What CUDOS does and why it is important

Annual Report 2004

The Centre for Ultrahigh bandwidth Devices for Optical Systems (CUDOS)

An Australian Research Council Centre of Excellence

What CUDOS does and why it is important

The research being performed at the Centre for Ultrahigh bandwidth Devices for Optical Systems (CUDOS) directly affects the prosperity and social cohesion of Australia. If CUDOS' efforts lead to commercial success, the export opportunities are compelling and the benefits to communications are dramatic.

The appetite for bandwidth

Bandwidth is a term used to quantify the rate at which information can be transmitted from one place to another – be it between two PCs in the same office or between two cities located on opposite sides of the world. The more bandwidth you have, the more information you can send in a given amount of time.

Bandwidth is like computer memory; you live with what you've got, but more is always better. Witness the dramatic uptake in broadband. Every time Internet Service Providers (ISPs) and telecoms companies increase their bandwidth offerings, the rate of user uptake and application ingenuity exceeds even the most optimistic expectations. Internet surfing, e-commerce, remote PC networking, on-line MP3 music libraries, video conferencing… the list goes on. And waiting in the wings are Internet telephones (known as "Voice over IP"), video streaming and on-line "virtual" medicine.

So just imagine what would happen if service providers were able to offer a bandwidth to users that was not twice as fast, nor even ten times as fast, but hundreds of times faster – at almost the same cost? It would literally change our lives.

And not just in our leisure activities. Australia – like the rest of the developed world – is moving from the industrial age into the "knowledge worker age". In the industrial age a nation's wealth and social prosperity was largely generated by manufactured or administrative output produced by manually operated machines and human labour. In the knowledge worker age, industrial and administrative machines are – and will continue to become – so intelligent, accurate and automated that only a fraction of the number of people once required will be needed to operate them to produce the same output.

As a result, the value that a private or public organisation in a developed economy can deliver will not be measured by its capital equipment list and skilled manual work force, but from the ideas, motivation, knowledge, education and skills of its people. People will be the fundamental economic and social driver in the 21st century. And people need to communicate in an effortless, quick, easy and natural ways. Applications include secure business transactions, medical consultations and education. To perform these vital tasks efficiently demands wide bandwidth.

As another example, Australian regional communities will enjoy equal access to a range of services taken for granted in urban areas, including online specialised medical consultations. This may facilitate a significant rural shift in Australian demographics. Streaming video applications, broadcast in real time across the Internet, consume vast amounts of bandwidth, and require high latent capacity to ensure that the video images do not break up.

However, we can't fully exploit the bandwidth potential of optical communications today because there are some technical and cost hurdles to overcome first. These represent CUDOS' challenges.

Communications bottleneck

Light is not only the fastest way to transport information, but the frequency of oscillation of a light wave is so high that far more information can be "carried" by an optical wave than the much lower frequency radio frequency waves in copper cable.

Consequently, glass fibre-based (fibre-optic) cables, carrying photons instead of electrons to transport information, are already preferred as the method to carry high speed communications over vast distances (so-called long haul) and form the backbone of today's international telecommunications infrastructure.

However, there are plenty of bottlenecks that slow the performance of the network. As an example, consider routers. Routers are like postal workers; they direct information to the correct "address" on the network, such as the PC on your desk. Routers don't deliberately slow information, it's just that technical restrictions mean that the information carried by light has to be converted into electronic signals carried through copper, directed (or switched) by the router, and then turned back into light to continue their journey across the network.

You can think of the router as the neck of an hourglass throttling the rate of information transfer. In addition, routers are expensive, cumbersome and consume a lot of power. And worse, because routers are reaching their technical limits, there is little we can do to make them faster. It's time for a new approach.

CUDOS' five year mission is to replace the router and other electronic components in todays networks with an all-optical (or photonic) chip. To do this we have to conduct detailed research into "nonlinear optics", and to miniaturise optical devices based on nonlinear optical effects. The challenge is formidable: ultimately we are pursuing a device – a "photonic chip" – that would remove the need to convert light to electronic signals and back, be the size of a thumbnail, cost a fraction of a router and consume very little power.

This technology would remove the restriction from the optical network, dramatically enhancing bandwidth cost-effectively. It's not hard to visualise the commercial opportunities for the inventors.

The CUDOS solution

CUDOS' photonic chip can be thought of in the same way as the microprocessor integrated circuit (IC) driving a typical PC. This device is incredibly powerful, yet inexpensive. The key to advances in microelectronics has been the use of scaleable manufacturing processes for integrated electronic circuits that could be improved cost-effectively.

The complex functionality of a microprocessor has been achieved through miniaturisation and integration. The real cost of these devices is not much different to the cost of "leading edge" products of forty years ago, but there have been extraordinary improvements in performance.

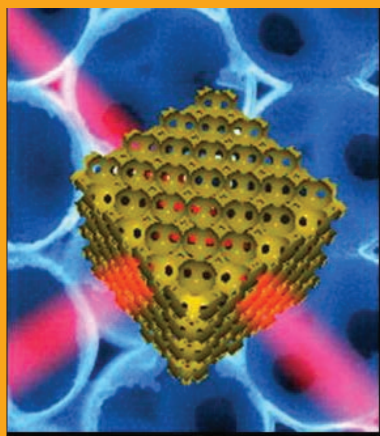
What is a Photonic Crystal?

Electron micrographs of a butterfly wing show a regular crystalline structure that produces colour-variable reflection.

Structured optical materials where the refractive index varies periodically in two or three directions are called Photonic Crystals. When the scale of the periodicity is comparable to the wavelength, Bragg reflection occurs, but only over wavelength ranges that depend on the propagation direction in the crystal and the periodic refractive index modulation. These "bandgaps" are analogous to the electronic conduction bandgaps found in semiconducting materials. Some photonic crystals have complete bandgaps. In this case light cannot propagate in the photonic crystal in any direction and all light incident on the crystal will be reflected, regardless of direction.

Photonic crystals occur in nature. The coloured reflection from butterfly wings, for example, comes from wavelength-selective reflection of light from two and three dimensional microstructured features on the surface of the wing. Synthetic photonic crystals with tailored optical characteristics can also be fabricated, in silicon for example using semiconductor fabrication techniques.

Photonic crystals will be a key enabling technology for the development of microphotonic devices. Consider, for example, a photonic crystal with a row of periods taken out. This acts as a waveguide for wavelengths within a bandgap, since this light cannot "leak away" through the crystal. In principle, then, waveguides in photonic crystals can guide light through 90° bends with micrometre-scale radii of curvature. The enormous dispersion at frequencies close to the edges of the photonic bandgap is strongly dependent on propagation direction and wavelength, so small changes in incident direction or wavelength may lead to large changes in propagation direction inside the photonic crystal. This "superprism" is the basis of the CUDOS logo.



Artist's inmpression of a three dimensional photonic crystal, so called because the structure is periodic ("crystalline") in all three dimensions.

CUDOS is striving to apply the lessons learned in developing microelectronic components to optical communications. The success will depend upon miniaturisation and integration of photonic components into a single chip that could replace expensive, cumbersome routers. If the optical components can be integrated onto a single tiny chip, and CUDOS can develop optical ways of carrying out the switching and pulse "re-shaping" functions that are presently done electronically, we could make the photonic chips using the same scaleable processes that are used for microelectronics.

With the next generation of optical communications systems built around these photonic chips, we can open the gate to a path of development that will lead to a level of personal, business and regional interconnectivity unimaginable even by today's standards, with significant benefits for personal well-being, business productivity, and the knowledge economy. Ultra-bandwidth telecommunications systems will underpin Australia's future prosperity.