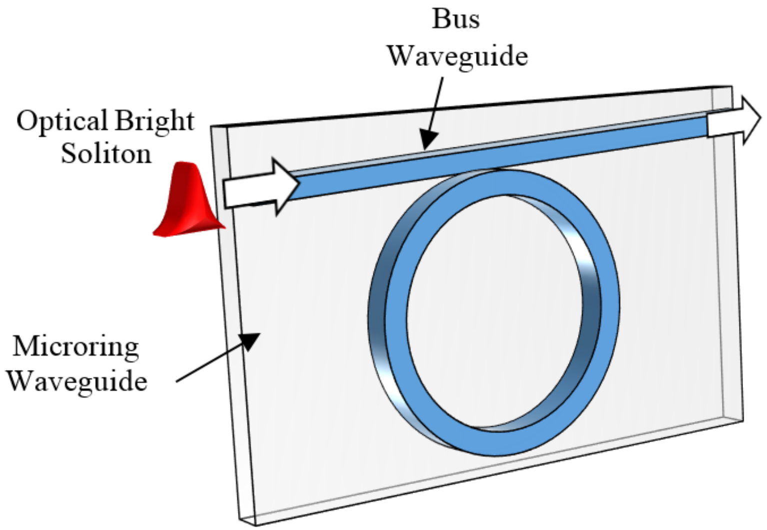
Edge emitting lasers

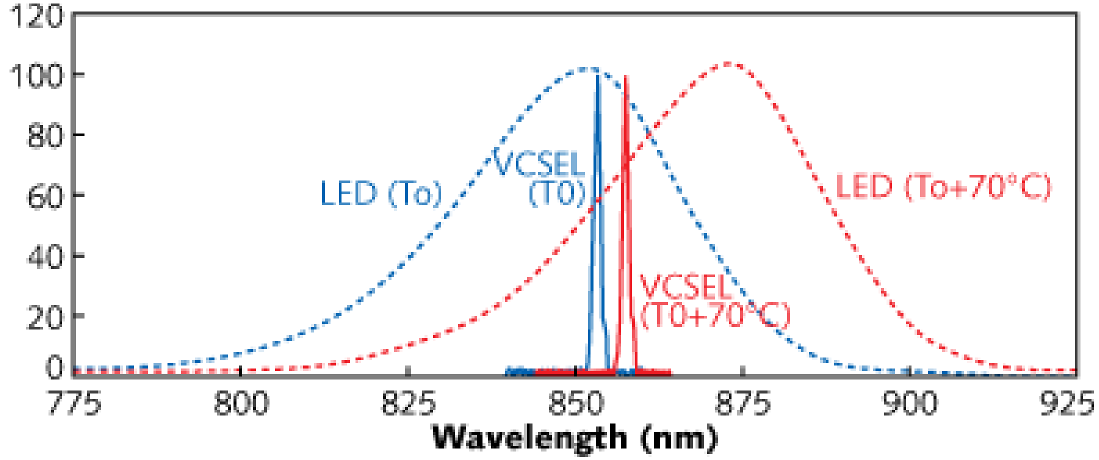
Material	Pros	Cons
InP	Well established material for comms Good gain at high frequencies Excellent noise figure at higher frequencies Low dark current	Difficult to integrate with Si Compounds tend to have high loss (>50%) at C-band Losses dramatically increase with temperature Low power density Lower operating voltage Expensive material
Si	Compatible with CMOS Cheap High yield Small footprint Excellent native oxide Moderately temperature insensitive	Indirect bandgap – thus cannot lase No second order nonlinearity Cannot be used in cryogenic applications (weak EO at low temperatures)
SiN	Better passive CMOS compatible material than Si Moderate refractive index Low loss Wide transparency window	Due to undesirable doping diffusion at high temperature, needs to be integrated with graphene or other integrated waveguides for use in PICs. Low modulation speeds Cracking due to internal stress
GaAs	Integratable with Si Enhanced electron confinement High thermal stability Low substrate cost High voltage operation Second order nonlinearity Weak piezoelectric coeffcicent	No native oxide Limited gain at higher frequency Moderate noise figure at higher frequency
Si-Ge	High electron mobility Low cost High bandwidth High speed High yield	Moisture and oxygen sensitivity Restricted surface functionalisation
Sb	Similar to GaAs High quality growth due to direction of dislocations	High threshold current densities High temperature sensitivity
GaN	High temperature High voltage Wide bandgap High speed Low switch loss	Lack of native GaN substrate Small crystals High quality growth currently difficult

Structures


Bulk
Quantum Well
Quantum Wire
Quantum Dot
Density of States
Energy


(a)
(b)


Bus Waveguide
Optical Bright Soliton
Microring Waveguide


120
100
80
60
40
20
0
775
800
825
850
875
900
925
Wavelength (nm)
LED (To)
VCSEL (T0)
LED (To+70°C)
VCSEL (T0+70°C)

PIC Use cases

Examples of where PICs may sit in our Network.

The use of PICs focuses on the reduction of SWaP-C.

Quantum

QKD in the access section of the network.

Parallel QKD to increase key rates (QKD WDM) using PICs in the core.

Timing

PICs for timing distribution would have a significantly decreased footprint compared to current timing devices

Optical Packet Switching

Development of PICs may assist in the long-held ideal of Optical Packet Switching.

Multiband Access

Reduction in DSP.
PIC OADMs.

Radio over Fibre

Analogue (A-RoF) or Hybrid Digital Analog (DA-RoF)

A growing industry

The growing landscape of companies researching in the PIC/Photonic Materials space (to name only a few)

IQE	CSA Catapault	Alter Technology	Cambridge GaN Devices	Bay Photonics	Coherent Group
Effect Photonics	Sivers Semiconductors	Fraunhofer	Toshiba	Pilot Photonics	Senko/Cudoform
Covesion	iPronics	Photon Path	Xceleprint	Wave Photonics	Phabulous

Where is BT?

What have we done and what are our next steps?

What have we done:

- Developed potential use cases in our network.
- Understood what our limitations are (what BT can and cannot do).

What are our next steps?

- Demonstrate the use of PICs in our network.
- Show that PICs have commercial benefits when used in the network.

Please get in touch!

Thank you

I will now take questions.

BT Group