Background information
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Photonics – The key technology for tomorrow's computers and entertainment electronics

No one likes to wait. Particularly if they are in a hurry. Wouldn't it be great if files from the Internet really were available on demand? If videos could be shown immediately without buffering? If synchronizing mobile phones with a PC or uploading to an iPod* would no longer be painfully slow, but rather over in fractions of a second? Innovations over recent years have enormously increased the speed of computational processes, as well as Internet bandwidths. However, the technologies that are currently in use for data transfer are already encountering their physical limits. We have reached the end of the line, so that new innovations are called for. There are two areas in which a new technology is needed in order to be able to maintain the past speed of innovation into the future as well. Firstly, data transfer via the Internet; secondly, data transfer within and between microchips.

Data transfer via the Internet

Data streams within the Internet have now reached immense proportions, and data traffic is growing from day to day. Just consider YouTube*, which more and more people are using to share more and more data with others – and that is only one data-intensive application amongst many. At the same time, the quality of content such as HD videos, and thereby their file size, are increasing continuously. The result is a data traffic jam on the digital superhighway – or more precisely: at its "exits".

When data is sent via the Internet, it needs to be sorted by means of a kind of distribution station (routers and switches), then forwarded to the correct recipient. At present, this job is undertaken in a convoluted manner by complex computer hardware, which is sooner or later going to hit the buffers. Generally speaking, the data reaches the distributor in the form of photons sent via fiberglass cables. In the distributor, it is converted into electronic signals (electrons[1]), sorted, converted back into photons[2] and sent on its way via another fiberglass cable. This is laborious, expensive and takes a lot of energy. The data throughput can only be increased with difficulty using existing technology, because its scope for development has been practically exhausted. Additional hardware must be purchased in order to forward more data. Or, a different technology could be used[i].

An optical chip, for example, that could process photons directly would work much faster and use less energy. In this way, the 19-inch cabinets stacked as tall as a man with electronic components could be replaced by a single small chip[ii] tomorrow.

Data transfer within computers

The current technology is also reaching its limits within computers. Data on microchips is transferred via metal conductor paths, for example between the individual processor cores or the processor and the main memory. However, processors are now able to process so much data in such a small time that the conductor paths will soon be unable to carry data fast enough. And what is the use of an extremely fast processor core if it cannot transfer its data as quickly as it has done the calculations? New transfer technology would not only permit extreme performance increases, but also act as the midwife for completely novel devices. Entirely new supercomputers could accomplish important calculations, such as in medicine or climate research, within the blink of an eye. Today's supercomputers, housed in cabinets as big as wardrobes and linked together in enormous halls, could be shrunk down to the size of a notebook. Perhaps, in the near future, we will also start to use small mobile computers which we will always carry with us like mobile phones or smartphones, but which will deliver significantly greater performance than current high-end notebooks do.

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[1] Electrons are negatively charged elementary particles. They can move freely within metals and form the basis for the electrical conductivity of metal. The electrons in the outer shell of atoms are called valence electrons. The movement of valence electrons means that electric current flows. See http://www.elektronik-kompendium.de/sites/grd/0110271.htm

[2] To simplify things greatly, it is possible to say that photons are "light particles". However, in contrast to all other particles, they have no mass. In a laser, atoms are artificially excited, prompting them to give off their photons in a specific way. Mirrors enable these to be directed and combined. When the light waves are running in parallel and in synchronicity, they are referred to as coherent (laser) light. See http://www.weltderphysik.de/de/1487.php

Photons instead of electrons – how Intel is making the future possible

For more than half a decade, Intel has been researching data transfer via light at its Intel Silicon Photonics lab in sunny California. In 2008, the company presented a fully functioning prototype of an optical microchip which is far superior to conventional methods of data transfer. Now, a further breakthrough is about to be made, and one which will revolutionize the possibilities of the Internet: The first tera-scale microchip. Conventional processes work with bandwidths between 10 and 40 Gbit/s[3]. A tera-scale microchip has a transfer rate of 1 Tbit/s, which is the same as 1000 Gbit/s. This corresponds to the volume of 35 DVDs per second[iii]. Bandwidths of this kind open up the door to completely different utilization scenarios. Multimedia content will be able to be provided "on demand" without any waiting times, whilst backing up data onto the net by uploading it will become the norm and will only take a matter of moments. However, entirely new applications are also conceivable. In medicine, transfer speeds of this kind would enable remote diagnoses that require a great deal of data to be transferred in real time. And if this technology is used inside computers as a second step, completely new possibilities would open up for both professionals and enthusiasts: not only 3D online gaming with fantastic graphics, video processing and 3D modeling in real time as well as many other benefits, but also the ability to transfer enormous quantities of data practically instantaneously. Would you like to send a film from your PC over to your netbook? A matter of mere fractions of a second.

Optical microchips – how they work

The optical microchips that Intel is researching are made from silicon – just like conventional microchips. This offers the advantage of being able to use existing production systems and expertise spanning four decades in their manufacture. Furthermore, silicon is a practically inexhaustible resource. After oxygen, it is the next most common element on the Earth, and can be obtained from quartz sand.

An optical microchip functions in a similar way to a conventional chip, except that its conductor paths are not made from metal, and that data is not transferred in the form of electrons. Rather, photons are transported through the silicon in light ducts, referred to as waveguides. To a large extent, an optical microchip is made of three components: a modulator that converts electronic data into light, a laser which acts as a light pump to send the photons through

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[3] Gbit/s is the normal international unit of measurement for data transfer rates, and stands for gigabits per second. A bit is the smallest possible unit in data processing, namely either a zero or a one. 1 Gbit/s corresponds to 1,000,000,000 bits per second.

the silicon, and a demodulator that converts the photons back into electronic impulses.

The electronic data is recoded into light pulses in the modulator. Theoretically, this is very straightforward, because digital data only occurs in two states, namely "zero" / "one", or "on" / "off". To put it simply, the modulator operates like a light switch which switches the laser on and off, thereby passing on the digital data in the form of photons. To enable the photons to be transmitted, it is necessary to have a certain type of laser, in this case a Raman laser[4iv]. Intel has developed a Raman laser composed of silicon and indium phosphide, which will be used on the company's optical microchips. The photons are converted back into electrons by the demodulator, the last missing component of an optical microchip. The demodulator is made up of a silicon core, but has a special germanium coating in order to absorb the light. When the laser pulses strike the demodulator, they are absorbed by the germanium layer, thereby causing electronic pulses to be created. These pulses are passed on to the silicon where they are amplified and can then be processed electrically.

Status quo and outlook

The prototype presented in 2008 worked with eight channels, i.e. eight modulators, eight lasers and eight demodulators on one chip. Each of these was able to transfer 25 Gbit/s, amounting to a data throughput of 200 Gbit/s. The tera-scale microchip that will be presented soon contains 25 channels, each with a throughput of 40 Gbit/s. This means the theoretical data transfer rate is up to 100 times as fast as currently. A file that now requires 10 minutes to transfer would be downloaded in six seconds. This chip will be used in optical telecommunications in order to avoid bottlenecks in Internet data transfers. Optical silicon chips are much cheaper and use much less energy than chips with conductor paths made from copper. Intel is planning for the market launch to be within two to three years, thereby laying the foundation for highly efficient, extremely fast Internet connections available at a lower price than today.

As a second step, photonic technology will be used in PCs, namely in the form of an optical interface for connecting a memory medium or another peripheral unit, for example. Intel presented this technology in autumn last year under the name "Light Peak". Delivery of these components to partner companies for testing and research purposes is expected to start during this year. An interface

[4] A silicon Raman laser is a laser that is manufactured wholly or partially from silicon and uses the so-called Raman effect first demonstrated by the Indian mathematician Chandrasekhara Raman in 1928. Raman lasers are suitable for building optical chips due to the specific properties of their scattered light.

of this type would allow a complete Blu-ray film to be transferred in 30 seconds, for example[v]. Ultimately, within the next few years, it will be possible to interconnect several processor cores using photonics, enabling them to exchange data very quickly between one another and with other components[vi]. An innovation of this kind would be as revolutionary as music in digital format: Nowadays, one CD can hold more than a dozen LP records converted into MP3 format, whereas a single Blu-ray disk can store more than 600 albums. Alongside research into quantum computers and biocomputers, optical data transfer is the third key technology that will fundamentally change our lives with digital technology in the near future.

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[i] http://www.intel.com/pressroom/archive/releases/2008/20081207corp_sm.htm#story
[ii] See http://www.heise.de/tr/artikel/Erleuchtetes-Silizium-280575.html
[iii] See http://www.technologyreview.com/computing/19182/
[iv] See http://blogs.intel.com/research/2008/02/cascade_laser.php
[v] See http://techresearch.intel.com/articles/None/1813.htm
[vi] See http://www.technologyreview.com/blog/editors/17671/?a=f