Small and bright—what nanophotonics means for you

May 4 2016, by Benjamin J. Eggleton

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Twenty fifteen was UNESCO's International Year of Light and Light based Technologies. It was a celebration of past milestones in optics and photonics and a look forward into its future.

We celebrated 1,000 years of Arabic optics, 150 years since James

Maxwell's electrodynamics, 100 years since Albert Einstein's general relativity and 50 years since the invention of optical fibres. This year we celebrate 100 year since Claude Shannon, who introduced the theory of information, was born.

Optics began with the development of lenses by the ancient Egyptians and Mesopotamians, followed by theories on light and vision developed by ancient Greek philosophers.

The basic principles of optics are familiar: we wear glasses that rely on refraction to bend light in ways that magnify and sharpen images, use microscopes to see into microscopic worlds and telescopes to look to the stars.

We are probably less familiar with photonics. Photonics deals with the generation, detection and manipulation of photons, the building blocks of light. The field sprang from the invention of the laser and fibre optics in the 1960s.

Optical fibres are silica glass wires the size of a human hair that transmit vast amounts of laser-generated information, forming the backbone of today's internet.

The smartphone also exemplifies the importance of photonics: we use lasers to machine the casing; optics are used in the lithography that manufactures the microelectronic circuits; and the display and the network that connects the phones are both photonics based.

The next milestone will be when the photonics is integrated into the smartphone itself.

Dawn of nanophotonics

The 21st century will be the century of photonics and nanotechnology – nanophotonics – which deals the study of the behaviour of light on the nanometre scale, and of the interaction of nanometre-scale objects with light.

It is worth noting that the nanoscale is usually cited as 1–100 nanometres, so a nanometre is a billionth of a metre. In photonics, we are dealing with light waves that have a wavelength around a micron (one thousand nanometres).

However, these light waves interact at around the nanometre scale. So too are the structures that matter when it comes to manipulating this light.

At the University of Sydney we have been creating a new optical processing technology based on nanophotonics. This research is being undertaken by the CUDOS ARC Centre of Excellence, which is headquartered in the School of Physics and the Sydney Nanoscience Hub at the University of Sydney with nodes at ANU, RMIT University, Macquarie University, Monash University, Swinburne University and UTS.

At CUDOS we want to take the next step in the evolution of this technology. We want to build a truly photonic chip that will essentially put the entire optical network on to a chip the size of your thumbnail.

By doing this, we can leverage the massive semiconductor industry to harness the processing power of light on a length scale that can be mass produced and integrated into smart devices.

Fortunately silicon – which is the basis of microelectronics – is compatible with photonics. Most silicon chips today, such as the one in your computer and smartphone, use electrons to transmit information and perform computations. The trick has been getting these chips to work with light as well as electrons.

We now can build photonic circuits into the same silicon, although we are not talking about replacing the transistors in conventional chips with optical transistors. Photonics complements and interfaces with electronics.

Photonic chips, or photonic integrated circuits (PICs), represent a new paradigm in information processing. Over the past decade, CUDOS and other researchers around the world have created PICs for a range of applications spanning communications, computing, defence and security, medicine and sensing.

In communication systems, photonic chips can increase the capacity of our communications networks. In data centres, they are reducing the energy consumption, which matters because every Google search today consumes the energy required to boil a cup of water.

In defence photonic chips can enhance radar technology that helps protect our assets and personnel. And in health, we can reduce the scale and complexity of medical devices that are used to diagnose disease.

Another benefit is in "switching", which is central to all communications networks. At the new Sydney Nanoscience Hub, we are building nanoscale switching technologies that can switch at the speed of light, thousands of times faster than current switching technology.

We are using state of the art lithography, such as the tools in the Nanoscience Hub's clean room, to fabricate nanoscale circuits and structures. Lithography literally means printing, but in this context we are printing circuits on silicon wafers with nanometre scale features.

Bright future

So what's next? We need to transform PICs into active devices that sense and interact, analyse, respond to and manipulate their environment.

We are already building photonic spectroscopy techniques into the same silicon chip that performs electronic processing in your smartphone. This will potentially enable your smartphone to perform tasks such as medical diagnosis, including analysing blood or saliva, or sense pollutants in the environment via spectroscopy technologies.

But photonics is not well suited to some of these tasks.

So we need moving parts that can manipulate the microscopic world; we need mechanical actuation at the nanoscale, and we really would prefer a chip with no moving parts.

Our approach is to use sound waves that can be generated on the chip. These are not the traditional sound waves that we hear or use in ultrasound, but ultrahigh frequency sound waves. We refer to them as "phonons", which are particles of sound, just as photons are particles of light.

We are talking about hypersound, phonons with frequencies from 100 megahertz to tens of gigahertz. We are building a completely new chip that incorporates a photonic circuit for these hypersound phonons.

Harnessing hypersound on a chip enables the manipulation of microscale biological and chemical elements, which means we can mix, sort and select and even create a centrifuge on a chip. This is a laboratory-on-a-chip that can be integrated into the smart phone.

This represents a new paradigm for information processing. The speed of sound is about 100,000 times slower than the speed of light. We can couple information from the light wave to hypersound and store information.

The phonon frequencies coincide with the radio frequencies that are important in next generation mobile communications and radar, which allows us to process these microwave waves via the interaction between optical and phonon waves.

Australia has always punched well above it's weight in photonics research and commercialisation. We now have the nanoscience and nanotechnology infrastructure and capacity to take the next big step, which is to bring photonics on to the chip where it will transform our lives.

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