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President's Column

MILTON CHANG

I will write about "Business and Industry" for this issue as I planned to do in the beginning of the year. I will give you an update on my goals, and also report on the results of OFC 2002 and on the IEEE budget.

Many people are asking, "When will the recovery occur?" The reality is no one really knows, and I am also not sure that's the right question to ask. Until the carriers' financial picture improves significantly, they are not going to able to borrow to go on a buying spree. Since earning money the old-fashioned way takes time, we can expect the recovery will be gradual. A better question to ask may be what the recovery might look like. We can get a little hint by reminding ourselves that until the last few years, telecom companies never used to buy from small companies. I was told years ago that they didn't want to worry about the system not working for a "hundred years" after they buried it under the ground. Long time any way. Buying from new suppliers seems highly risky by that definition. So the likelihood is carriers will only buy from new companies when there is a compelling reason for them to switch from established suppliers.

Most of us are asking about the recovery because we are feeling vulnerable about our companies and our jobs. Just how bad can things get? Being an eternal optimist, I am going to go overboard on my pessimism to err on the side of playing safe. The once overly exuberant market forecasters are now perhaps overly depressed. They are now predicting the optical telecom business will return to last year's level around 2005! The venture community gurus are also forecasting gloom and doom, predicting out of the 700-800 optical telecom companies started in the last three years, less than 10% will survive, and some people think that's being too optimistic. So, company management has two choices, cut back the workforce too far, or not far enough. The right choice is obvious since one is a recoverable mistake, the other one is not. The reality is there is no way getting around the reality of being out of money, out of business. Most of these companies were started with the assumption of being able to go IPO in two to three years. Since fewer than a handful of companies will go IPO this year, the loss of investor confidence will further aggravate the problem, and is going to be a major cause to make the 10:1 prediction a self-fulfilling prophecy. So, my advice is to think conservatively in whatever you do. And for those companies that have had the fortune of going IPO during the bubble, conserve cash because when the interest rate rises, which most certainly it will, cash is going to be king.

For my "president's goals," we have formed an ad hoc committee to address what LEOS can do in support of Chapter activities and to activate retired members. Karen Bergman, Robert Lang, Del Owyoung, and Shoichi Sudo graciously volunteered. We need input from you, especially if you are active in Chapters or have retired. Some of the action items we initiated for Chapters are: Organize and post best practices on the LEOS website; hold a Chapter retreat at LEOS annual meetings; Karen will write an article listing all the LEOS benefits available to Chapters and student members; and Chapter Chairs are encouraged to have more interaction with LEOS officers and also to make use of the staff resources at the Executive Office. Del is the first of a few retirees who have contacted me, and he has already volunteered in LEOS activities. So I would like to hear from more

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Editor's Comments

MARY WISNIEWSKI

In this month's issue, we would like to ask for your feedback on our technical coverage in the *LEOS Newsletter*. Do you find the articles timely and well-written? Is our selection of topics interesting? Have you enjoyed the choice of topics and articles in each annual Special Issue? Please send your feedback via email to myl@us.ibm.com.

In this issue, our "University Research Highlights" section presents the research of Prof. Ivan Deutsch and his group at the University of New Mexico and Prof. Poul Jessen and his group at the University of Mexico. Their article is entitled "Quantum Information Processing in Optical Lattices: Cold Atomic Qubits in a Virtual Crystal of Light". For more information, see Prof. Deutsch's webpage at http://panda30.phys.unm.edu/Deutsch/Homepage.html.

This issue also presents a profile of Prof. I. C. Khoo, who is a newly-elected member of the IEEE-LEOS Board of Governors and is Vice-President of Technical Affairs. Prof. Khoo is Distinguished Professor of Electrical Engineering at Pennsylvania State University, where he performs research on the development of nonlinear optical fibers and fiber arrays for optical switching and sensor protection application, and electro-optical and nonlinear phenomena and devices based on liquid crystalline materials. Prof. Khoo wrote the "Profile" that is included in this issue. His website is: http://www.ee.psu.edu/faculty/khoo/khoo1.htm.

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IEEE Lasers and Electro-Optics Society

Quantum Information Processing in Optical Lattices: Cold Atomic Qubits in a Virtual Crystal of Light

IVAN H. DEUTSCH

Department of Physics and Astronomy, University of New Mexico, Albuquerque

POUL S. JESSEN

Optical Sciences Center, University of Arizona, Tucson

I. Introduction

Every student of modern physics comes away from their first course on the subject with the same unsettling feeling – quantum mechanics is just plain weird. Electrons are both particles and waves, wave functions "collapse" when they are observed, nonlocal correlations cannot be explained by a local realistic theory, "indivisible" photons simultaneously take two paths in an interferometer, or in Schrödinger's most extreme brain-twister, cats can be forced into a virtual purgatory, being both dead and alive. We are generally taught to just accept these paradoxes and move on. Quantum theory has been put to test and has predicted the proper statistics for every experiment from the lowest to the highest energies in the universe. It explains the conductivity of silicon and the scattering cross sections of elementary particle collisions in our most powerful accelerators. Reconciling the bizarre aspects of quantum theory is better left for the philosophers. Scientists and engineers should get on with more pragmatic work.

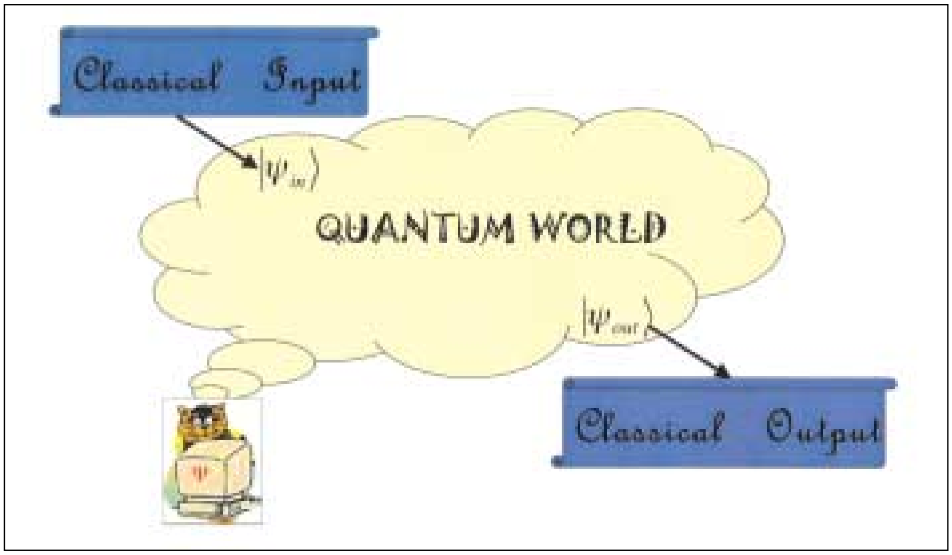

Fig. 1. Quantum information processing involves three crucial steps: (1) Preparing an input quantum state based on some classical information, (2) processing the system to some final state through the murky quantum world, (3) measurement of the output state.

If we're taught one thing as scientists, it is never to stop asking, "why;" "what does it mean;" "if I push that line of reasoning to its logical conclusion what are the implications?" It turns out that implications of quantum weirdness are of profound pragmatic significance. Quantum mechanics is a theory of probabilities, and probabilities in modern Bayesian statistics are statements of information – predicting outcomes given our prior knowledge – what we know and what we don't know. Following this line of reasoning to its logical conclusion we are lead to a radically new idea — *quantum information*. The lesson here is one we were taught by the late Rolf Landauer, "information is physical". The laws of information processing cannot be divorced from the physics of the devices that carry out the tasks.

Contrary to common belief, quantum theory is not a paler version of pristine classical physics, filled only with pesky uncertainty and uncontrolled random behavior. Quantum information processing (QIP) opens the door to tasks which are otherwise impossible. Examples included perfectly secure secret-key distribution based on the principle of information-gain vs. wave function disturbance, and improved efficiency for complex communication tasks based on the principle of quantum entanglement and teleportation. Perhaps most exciting is the prospect of new computers which can implement algorithms unfathomable with the worlds most powerful "classical" supercomputers. Peter Shor's algorithm to factor numbers into their prime constituents is an example of this sort; it was the spark that caused the major explosion in quantum information science research that we see today. What lies ahead on Moore's roadmap of ever shrinking microprocessor components is not just a tinier version of devices where switches open and close valves for classical currents, but a broad new principle based on quantum theory.

What will it take to unleash the great power of quantum information? The most general task requires input of classical information into a quantum system, processing that quantum system in some way, and then reading out the result (Fig. 1). These tasks involve state preparation, quantum control, and measurement. Much progress has been made on these fronts, especially in atomic-molecular-optical systems. The quantum optics community has for years been engaged in experimental studies at the foundations of quantum mechanics, based on the preparation, manipulation, and measurement of individual photons and atoms and more generally, precision spectroscopy. These techniques are now "online", ready for application to QIP. Indeed, some tasks, such as quantum key distribution, are close to practical reality based on advances in photon sources and detectors.

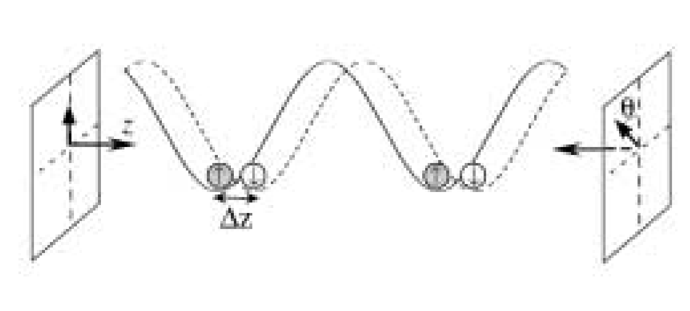

Fig. 2. A one dimensional optical lattice with polarization gradients forming separated standing waves of right and left helicity, and trapping spin-up and spin-down states of an atom. The application of a transverse magnetic field couples the two states leading to double-well potentials. Tunneling is accompanied by a changing in the atomic spin.

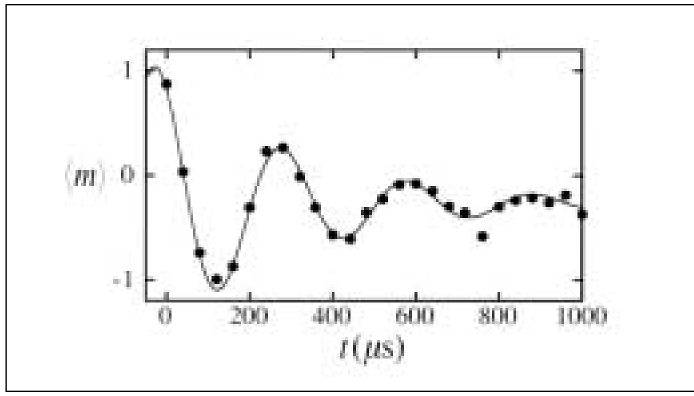

Fig. 3. Typical oscillation of the atomic magnetization as a function of time. The solid line is a fit to a decaying sinusoid.

Given this progress one might imagine that a quantum computer is around the corner. Unfortunately, that is far from true. Full QIP, such as quantum computation, requires quantum control and measurement of a *many-body* system. This is a daunting task. It is tantamount to engineering our own version of "Schrödinger's Cat". Luckily, quantum information theorists have taught us that it is not insurmountable. The control problem can be decomposed into basic building blocks known as quantum logic gates, in analogy to classical Boolean circuits. If state preparation, gate operation, and measurement can be performed with sufficiently fidelity, QIP is robust, secure from the ravages of errors through special quantum-error-correction protocols. Nonetheless, the gap between the fault-tolerant thresholds and the state of the art in experiment is huge. Further progress requires new implementations and experimental tools for preparation, control, and measurement, along with new theory, to help build a bridge that can span the gorge.

Our research at the University of New Mexico and University of Arizona is focused on developing these tools. The system we study is the "optical lattice", ultracold atoms trapped in the microscopic potential wells created by the interference pattern of a set of intersecting laser beams. Atoms are effectively sucked into the nodes or antinodes of a standing wave (generally three-dimensional) in the same way that a polystyrene ball is sucked into the focus of a laser beam as used in "optical tweezers". The resulting trap is very tight due to the sharp gradients in the field that varies on the scale of the optical wavelength, but shallow due to the weak force acting on the small neutral atoms. The atoms must be ultra-cold (microKelvin regime) in order to remain in their virtual egg crate (see Fig.6). Fortunately, the tools of laser cooling provide a good starting point to prepare the system. With these trapped atoms we can work to prepare, manipulate, and measure them, thereby growing our quantum toolbox and build the bridge to QIP.

II. Quantum Control of Atomic Motion in Optical Lattices

Motion of a particle in a double-well potential has long been used as a paradigm for quantum control and quantum coherent dynamics. We have implemented a unique version of this basic system using cesium atoms trapped in a 1D lattice. This problem represents control of an ensemble of uncoupled atomic quantum systems; it is not intended to lend itself directly to quantum information encoding and processing which requires atom-atom coupling, but its successful realization involves manipulation and observation of spin- and center-of-mass degrees of freedom, in the presence of non-trivial interactions between them. This makes it a perfect training ground for the development of control and measurement tools needed to undertake the much harder challenge posed by few-atom control processes such as quantum logic. From another perspective the cold atom/optical double-well system is interesting because it is *mesoscopic*, in the sense that the characteristic action can be varied continuously across the quantum classical border (the range $0.1-10\hbar$), and therefore is subject to rapid decoherence if the lattice and its environment is poorly controlled. It is also *complex*, in the sense that the atomic wavepackets are *spinors* that represent highly entangled states of the atomic center-of-mass and external degrees of freedom, and that the coupling of the two leads to dynamics whose classical counterpart exhibits deterministic chaos. Last but not least, we have a series of powerful laboratory techniques available that allow us to prepare well defined pure states, subject them to controlled unitary evolution, and accurately measure the quantum state along the way.

The lattice potential is formed by two linearly polarized, counter-propagating beams whose polarization vectors are misaligned by an angle θ (see Fig. 2). The field can be decomposed into two circularly polarized standing waves of opposite helicity ($\sigma_{\pm}$) whose nodes are separated by $\Delta z = \lambda(\theta / 2\pi)$. Cesium, like all the alkalis, has one valence electron with spin 1/2. Under appropriate conditions, the spin-up (down) state will be trapped near the nodes of the $\sigma_{+(-)}$ standing wave. Now imagine adding a transverse magnetic field. Without the lattice, the atomic spin would Larmor precess about the field at the frequency $\Omega = \mu_B B_{\perp}$. In our system, however, because the atom's internal state is correlated with different potential surfaces, spin precession is accompanied by motion of the atoms between the two wells. For small enough magnetic fields, and low enough energy, the atom must *tunnel* to get from one well to the other. This tunneling is accompanied by a rotation of the atomic spin. These two degrees of freedom become *entangled*. Thus, we can think of the spin as a "tunneling-meter". We measure the spin at different times, for many runs of the experiment, using a Stern-Gerlach apparatus. The oscillation of the atomic magnetization is then evidence of coherent tunneling back and forth in the double-well. In the actual experiment, the real Cs atom is not spin 1/2 due to the hyperfine interaction with the nuclear spin. Our atoms are prepared in a state with total angular momentum F=4, giving a total of $2F+1=9$ sublevels. Nonetheless, the physics of the full system has the same qualitative features as the simple spin-1/2 model.

To observe coherent tunneling we first prepare a dilute vapor of $\sim 10^6$ noninteracting Cs atoms, each in an initially localized quantum state, say the left ground state $|\psi_L\rangle$, and then observe the subsequent quantum evolution of the ensemble.. Figure 3 shows a typical oscillation of the atomic magnetization as a function of time. Our data fits well to a damped sinusoid, and allows us to extract a good measurement of the tunneling frequency. We find generally excellent agreement between the measured frequencies and a bandstructure calculation of the energy spectrum, with no free parameters, over a wide range of experimental conditions. In this first experiment the tunneling oscillations dephase on a timescale of a few hundred microseconds, most likely due to variations in the tunneling frequency across the atomic sample. A next generation of the experiment is now underway, in which we hope to increase the dephasing time by an order of magnitude by better control over lattice beam and magnetic field inhomogeneities. With better homogeneity and larger detuning we hope to explore coherent dynamics on a time scale much longer than the Rabi period.

At a quarter of the oscillation period, the system is in a superposition state reminiscent of Schrödinger's cat. The positive atomic magnetization is analogous to the undecayed nucleus correlated to the live cat (here, the left localized wave packet), and the negative magnetization is analogous to the decayed nucleus that triggers the poison vial and thus correlated to the dead cat (right localized wave packet). Using our Stern-Gerlach apparatus we can measure the individual magnetic sublevels of our atoms to reveal these correlations. Figure 4 shows a plot of the theoretically calculated squared wave function components at 1/4 of the tunneling period, with position and spin probability distribution projected on the walls. This clearly demonstrates correlation between spin and motion in the "Schrödinger-cat" state, with depressed probability in the "classically forbidden zone". Comparing theory and experiment we see strong qualitative agreement and quantitative agreement to within experimental uncertainties.

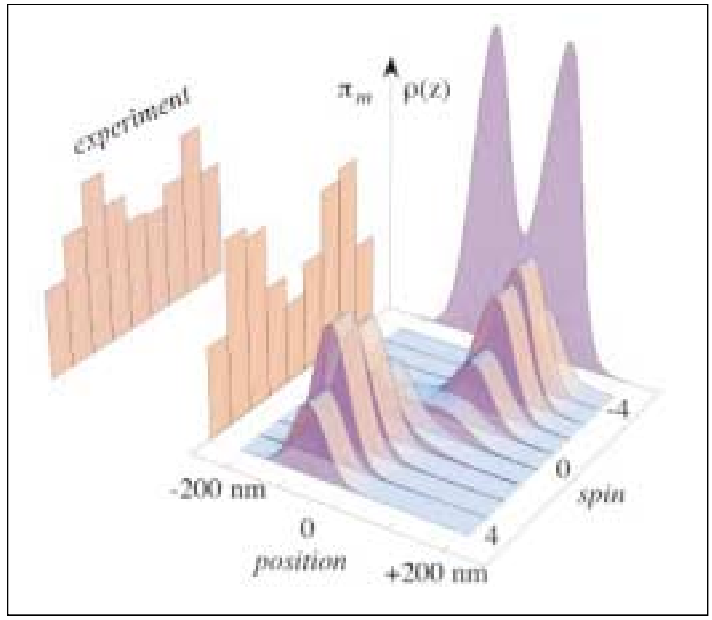

Fig. 4. At a quarter period of the tunneling oscillation the atomic state is a Schrödinger Cat-like superposition, where the internal and external degrees of freedom are strongly entangled. This figure shows the position dependent probability density for each of the nine magnetic sublevels of the F=9 hyperfine ground state of ^{133}Cs. The marginal probability distributions in position or spin are shown in shadow, projected on the wall. In addition, we show for comparison the experimentally determined m-state distribution, measured with a Stern-Gerlach apparatus.

III. Quantum Control of Many Atoms

III.A. Quantum Logic Gates

Quantum information processing borrows much of its language from classical information theory. In the latter, the fundamental unit of information is the "bit", short for "binary digit" 0 or 1. In quantum information, the fundamental unit is the "qubit", short for "quantum bit" $|0\rangle$ or $|1\rangle$. The logical basis $\{|0\rangle,|1\rangle\}$ are two orthogonal states of a quantum system, for example, the spin-up and spin-down states of a spin 1/2 electron, or two well defined energy levels of an atom. However unlike its classical counterpart, the qubit can be in a continuum of states which have no classical description, the coherent superpositions $|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$. Of course, when the qubit is measured we will find only one classical bit of information, $|0\rangle$ or $|1\rangle$, with probabilities $|\alpha|^2$ and $|\beta|^2$ respectively. Nonetheless, the quantum bit can in some sense store both $|0\rangle$ and $|1\rangle$ simultaneously, in the same way that the photon can take both paths in an interferometer. The interference of probability amplitudes is at the heart of the working of the quantum computer.

The quantum computer involves many qubits, at least one for every classical bit of information we want to process, and lots more when we include redundant encoding needed for error correction. The state of the many-body system will generally be a highly *entangled state*, of the sort behind the famous Einstein-Podolsky-Rosen paradox and Bell's theorem for the two-body problem. A state with N qubits will require 2^N probability amplitudes. This exponential explosion of Hilbert space, without an exponential explosion of physical resources (here, the number of qubits) is one of the key features that distinguishes quantum computers from classical analog wave computers (e.g. Fourier

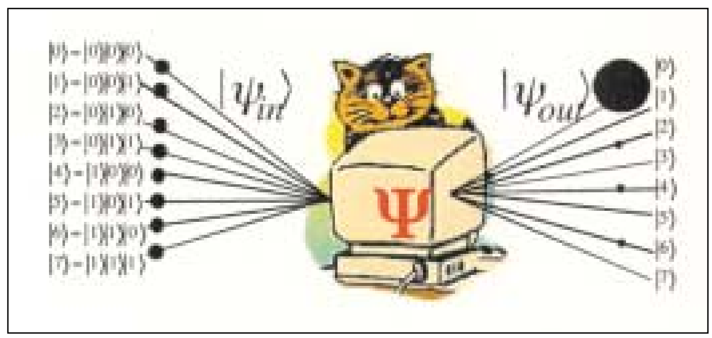

Fig. 5. Quantum Parallelism: A quantum computer acts like a multi-port interferometer, operating simultaneously on many classical outcomes. Shown here is a schematic of a three qubit system which can encode 8 possible outcomes (0-7). Interference between paths, driven by the quantum algorithm, leads to constructive interference for the desired answer to a computational problem (here 0), which can then be read out with high probability.

image processors). It allows us to interfere an *exponential* number of paths of our virtual interferometer. Each path can be a classical outcome (like the prime factors) which gets processed simultaneously. This picture of computation is known as "quantum parallelism" (see Fig. 5).

How does one run a quantum algorithm? Again, we borrow from classical information theory. A collection of classical bits can be processed thorough a Boolean circuit consisting of a collection of logic gates acting in sequence only on small subsets of bits. Examples of gates include the single-bit gate NOT and the two-bit gates AND, OR. An arbitrary transformation between input and output can be constructed from a small number of "universal gates". In QIP we have analogous constructs. Quantum logic gates map input states to output states (they are unitary transformations). Thus, the analogy to the classical NOT is the quantum map $NOT|0\rangle = |1\rangle$, $NOT|1\rangle = |0\rangle$. However there are a multitude of nonclassical single-qubit gates such as $\sqrt{NOT}$ which maps $\sqrt{NOT}|0\rangle = (|0\rangle - i|1\rangle)/\sqrt{2}$, $\sqrt{NOT}|1\rangle = (|1\rangle - i|0\rangle)/\sqrt{2}$.

It is a nice exercise to prove to yourself that $\sqrt{NOT} \circ \sqrt{NOT} = NOT$ (up to an overall negligible phase). Another example is the Hadamard $H|0\rangle = (|0\rangle + |1\rangle)/\sqrt{2}$, $H|1\rangle = (|0\rangle - |1\rangle)/\sqrt{2}$. Though both $\sqrt{NOT}$ and H map the logical basis into 50-50 superposition, the relative phases make them quite different from each other. You can show yourself that $H \circ H = I$, the identity operator.

To deal with many-body control we will need a nontrivial two-qubit gate that *entangles* the two qubits. A nice example is the "controlled not" (*CNOT*) which applies a *NOT* on a target qubit conditional on the state of the control qubit. In the logical basis, treating the second qubit as the target, the truth table is $|0\rangle|0\rangle \to |0\rangle|0\rangle$, $|0\rangle|1\rangle \to |0\rangle|1\rangle$, $|1\rangle|0\rangle \to |1\rangle|1\rangle$, $|1\rangle|1\rangle \to |1\rangle|0\rangle$. In classical theory, this is the familiar truth table for *XOR*. But in the quantum world there are new possibilities. Suppose the control qubit is in a superposition state. Then after the gate, $(\alpha|0\rangle + \beta|1\rangle)|0\rangle \to \alpha|0\rangle|0\rangle + \beta|1\rangle|1\rangle$, which is an *entangled state*! Another example of a two-qubit gate which has no classical analog is the "*CPHASE*", $|0\rangle|0\rangle \to |0\rangle|0\rangle$, $|0\rangle|1\rangle \to |0\rangle|1\rangle$, $|1\rangle|0\rangle \to |1\rangle|0\rangle$, $|1\rangle|1\rangle \to -|1\rangle|1\rangle$. This seemingly innocuous operation puts a phase –1 on the $|1\rangle|1\rangle$ state, but it is anything but trivial. It too can produce entangled states. It is a good exercise to show yourself that the following circuit is correct: $CNOT(a,b) = H(b) \circ CPHASE(a,b) \circ H(b)$, with a and b labeling the two qubits.

This last relation is an example of an extremely important result in quantum information theory. A few logic gates can form a *universal set*. Arbitrary many-body transformations can be built out of a sequence of a few single qubit gates plus *one* entangling two-qubit gate, such as *CPHASE*. This greatly simplifies the task of implementation. Arbitrary many-body states can be built out of a sequence of single-body and two-body interactions! The single-body transformations can be performed today with great precision due to decades of advances in NMR, microwave, and laser spectroscopy. The new challenge is to design coherent *two-body* interactions, of the sort *CPHASE*. This is the task we have been exploring in the context of our optical lattices.

III.B. Entangling Dipole-Dipole Operations

Neutral atoms don't naturally interact with each other unless they're forced to through some kind of "collision". Collisions tend not to be controlled, the key word for QIP. The challenge then is to design a kind of controlled collision that achieves the two-qubit quantum logic gate. Our approach has been to consider a photon-mediated collision. Classically this is the electric dipole-dipole interaction. To see that this collision might be controlled, consider the following scaling argument. In the near field, the strength of the dipole-dipole coupling energy goes like $V_{dd} \sim \frac{d^2}{r^3}$. At the same time, an optically excited dipole can radiate spontaneous emission. The spontaneous emission rate is bounded, and goes like $\hbar\Gamma \sim \frac{d^2}{\lambda^3}$ (in energy units), where $1/\lambda$ is the radiation wave number. Spontaneous emission is generally an uncontrolled process and must be avoided for proper performance of the gate. Thus, a figure of merit for the gate can be defined,

$$\kappa \equiv \frac{V_{dd}}{\hbar\Gamma} \sim \left(\frac{\lambda}{r}\right)^3$$

We therefore see that if the atoms can be localized to distances small compared to the radiation wavelength, $\kappa >> 1$, they can be coherently coupled by a photon.

The optical lattice provides an ideal platform to put these ideas to the test. Atoms trapped near the bottoms of the potential wells are highly localized. Furthermore, atoms can be moved together pair-wise using the polarization gradients as in Fig. 2. We imagine then encoding a qubit in the internal hyperfine ground states of the atom (like those used in an atomic clock). An entangling quantum logic gate would then be performed as follows (Fig. 6). Atoms are trapped in a three dimensional trap consisting of linearly polarized standing waves along the three Cartesian axes. Rotating the polarization vectors along one axis, we bring an ensemble of atoms together in neighboring planes, ready for interaction. A separate "catalysis" laser excites dipoles. For appropriately chosen pulses the required phase is imprinted jointly on the two-atom target state, thereby achieving a *CPHASE*. Errors can occur in this gate due to spontaneous emission. If the gate operating time is Δt, the probability of spontaneous emission goes like, $P_{error} \sim 1 - e^{-\Gamma\Delta t}$. The gate operating time scales like $\Delta t \sim \hbar / V_{dd}$, so

$$P_{error} \sim 1 - \exp(-\hbar\Gamma / V_{dd}) \approx \frac{1}{\kappa}$$

For a very large figure of merit, the error probability can be made to approach zero as required.

A more complete theoretical model involves a detailed study of the atomic/molecular energy level structure (when two atoms get close enough to couple, they look like a molecular dimer) and proper treatment of the quantized motional states in the trap. We have performed such a study and found excellent prospects for high fidelity operation in realistic scenarios. We are currently working to test these ideas in the laboratory. Of course, many technical challenges remain, including proper filling of the lattice, and individual addressing and measurement of the individual atomic qubits. We are confident these hurdles can be overcome once the more fundamental task of controlled collisions have been implemented, as is our focus.

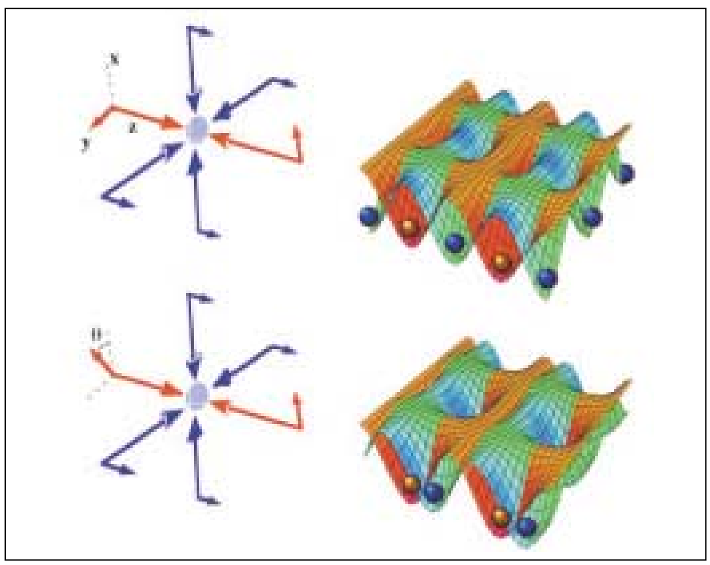

Fig. 6. Controlled collisions for quantum logic can be performed in a three dimensional optical lattice. Along the quantization z-axis, polarization gradients trap two different groupings of atoms, labels by their internal states. By rotating the polarization vectors, atoms can be brought together pair-wise for coherent interaction. In our protocol an additional laser field acts to excite entangling electric dipole-dipole interactions.

IV. Summary

Information is physical. One cannot divorce the information processing capabilities of a device from the physics that governs the operation of the device. Rolf Landauer's realization has important consequences for the foundations of information theory and new possible technologies. This is particularly true when the devices are nanoscopic; the physics of the quantum world is so profoundly different from our "classical" macroscopic description that nanotechnology is likely to have elements unlike anything we've seen to date. Quantum information provides the potential for secure secret-key distribution, efficient communication, and new computational power beyond the hope of any device acting under the laws of classical probabilities.

Bringing the full theoretical promise of quantum information into the laboratory is a grand challenge. It requires quantum control of a many-body systems with a very large number of degrees of freedom. It demands a degree of isolation from the perturbing effects of noise and manipulation with a precision never before achieved. Nonetheless, the exciting prospects for new fundamental breakthroughs has sparked worldwide research efforts to implement quantum information proces sors in a variety of systems, ranging from superconducting SQUIDS, to single electron quantum dots in semiconductors, to trapped ions.

We at the Universities of New Mexico and Arizona have conducted theoretical and experimental research to implement QIP with trapped ultracold neutral atoms in optical lattices. This flexible system allows us to fully control the atomic external and internal degrees of freedom, by building on the strong tradition of precision spectroscopy in the atomic-molecular-optical community. In developing our toolbox, we have observed mesoscopic quantum coherence of Cs atoms tunneling in engineered double-well potentials. This system represents a clean arena in which study the basics of control and measurement. In addition we are working towards implementation of universal quantum logic based on controlled atomic collisions. These two-atom interactions have a strong kinship with control of a molecular dimer. This represents a new frontier in the manipulation of atomic-molecular-optical systems, with new possibilities for basic science and technologies.

Further Reading

For an overview of the field see *Quantum Computation and Information*, by M. A. Nielsen and I. L. Chuang (Cambridge University Press, New York, 2000).

For a review of optical lattices, control and logic therein see:

- P. S. Jessen and I. H. Deutsch, Optical Lattices," *Advances in Atomic, Molecular, and Optical Physics* 37, p. 95-136,B. Bederson and H. Walther eds., (Academic Press, San Diego, 1996).
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Iam-Choon Khoo was born in Penang, Malaysia in 1949. He attended the Chung Ling High School, the St. Xavier's Institution for Sixth Form, and the University of Malaya in 1968 and obtained the B.Sc with First Class Honors in Physics in 1971. He then went to the University of Rochester, NY, where he studied statistical mechanics with the late Elliott Montroll and theoretical quantum optics with Joseph Eberly. He received the M.A. and Ph. D. degrees in Physics from the University of Rochester in 1973, and 1976 respectively. After some post-doc and faculty experience at Ames Laboratory, University of Michigan, University of Toronto, Wayne State University, he joined Penn State in1984 as an Associate Professor of Electrical Engineering, becoming a Full Professor in 1987. In 2000, he was awarded the title of Distinguished Professor.

Iam-Choon Khoo

Currently his research programs are centered on nonlinear optics and liquid crystals, and the development of nonlinear optical fibers and fiber arrays for optical switching and sensor protection application, and electro-optical and nonlinear optical phenomena and devices based on liquid crystalline materials. He is the principal author of over 390 technical publications [175 refereed journal publications/proceedings and 215 technical conference presentations], 11 invited book chapters, and the author, co-author or co-editor of 6 books. He has been the Editor-in-Chief for the journal Nonlinear Optical Physics and Materials since its inception in 1991. He is named the inventor in several patents, including one on extremely nonlinear photorefractive dyed-doped nematic liquid crystals, and one on nonlinear fiber array for optical limiting and sensor protection against laser radiation. Among the awards and honors he received are:- the Pennsylvania State Engineering Society PSES Outstanding Research Faculty Award in l987, the Penn State University Faculty Scholar Medal for Outstanding Achievements in Science and Engineering in 1988, the Fellow award of the Optical Society of America in l988, the PSES Premier Research Award in 1995, the IEEE Fellow award in 1998, and the United Kingdom Institute of Physics Fellow award in 1999.

Over the years, his laboratory has received continuous research funding from various Government agencies including:- the National Science Foundation, Defense Advanced Research Projects Agency, Navy Air Development/Joint Services Program, Air Force Office of Scientific Research, Air Force Phillips Laboratory, and the Army Research Office. He is a co- Principle Investigator in a Multi-University Research Initiative [MURI] beginning June 2001, and a senior investigator and Photonic Thrust leader in the National Science Foundation Material Research Science and Engineering Center at Penn State. He has developed and taught several undergraduate and graduate courses in lasers and electro-optics area, including the senior/graduate level "Lasers-Principles and Applications", and the graduate level "Lasers and Optical Electronics". He has also taught undergraduate courses in Fiber Optics, Electro-Optics and graduate level Nonlinear Optics, Quantum Electronics and Liquid Crystals.

He has served as panelist and reviewer for several US government agencies including the National Science Foundation, Air Force Office of Scientific Research, and Army Research Office, the Italian Institute of Physics of Matters [INFM], and the Hong Kong Government Research Council. He has also been appointed external Ph. D. examiner [in physics and electrical engineering] for oversea universities such as Nanyang Technology University [Singapore], Trinity College [Ireland], and Chalmers University [Sweden], and served as reviewer for various technical journals including Physical Review, Applied Physics, Optics Letters, J. Optical Society of America, IEEE J .Quantum Electronics, Photonic Technology, Optical engineering and Optics Communication.

His previous responsibilities in LEOS include organizing and chairing the first and to date still the most attended Nonlinear Optics: Material, Phenomena and Devices Conference [Kauai, 1990], chairing the Nonlinear Optics Technical Subcommittee [1992-1995, 1999-2001], participation as committee members or chair in various nonlinear optics sub-committees for LEOS. He has also been very active in organizing and chairing the 'Novel Optical Materials and Application' biennial conference series [LEOS and OSA as cooperating societies] in Italy since 1993, and the annual SPIE - Liquid Crystal Conference series since 1997. As the Vice President of Technical Affairs for LEOS, one of his goals is work with the Technical Council and the various Technical Committees in a vigorous collective effort to enhance all technical activities of the society, and to better serve the needs of the membership. He will also seek to establish closer connection and working relationship with colleagues in other technical societies in US, Europe and the Pacific Rim. He believes that the quality, breadth and depths of the technical fundamentals of the various disciplines comprising LEOS, in addition to the international reach of LEOS membership, are valuable assets that could be further utilized to move forward and grow.

Iam-Choon and his wife, Chor San have been married for 26 years. Chor San is the Senior Director of Global Nutrition and Health Sciences for Campbell Soup Company World Headquarter. They have two sons - Richard, a senior at Cornell University, and Paul a ninth grader at Moorestown Friends School (Moorestown, New Jersey). I. C., as most people call him, is a veteran commuter – he has been driving back and forth between State College, PA and Mt. Laurel, NJ for almost 20 years. In his spare time, one of his favorite [but unfortunately too infrequently practiced] pastimes is to cast a line out near the Barnegat Light House in New Jersey; he managed to land some flounder, stripe bass and rock bass over the years. Other fun things he pursues involve mostly family members, and include cooking Italian foods, seeing some Broadway shows in NY, and frequenting the dim-sum joints in Chinatown, Philadelphia and watching Richard and Paul play their tuba and baritone in the school band.

LEOS Graduate Student Fellowships

LEOS is continuously striving to provide its members with relevant and beneficial professional services. In particular, we aim to develop and enhance the careers of students in the field. Each year, since the program inauguration in 1999, LEOS has recognized the most outstanding LEOS student members by awarding them Graduate Student Fellowships. I would like to use this column to draw your attention to the tremendous success of this program and to its positive impact on the young careers of many LEOS student members. If you are a student (or if you know of outstanding students in the LEOS fields) I would like to encourage you to apply to this program. The LEOS Graduate Student Fellowships award a prize of $5,000 and provide a travel grant to the LEOS Annual meeting of up to $2,500. Twelve fellowships are awarded annually to eligible LEOS student members pursuing graduate studies in the technical LEOS fields. The deadline for this year's round is May 30, 2002. More information on the application requirements is available on the LEOS web site: www.i-LEOS.org

Here are some first hand comments from recent winners of the LEOS Fellowships:

Mirvais Yousefi a recent Fellowship winner from the Netherlands writes:

"It was a great pleasure and honor to receive the LEOS graduate student fellowship. Pleasure because the fellowship was accompanied by a sizeable chunk of cash, which is always useful for a student and honor because it gave me a big boost of self-confidence. As a graduate student one seldom receives such direct acknowledgement of ones accomplishments. The fellowship has inspired me to pursue a career in science, especially optics."

Mathieu Allard a Ph.D. student at the University of Toronto shares his experience:

"I was extremely pleased to be awarded the LEOS Graduate Fellowship in 2001. On top of being a very welcome and substantial amount of money, I felt it was an important mark of recognition of my academic and research accomplishments. LEOS is a well-known and prestigious society, and this award constitutes a very important addition to my credentials. Attending the LEOS Annual Meeting, which was made possible by the travel grant, was also a positive experience and gave me the opportunity of meeting world experts and interesting people working in my field. For all that, I am grateful to LEOS and I encourage all eligible students to apply for this award."

And, Elaine Wong, a graduate student at Photonics Research Lab at the University of Melbourne writes:

"It is indeed an honour to be one of the recipients of the 2001 LEOS Graduate Student Fellowship. The prestige and recognition of the fellowship will no doubt enhance my prospects in pursuing a career in the field of lasers and electro-optics. The accompanying travel grant has allowed my travel to the LEOS Annual Meeting, an experience that has greatly benefited my research work. I had the opportunity to interact with world-wide researchers and industry experts, which not only provided valuable feedback on my work, but also broaden my knowledge in the fields beyond my research interests. I strongly urge all LEOS student members to consider applying for the fellowship."

Finally, Sagi Mathai from UCLA submits:

"While the monetary award is an attractive incentive to apply for the LEOS Graduate Student Fellowship, its true value cannot be quantified. It provides an opportunity to participate in the LEOS Annual Meeting and receive a broad perspective on the research activities pursued throughout the globe. The most rewarding aspect of the fellowship package is the chance to mingle, make new friends and future colleagues. I thank the LEOS Membership Committee for selecting me as a recipient and encourage all LEOS student members to participate in the fellowship program."

Keren Bergman
VP Membership & Regional Activities - Americas

Editor's Comments

Continued from page 2

The next meeting of the LEOS Board of Governors will be at CLEO/QELS 2002 on May 19-24, 2002 in Long Beach. The third and last meeting in 2002 will be at the LEOS Annual Meeting to be held on Nov. 11-14 in Glasgow, Scotland. The submission deadlines for OFC2002 and CLEO/QELS2002 have passed; however, the submission deadline for the IEEE-LEOS Annual Meeting is June 26, 2002. For more details, see the LEOS Conference web page at the URL: http://www.i-leos.org/info/calendar2002.html

New Senior Members

The following individuals were elevated to Senior Member membership grade thru February:

Jonathan Bernstein

O. Eknoyan

Robin J Evans

Kiichi Hamamoto

John D Moores

Wim Nijman

Shinji Nishimura

David K Probst

Senichi Suzuki

REMINDER!!

The deadline for submitting nominations for the **2002 IEEE/LEOS William Streifer Scientific Achievement Award**, **Engineering Achievement Award**, **Aron Kressel Award** and **Distinguished Service Award** is 30 April.

The **IEEE/LEOS William Streifer Scientific Achievement Award** is given to recognize an exceptional single scientific contribution that has had a significant impact in the field of lasers and electro-optics in the past 10 years. It may be given to an individual or to a group for a single contribution of significant work in the field. No candidate shall have previously received a major IEEE award for the same work. Candidates need not be members of the IEEE or LEOS.

The **IEEE/LEOS Engineering Achievement Award** is given to recognize an exceptional engineering contribution that has had a significant impact on the development of laser or electro-optic technology or the commercial application of technology within the past 10 years. It may be given to an individual or to a group for a single contribution of significant work in the field. No candidate shall have previously received a major IEEE award for the same work. Candidates need not be members of the IEEE or LEOS.

The **IEEE/LEOS Aron Kressel Award** is given to recognize those individuals who have made important contributions to opto-electronics device technology. The device technology cited is to have had a significant impact on their applications in major practical systems. The intent is to recognize key contributors to the field for developments of critical components, which lead to the development of systems enabling major new services or capabilities. These achievements should have been accomplished in a prior time frame sufficient to permit evaluation of their lasting impact. The work cited could have appeared in the form of publications, patents, products, or simply general recognition by the professional community that the individual cited is the agreed upon originator of the advance upon which the award decision is based. The award may be given to an individual or group, up to three in number.

The **IEEE/LEOS Distinguished Service Award** was established to recognize an exceptional individual contribution of service which has had significant benefit to the membership of the IEEE Lasers and Electro-Optics Society as a whole. This level of service will often include serving the Society in several capacities or in positions of significant responsibility. Candidates should be members of LEOS.

The list of previous winners and nomination forms can be found on the LEOS Home Page http://www.i-LEOS.org.

See next page for Nomination Form for IEEE/LEOS awards

Nomination Form for IEEE/LEOS Awards

Please check the appropriate award category:

❑ Quantum Electronics *(16 February deadline)*
❑ Engineering Achievement *(30 April deadline)*
❑ Aron Kressel LEOS Award *(30 April deadline)*
❑ Streifer Scientific Achievement *(30 April deadline)*
❑ Distinguished Service *(30 April deadline)*
❑ John Tyndall Award *(10 August deadline)*

1. Name of Nominee *(For joint nominations, give the names, address information of the co-workers on a second sheet of paper)*:

____

2. Nominee's Address *(include city, state, zip)*:

____

____

____

____

3. Nominee's Phone:__________________ Fax:__________________

Email: ______________________________

4. Proposed Award Citation *(20 words or less)*:

____

5. Below, briefly list the Nominee's most significant contributions to the specific area of this award. On the second sheet of paper, discuss in more detail (in 300 words or less) the specific contribution(s) that qualifies the Nominee for this award, as well as other related accomplishments. List five of the Nominee's most significant publications, patents, or other evidence of achievements in the field. If you know of any invited talks that the Nominee has given on his/her research, list them also.

____

____

____

6. IF the candidate is chosen as a finalist, a more complete description of the candidate's scientific accomplishments and professional activities will be requested to provide the information necessary to fully evaluate the nomination. If you do not feel qualified to prepare a full nomination packet, indicate on the second sheet of paper someone who is qualified and willing to complete a full nomination. Also indicate on the second sheet the names of two individuals who are familiar with the Nominee's work and who are qualified to write a letter of support for this nomination. List the full name and address, phone number and FAX number for each individual.

7. Your name: ______________________________

8. Your Phone:__________________ Fax:__________________

Email: ______________________________

9. Your Telephone & Fax:______________________________

NOTE: *The information requested above may be typed on this form or prepared using any text processing procedure and sent by FAX or by mail to the LEOS Office. The use of the form itself is not required; however, all of the requested information must be provided.*

Mail or fax this nomination form together with any supporting material to:
IEEE/LEOS Awards Committee, 445 Hoes Lane, Piscataway NJ 08855-1331.
Fax: +1 732 562-8434.

Chapter Highlights

Montréal LEOS Chapter: Une Renaissance

In light of all the events that have transpired at the Montreal LEOS Chapter over the past two years, one can say, quite honestly, that a renaissance has taken place. At the root of this rebirth, one can find energetic and enthusiastic people who believe in the principles of the IEEE and in the spirit of carrying the torch of knowledge and continuity. The Montreal LEOS Chapter, joint with MTTS and APS, was awarded the Most Improved LEOS Chapter Award for 2001 in recognition of its significant improvements.

Our Chapter's rebirth began in earnest on a cold winter night in January 2000 at an IEEE Montreal Section meeting. That night, the most important agenda item focused on the somber news of the death of our past Chapter chairman, Prof. Gar Lam Yip, in October 1999, who had been involved in so many activities over the past 25 years. At that meeting, Section President, Eric Holdrinet, requested for volunteers to carry on the Chapter activities. In attendance that night, were Prof. Ke Wu, Director of Ecole Polytechnique's Poly-Grames Research Center and Dr. Peter Noutsios, Systems Engineering Technical Advisor at Nortel Networks and graduate student of the late Prof. Yip. Both had met just a month earlier, introduced by Alice Chan, Prof. Yip's widow. Right after the Section meeting, Ke and Peter discussed how they could work together to re-establish the Chapter to a more active level. That very night, they agreed to share the responsibilities, Ke taking on the MTTS/APS events, with Peter handling the LEOS part. Both were motivated to rekindle the Chapter that, due to Gar Lam's deteriorating health and energy, had reached to a minimum level of activities. Their goal was to significantly exceed this level and for that, they realized that more new blood was needed. Peter knew of a new Assistant Professor, Prof. Lawrence Chen, who was just hired by the Photonics Group of McGill University's Dept. of Electrical and Computer Engineering and who, as an undergraduate student, worked on research projects, supervised by Prof. Yip. They approached Lawrence to become secretary/treasurer of the joint Chapter and he agreed enthusiastically!

Thus, this new team, with common ties to the past, was formed. These officers were dedicated to rebuilding a Chapter with the motivation and energy to promote the field of photonics, microwaves and antennas. In 2000 – 2001, the Chapter went through an exciting and active year of technical meeting and activities. Nine technical meetings were organized, a substantial increase from the minimum of two. LEOS membership increased by 37% and the average technical meeting attendance was up by 240%. This latter figure was quite substantial; not only was there an increase in IEEE student and member participation, but interest from the Montreal scientific community was also raised. About 53% of the average meeting attendance was composed of non-IEEE members, suggesting the potential growth of the Chapter's membership.

The joint Chapter was also at the heart of the 8th International Symposium for Microwave and Optical Transmission (ISMOT 2001) held in Montreal June 19-23, 2001. Ke was Symposium Chair and also part of the Organizing Committee. Peter and Lawrence were part of the Technical Program Committee and also co-chairs of a Special Session on Guided Wave Photonics, in memory of Prof. Yip. About six months prior to the event, the team was setback by the sudden news of Ke's illness and his urgent hospitalization. Fortunately, his hospital stay and recovery lasted about two months and Ke returned to support the symposium. Nevertheless, the Symposium turned out to be a resounding success and a fitting end to a great year for the Chapter!

So far, the 2001-2002 year is progressing very well. Eight technical meetings have been organized so far, five related directly to LEOS. This year, a new theme was introduced to the technical meetings, entitled "LEOS Montreal Seminar Series on Montreal-area Companies", to encourage participation from industry and to get a better appreciation of some of Montreal's optical companies. Thus far, it's been quite successful. Technical meeting attendance is sharply higher (about 40%) compared to last year's average attendance. Thus far, five seminars have been organized and presented by Chief Technology Officers and Directors of companies such as Lumenon Innovative Lightwave Technology, ITF Optical Technologies, MPB Communications, Bragg Photonics and EXFO. Furthermore, three MTTS/APS events to date have been organized with an upcoming workshop on advanced millimeter-wave technologies for broadband wireless communications and sensor applications.

Dr. Peter C. Noutsios, Nortel Networks
Prof. Ke Wu, Ecole Polytechnique de Montréal
Prof. Lawrence Chen, McGill University

The IEEE-LEOS Benelux chapter

With a population of more than 25 million people, about 10 universities with activities in photonics and distances between those academic centres ranging from 100 to 400 km, the Benelux – Belgium + The Netherlands + Luxemburg – is an ideal breeding ground for a LEOS chapter. The chapter was founded in 1996, very much under the impulse of professor Djan Khoe of Eindhoven University. Since then the chapter has built a strong activity profile with close to 200 LEOS-members. The board counts about 12 active members from academic institutions as well as industry and the chairmanship rotates every two years.

Every year the chapter organizes an annual symposium, rotating between the universities and with participation by 150-200 participants from universities and industry. This symposium is an annual forum for just about all of the research activities in photonics in the region. While most of the research groups are very active internationally, the Benelux symposium brings a regional community together, with activities covering the broad variety of specialized subjects within the field of photonics. The symposium comes with proceedings with 70-90 contributions which reflect the high level of research in the Benelux region, Since the region is multilingual – with Dutch being spoken in The Netherlands and in Flanders and French in Wallonia – these meetings are held in English, at least in their formal part. During the more social part of the meetings one can hear a rich mix of English, Dutch and French. Each year there is also a topical workshop on a topic of special interest. These meetings typically focus on an important and timely research topic.

At both the symposia and the workshop the chapter invites LEOS distinguished lecturers. In the past years not many LEOS distinguished lecturers have managed to stay away from the Benelux. Doctoral students do obviously form an important fraction of the audience at our meetings and the chapter

These pictures show Milton Chang, president of LEOS, addressing the audience at the LEOS Benelux workshop on "How to start your photonics business" held during ECOC 2001 in Amsterdam.

invests in them by offering them a free LEOS membership as part of the registration fee of the annual symposium.

The PhD students are also represented on the chapter board and they organize their own activities, in particular company visits. Each year two or three companies with activities related to photonics are being visited by the LEOS student members.

The year 2001 was a special year for the chapter. Not only was the chapter 5 years old. Given that ECOC was organized in Amsterdam, with involvement of many LEOS Benelux members and chaired by Paul Lagasse and Djan Khoe, the chapter decided to organize a special event: on Sunday September 30, just before the start of ECOC, the chapter organized a half-day workshop on "How to start your photonics business"at the RAI in Amsterdam. For the program committee of this workshop – consisting of Peter Vetter (Alcatel), Erik Pennings (Papyron) and Roel Baets (Ghent University) – it was an interesting experience to bring a good program on entrepreneurship in photonics together during the turbulent year 2001. Eventually the workshop was quite a success both in terms of number of participants and quality of speakers. Milton Chang – president of LEOS – presented a tutorial about the do's and don't's in setting up a new company. Winfried Horsthuis, formerly with JDS-Uniphase, discussed the process of acquisitions by major players. Then 4 speakers presented case studies of their involvement in specific start-ups. They not only discussed the professional aspects of starting a company but also did not hesitate to emphasize the strong impact of this process on their private life. One speaker had been directly involved in a recent company failure, but nevertheless did not mind to talk about this openly. His comments and recommendations will be remembered by many in the audience.

For 2002 a range of activities is planned. The first on the list is a workshop on photonic crystals that will be held at Ghent University on May 29, 2002. For more information on our activities one can consult the chapter website at http://www.cobra.tue.nl/leos/index.html or contact the chapter chairman prof. Alfred Driessen (A.Driessen@tn.utwente.nl).

Roel Baets,
Ghent University

Map of the Benelux with the major centers where the LEOS chapter's activities have taken place.

Nominations for the JQE Best Paper Award

The Editors for the *IEEE Journal of Quantum Electronics* (*JQE*) are soliciting nominations for the *JQE* Best Paper Award for 2002. Recently approved by the LEOS Board of Governors, the *JQE* Best Paper Award is intended to recognize papers of exceptional quality that are published in *JQE* during the preceding calendar year. The overriding considerations in selecting the awardee will be: 1) the expected impact of the results presented in the paper on progress in quantum electronics, and 2) the clarity of presentation.

Nominations of papers published in *JQE* in the 2001 calendar year must be received at the *JQE* Editorial Office (c/o Ethel Godonoo) in Piscataway by Wednesday, May 1, 2002. The nomination should include a brief (1-2 paragraph) statement describing the significance of the results presented in the paper and their anticipated impact on the field. The awardee will be selected by the *JQE* Associate Editors and the award presentation, consisting of a $500 award for the first author and plaques for all authors, will be made at the LEOS 2002 Annual Meeting in Glasgow, Scotland.

For more information, contact e.godonoo@ieee.org

Elastic Bandwidth

The Flexibility of DWDM in Handling Continually Increasing Bandwidth Demands for Future Optical-Fiber Communication Networks

Advances in solid-state and photonic technologies have made the "can't be done" concept a thing of the past. Bit rates of 2.5 Gb/s, 10 Gb/s, and 40 Gb/s over many kilometers of single-mode fiber are a reality. The driver for this bandwidth appetite was triggered with early optical networks (SONET/ SDH) that demonstrated that glass fiber is a transmission medium that permits light to travel through it without amplification for hundreds of kilometers and at incredible data rates (many Gb/s), two accounts that were not possible with copper-twisted-pair cable. And this appetite has been accelerated ever since with the proliferation of transferring additional information over the communications network with major service contributors such as e-mail, e-commerce, the Internet, electronic documentation transfer, video, and ubiquitous mobile telephony. And this is just the beginning as more "exotic" services are planned for and contemplated to be offered over the communications network. This article discusses dense wavelength division multiplexing (DWDM) photonic technology and the role it will play in shaping future communications networks.

What Is DWDM and How Does It Work?

Bandwidth Elasticity

As bandwidth demand keeps increasing, how can we be assured that the network is elastic enough to cope with this increase? How do we assure that systems and networks are able to process and transport an increasing volume of voice and data (video, high-speed data, interactive multimedia, etc.) traffic? How do we assure that the network is able to manage a continuously increasing bandwidth (as new flexible services become available, such as bandwidth on demand)?

Currently, there are *technological choices* to answer these questions:

- Install more and better fiber, as the need arises. Although this is currently pursued, nevertheless, it requires substantial planning and investment, and it may not be possible in all cases.
- Use higher speed photonic technology to increase the bit rate (to 10 Gb/s, 40 Gb/s, > 100 Gb/s). This implies that to stay at the forefront of data rate, one has to always use the most advanced technology that is neither mature or cost attractive.
- Use optical components instead of electronic components (e.g., amplifiers, filters, etc.). This is a design choice that depends on the availability of a range of components and how well their specifications match. However, because most optic components are data-rate independent, the cost per bit turns out to be a tiny fraction compared with electronic implementation.
- Increase the number of optical carriers (wavelengths) per single fiber, a technology known as *wavelength division multiplexing* (WDM). This is a successful technology as it takes advantage of existing fiber, and the only changes required are at its termination points; in some cases, it greatly simplifies the traditional regeneration as optical amplification is much simpler and more cost effective.

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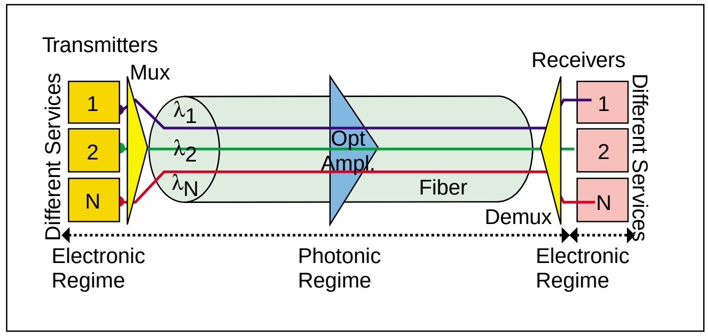

Figure 1. Fiber can support a large number of wavelengths, each carrying different payload in the same fiber.

In all these choices, *photonic technology* plays a pivotal role in the communications network. In particular, network bandwidth elasticity is better addressed with WDM.

Depending on network application, WDM comes in two fundamentally different flavors, each with its own complexity, specifications, and cost structure: dense-WDM (DWDM) with more than 80 wavelength channels per fiber, and coarse-WDM (CWDM) with less than 40 wavelength channels per fiber. However, as time progresses and technology permits, we will witness a shift of the demarcation points, and DWDM will have more than 200 (and perhaps 1000) wavelengths, whereas CWDM will have more than 40.

Wavelength Division Multiplexing

Early optical transmission in long-haul single-mode fiber applications used a single wavelength at 1310 nm, whereas wavelengths in the 800-nm band have been used in short-haul multimode fiber applications. However, photonic devices performing in the low-loss spectral band of about 1.55 μm have enabled more than a single wavelength in the same fiber (Fig. 1). Having put a number of wavelengths in the same fiber, the aggregate bandwidth per fiber is multiplied by this number. For example, 40 wavelengths at 40 Gb/s each yield an aggregate bandwidth of 1.6 trillion bits per second per fiber (1.6 Tb/s). In SONET terms, this is equivalent to 20 million simultaneous conversations per fiber.

Thus, DWDM technology exhibits an inherent flexibility: each wavelength is a huge transporting vehicle and it does not recognize the type of information it carries, nor does it care [1]. For example, one wavelength may carry Internet [2] and another SONET, or ATM [3-5]. The sender and the recipient alone handle the content cargo appropriately. Moreover, WDM technology with optical devices that provide functionality such as *add-drop multiplexing* can transform any type of network (mesh, ring, or star) into a physical single-fiber ring network (Fig. 2).

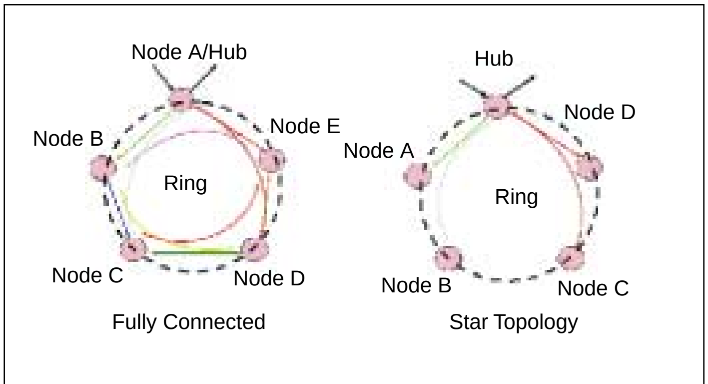

Figure 2. A fully connected topology and a star topology converted into a physical DWDM ring topology.

Table 1. Frequency Bands in Optical Communications

Window	Label	Range	Fiber Type	Applications
1st	–	820-900 nm	MMF	
2nd	S	1280-1350 nm	SMF	Single-
3rd	C	1528-1561 nm	SMF	DWDM
4th	L	1561-1620 nm	DSF	DWDM
5th	–	1350-1450 nm	SMF AllWave™	DWDM

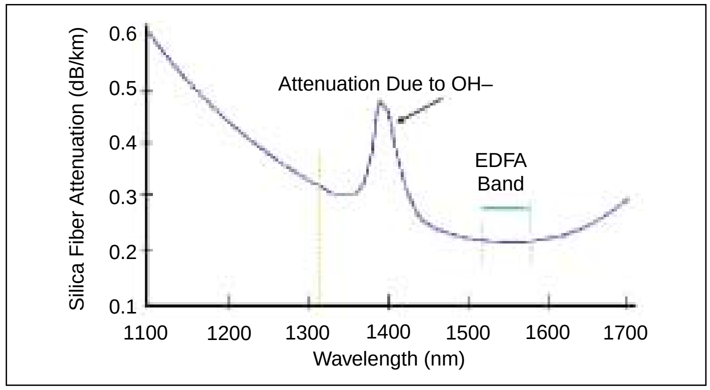

Figure 3. Loss performance of glass fiber.

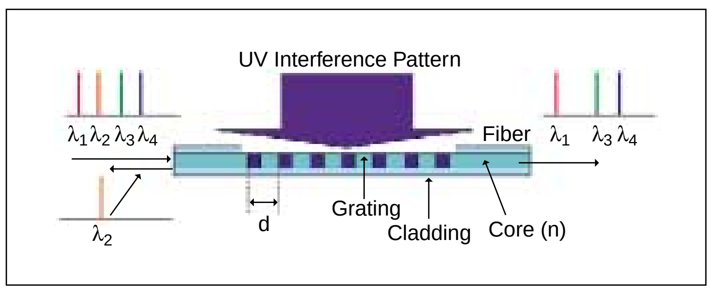

Figure 4. When the fiber core is exposed to a UV periodic pattern, the refractive index is affected permanently and a fiber Bragg grating is constructed.

Based on the low-loss behavior of glass fiber (Fig. 3), ITU-T has defined a grid of 81 frequencies in the C-band (196.10-192.10 nm) starting with a frequency at 196.10 THz (λ = 1528.77 nm), the remaining standardized frequencies are computed decrementing/incrementing by 50 GHz (0.39 nm). For 40 frequencies on the grid, the starting frequency is the same but the decrement/increment is 100 GHz, and for 20 frequencies it is 200 GHz. Decrementing by 50 GHz beyond the C-band results in 80 more wavelengths defined in the L-band. Similarly, when incrementing by 50 GHz, more wavelengths are defined in a band that requires specialized single-mode fiber with low loss characteristics in the 1.4-nm band where HO- has been causing high absorption. Table 1 lists the wavelength bands used in optical communications.

The scalability of DWDM does not stop here; research has demonstrated that the number of wavelengths per fiber could increase to more than 1000, and this clearly is not a limit. Bandwidth at this level would enable every single person in the United States to be continuously connected with anyone else—not only with voice but also with video and data. Moreover, considering that a cable could have more than 200 fibers lighted, one realizes that DWDM enables not only every single person in the United States to be continuously connected but also, perhaps, every single person in the world.

DWDM Technology Enablers

Pure DWDM systems are supposed to be "all-optical." That is, functionality that was previously implemented with electronics is now achieved with all-optical devices, such as those listed in the following sections.

Filters

Filtering is accomplished with passive Fabry-Perot, Bragg, thin-film, Mach-Zehnder, dielectric, and acousto-optic filters. Each filter is based on different principles of physics; for example, the Fabry-Perot is based on interferometry, the Bragg on diffraction, and the prisms on refraction.

Among the most significant are the Bragg gratings as they are passive devices, easily manufactured, easily integrated with other components, and cost effective. Diffraction gratings come in different flavors: reflected, pass-through, fiber, and so on. However, the diffraction theory is the same, and it may differ in only some parameters differentiating the plate from the fiber gratings. In all, the *condition for strong reflection*, also known as the *Bragg condition*, is:

$$d = -m\lambda_B/2$$

where m is an integer, d is the grating constant, and λ_B is the wavelength for which the Bragg resonates and reflects.

Figure 4 illustrates a fiber Bragg grating. Advanced fiber Bragg gratings, known as chirped Bragg gratings, have also the additional ability to compensate for chromatic dispersion.

Multiplexers and Demultiplexers

Wavelength multiplexing and demultiplexing is accomplished with passive components such as diffraction gratings, thin-films, and super-

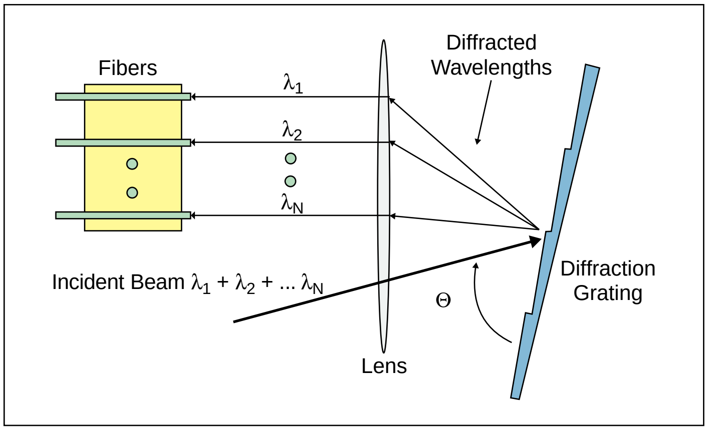

Figure 5. A grating-based optical multiplexer.

prisms. For reflected and pass-through gratings, the angular separation between wavelengths for a given order m, also known as the *angular dispersion D*, is:

$$d\beta/d\lambda = m/(d\cos\beta)$$

where m is an integer, d is the grating constant, and β is the angle of diffraction.

Figure 5 illustrates the principles of a diffraction-based demultiplexer.

Optical Switching

Switching is accomplished with solid-state technology (lithium-niobate), micro-electro-mechanical mirror systems (MEMS), tiny bubbles, liquid crystals, electro-holographic methods, and other technologies that are still in the experimental phase. However, each technology has its own merits and each one finds its own niche in the applications space. For example, MEMS make large optical cross-connecting fabrics (1000 × 1000) but are slow switching (ms) compared to lithium niobate, which makes small fabrics (32 × 32) but is faster (ns). Table 2 lists a comparative sample of optical switching technologies.

Optical Add-Drop Multiplexing

In communications, dropping and adding one or more channels is an important function that permits efficient bandwidth delivery and distribution over the network. Optical add-drop multiplexing is accomplished by combining optical demultiplexers and multiplexers, optical switches, filters, and other components. Figure 6 illustrates a single wavelength optical add-drop multiplexer that employs a Bragg fiber grating.

Employing tunable components, dynamic add-drop wavelength multiplexing enables dynamic wavelength assignment, dynamic bandwidth allocation, service and network protection and survivability, and overall great flexibility in cost-efficient bandwidth management.

Optical Amplification

Direct optical amplification [6] is accomplished with specialized doped fibers (e.g., erbium-doped fiber amplifiers (EDFA)), semiconductor optical amplifiers (SOA), and Raman amplification. Each amplifier has its own characteristics and is usable in a different spectrum (Fig. 7). In short-haul applications, the deployment of amplification is limited, but in long-haul, where it is most required, it is not unreasonable to use more than one amplification method, such as EDFA and Raman combined.

Optical Regenerators

In long-haul optical transmission, the signal requires periodic regeneration (or repeaters) in order to reach a destination that may be many hundreds of kilometers afar. Traditional regeneration requires conversion of the optical signal into electric retiming, reshaping, and regeneration (amplification), a function known as 3R. Then, the signal is converted to optical and transmitted to the next repeater, and so on. However, traditional repeaters are complex devices; they require maintenance and are costly. Optical technology allows for direct optical amplification that can stretch the distance between amplifiers to many kilometers, and thus lower the overall cost and maintenance; this is known as 1R, since all that the amplifiers accomplish is regeneration. However, there are optical components and techniques that can also accomplish reshaping, and more recently retiming, in the optical regime (the latter is experimental). For example, dispersion compensating fiber removes the pulse widening due to nonuniform propagation of wavelength in the glass medium (Fig. 8). Dynamic equalization restores the amplitude of each channel in the DWDM signal to within a small fraction of variability (~0.1%). Optical phase-lock-loop tech-

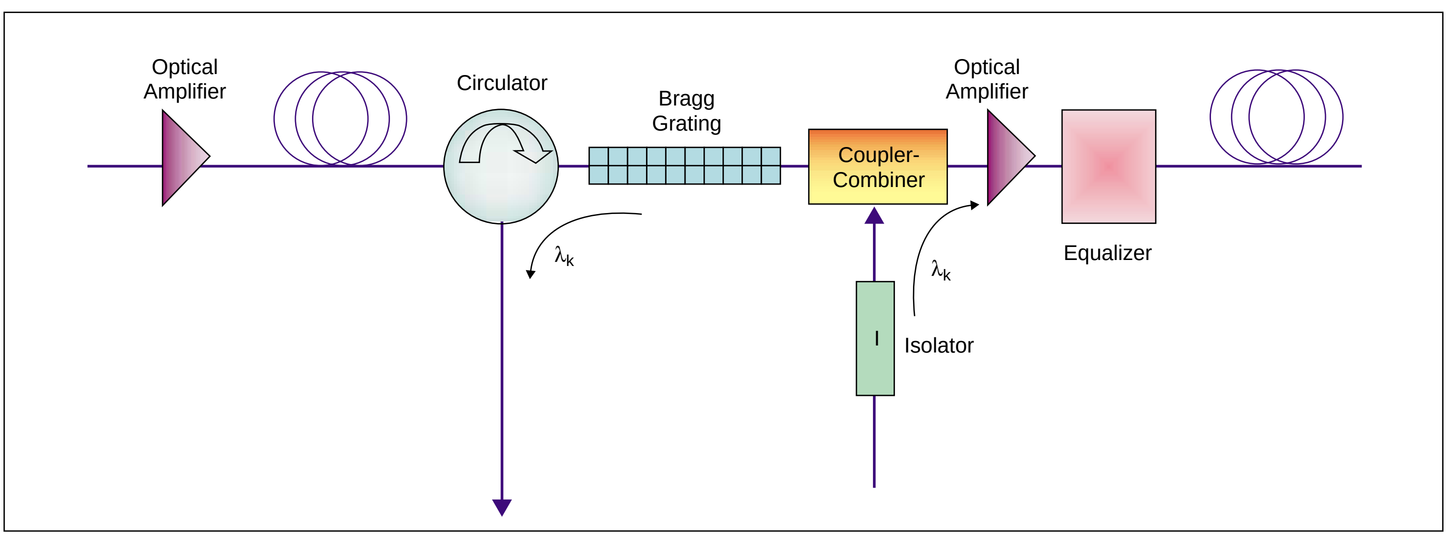

Figure 6. A grating-based single wavelength optical add-drop multiplexer.

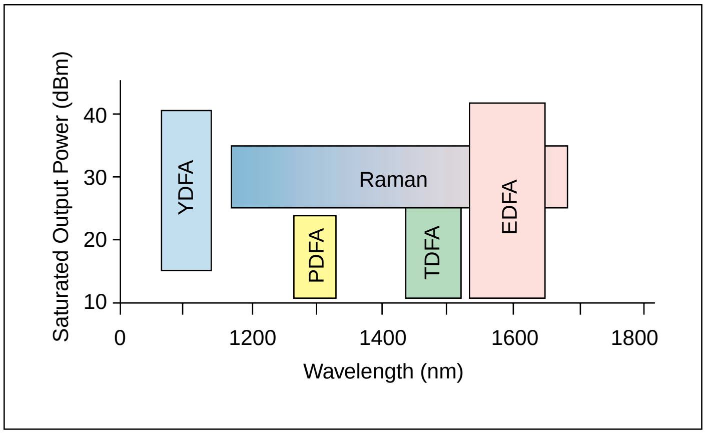

Figure 7. Optical amplifiers cover a wide spectral range.

niques retime the received optical pulses to remove drift and jitter. Thus, although the current state of the art is 1R or 2R repeaters, all-optical 3Rs are on the research and development bench.

Other Optical Components

The list of optical components and technology does not stop here. Lasers and laser pumps, detectors, wavelength converters, couplers and splitters, polarizers, isolators, equalizers, dispersion compensators, specialty fibers, fiber couplers, pigtails, micro-lens systems, pulse retimers, pulse reshapers, detectors, fixed or tunable devices, memories, and more will eventually transform the communications network landscape to an all-optical DWDM network (Fig. 9). In addition, new artificial materials with new photonic properties will make new additions to an optical designer's tool-box.

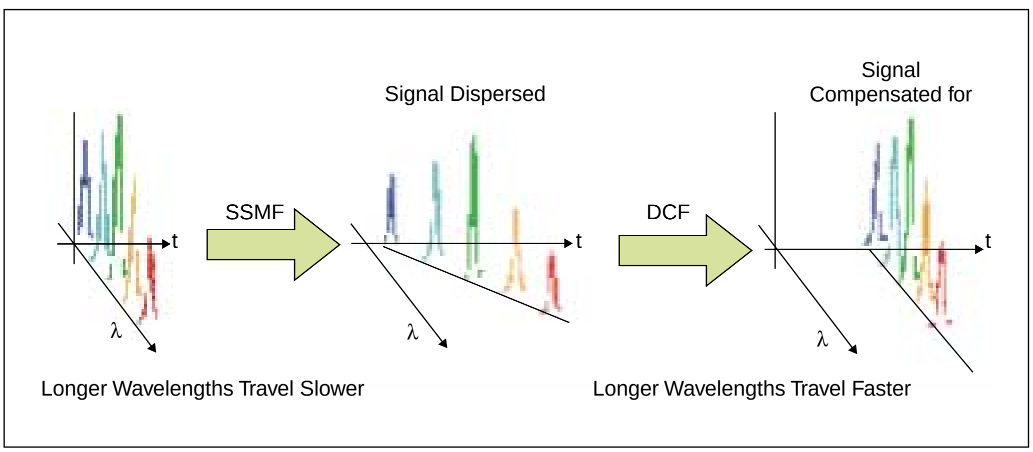

Figure 8. Dispersion is compensated for with dispersion-compensating fiber placed in regular intervals of standard single-mode fiber.

What About Electronics?

At this point, we are compelled to answer an important question. As the communications network is transformed to an all-optical network, what will the role of electronics be?

In an all-optical network, the signal path between transmitter (laser) and receiver (photodetector) will be "optical" (dominated by optical components), known as the *optical regime*, whereas the remainder of the path (before the laser and after the photodetector) will be fully electrical, known as the *electrical regime*, and in it electronics will be the only game. However, even in the optical regime, there are optoelectronic sensors to monitor the optical path for performance and all-electronic devices to process performance data as well as to control the behavior of (optical) devices and to communicate with the various units of a system and of a network. Thus, electronics will also be indispensable players in this "all-optical" network.

Network "Nodes"

Although we use the term "node" [7, 8] in a habitual manner (emanating from traditional networks), data networks employ "routers." However, in DWDM applications an advanced router performs DSn and OC-n grooming, optical multiplexing, and switching, and it also provides quality of service (QoS); that is, all attributes and functions of a traditional communications node. Similarly, traditional nodes have data (and packet) store- and-forward routing capability. In some configurations, traditional nodes and routers work side-by-side to provide traditional synchronous and asynchronous service, voice, and data. Therefore, although nodes and routers may be conceptually different, as the network evolves, there is a convergence of functionality, and therefore, here we do not discriminate between the two.

Future Direction

DWDM continues to evolve, and work continues feverishly on many fronts: technology, standards, and network architectures.

On the technology side, current systems support fixed wavelength assignment for each node, or they are manually reconfigurable. However, a wide range of tunable devices is emerging [9] that will enable dynamic wavelength assignment, optimized bandwidth allocation, wavelength and path protection, and better network survivability strategies. Advanced optical techniques will enable fault monitoring in the optical regime. Polymers and photonic crystals will provide improved and cost-effective photonic performance. Finally, nan-

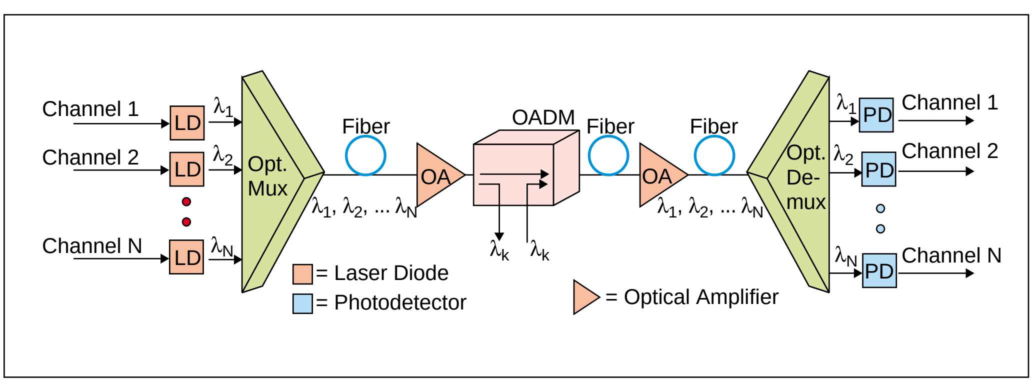

Figure 9. An all-optical point-to-point network with an add-drop multiplexer.

Table 2. Switching Technologies (Specs Are Approximate)

Switch Type	Switching Speed (Approx.)	Insertion Loss	PDL	Crosstalk	λ-Flatness	Typical Size
Fiber-Bragg Grating	~100 μs	~2 dB	0.5 dB/cm	−40 db	NA	Up to 32 × 32
Acoustic-Optic	~5 μs	~8 dB	~8 dB	−25 db	±10 dB	Up to 1 × 1024
MEMS	~10 ms	3-7 dB	~0.5 dB	−50 db	~1 dB	Up to 1000 × 1000
Electrorefractive Holograms	~ ns	~4 dB	~0.1 dB	−40 db	~0 dB	Up to 16 × 16 and perhaps 64 × 64
LC	~5 ms	1 dB	~0.1 dB	−40 db	~2 dB	Up to 16 × 16
Bubble-Jet	~10 ms	~0.2 dB	~0.2 dB	−50 db	NA	Up to 32× 32

otechnology, new materials, and integration of optical functionality will create miniaturized components with complex functionality and lower power.

In the standards arena, wavelength operation, administration, management, and provisioning (OAM&P); DWDM fault management [10]; DWDM network management [11]; latency; and quality of service are just a few examples of current intense activity. Optical DWDM networks are defined and deployed that are characterized by unprecedented bandwidth capacity, bandwidth elasticity, reconfigurability, reliability, and survivability of service of the DWDM system and of the network.

DWDM is here and in its infancy, but it will quickly grow into a technology for a global communications network that will allow anyone at anytime and at any place, with the same "identification number," to communicate with voice, with fast data, and with picture. The beneficiaries of DWDM photonics technology will not be only the communications field but also fields such as medicine, commerce, home appliances, and others that will shape future lifestyles and perhaps the world.

Stamatis V. Kartalopoulos, Ph.D., is president and chief technical officer of PhotonExperts in Annandale, New Jersey (e-mail: kartalopoulos@sprintmail.com).

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11. *Management Aspects of the Optical Transport Network Elements*, ITU-T Draft Rec. G.874, Oct. 1998.

What's New on the LEOS Portal – Plenary Talks

The Plenary Talks for the 2001 LEOS Annual Meeting are now available via streaming video. They include the following:

Optical Bits & Pieces: Fibers to Amplifiers by Donald B. Keck

Femtosecond Technology: A New Industrial Technology Platform by Teruo Sakurai

Optical Networking Research in Europe by Mike O'Mahony

All three talks are available to the general public using either RealPlayer by RealNetworks, Inc. or Windows Media Player by Microsoft. They are located on the LEOS portal (http://www.i-leos.org) in the lecturers section of the LEOS University webpage (under the education tab).

Stanford University

Department of Electrical Engineering

The Department of Electrical Engineering at Stanford University (http://ee.stanford.edu) invites applications for a tenure-track faculty appointment at junior or senior level in the field of photonic communication systems.

We seek an individual who is equally at home with advanced components, subsystems, networks and systems, and who can combine these to synthesize, build and test optical communication systems of novel design.

An earned Ph.D., evidence of the ability to pursue independent research and a strong commitment to both graduate and undergraduate teaching are required. The successful candidate will be expected to teach graduate and undergraduate courses both in the candidate's specialty area and in related subjects, and to build and lead a group of graduate students in Ph.D. research.

Applications should include a resume, a list of publications, a brief statement of research and teaching interests and the names of at least five references. They should be forwarded to:

Professor Joseph W. Goodman
Optical Communications Search Committee Chair
C/o Jenny Xu
Department of Electrical Engineering
Packard 359
Stanford University
Stanford, CA 94305-9515

The review of applications will begin on February 15, 2002, but applications will be accepted until May 1, 2002. Stanford University is an equal opportunity employer and welcomes nominations of women and minority group members and applications from them.

ICO Newsletter

Issue Number 51, April 2002

The April issue of the Newsletter of the International Commission for Optics and other ICO information has been posted on the ICO web, www.ico-optics.org.

It features the following :

1. President's Column, "2002 and beyond, the age of light", by Arthur H. Guenther
2. ICO/ICTP Award 2002 announced at Trieste Winter College, winner is Alphan Sennaroglu
3. Florence, Italy, to host 19th ICO Congress, August 25-31, 2002: the largest ICO scientific event yet will cover optics in its broadest sense
4. Photonic North, Quebec, June 2002
5. ETOP 7 report: meeting chair T.K. Lim and co-chair A.H. Guenther have posted on the ICO web page a report on the Education and Training in Optics and Photonics meeting held in Singapore, November 2001, sponsored by ICO, SPIE and OSA. The report stresses the initiative of building a Global Network for International Cooperation in Optics education and training.
6. A Synchrotron Radiation Facility in the Middle East
7. News, history and organization of ICO members: the Australian Optical Society
8. Forthcoming events with ICO participation

Pierre Chavel, Secretary
International Commission for Optics

Conference Calendar www.i-leos.org

Conferences between 1-Mar-2002 and 1-Dec-2002
For further information please see the LEOS conference calendar at www.ieee.org/leos

Joint Symposium on Opto- and Microelectronic Devices and Circuits (SODC 2002)
Conference Dates: 10-Mar-2002 to 16-Mar-2002
University of Stuttgart, Stuttgart GERMANY
Conference URL: http://www.uni-stuttgart.de/int/inhalt/sodc/sodc.htm
Conference Email:

Optical Fiber Communication Conference (OFC 2002)
Conference Dates: 17-Mar-2002 to 22-Mar-2002
Anaheim Convention Center, Anaheim, CA USA
Conference URL: http://www.ofcconference.org/
Conference Email: cust.serv@osa.org

International Conference on Transparent Optical Networks (ICTON 2002)
Conference Dates: 21-Apr-2002 to 25-Apr-2002
National Institute of Telecommunications, Warsaw POLAND
Conference URL: http://www.itl.waw.pl/icton/
Conference Email:

Int'l Conference on Optical Fiber Sensors (OFS 2002)
Conference Dates: 6-May-2002 to 10-May-2002
Hilton Portland, Portland, OR USA
Conference URL: http://www.ieee.org/organizations/society/leos/LEOSCONF/OFS/ofs.html
Conference Email: ofs@ieee.org

OPTO-CANADA 2002
Conference Dates: 9-May-2002 to 10-May-2002
Ottawa Congress Centre, Ottawa, Ontario CANADA
Conference URL: www.spie.org/info/canada
Conference Email:

IEEE Workshop on Interconnections within High Speed Digital Systems
Conference Dates: 12-May-2002 to 15-May-2002
La Posada de Santa Fe, Santa Fe, NM USA
Conference URL:
Conference Email:

International Conference on Indium Phosphide and Related Materials (IPRM 2002)
Conference Dates: 12-May-2002 to 16-May-2002
Stockholm City Conference Center, Stockholm SWEDEN
Conference URL: www.congrex.com/iprm2002/
Conference Email: iprm@congrex.se

Conference on Lasers and Electro-Optics (CLEO/QELS 2002) colocated with QELS 2002
Conference Dates: 19-May-2002 to 24-May-2002
Long Beach Convention Center, Long Beach, CA USA
Conference URL: www.cleoconference.org
Conference Email: custserv@osa.org

Quantum Electronics & Laser Science Conference (CLEO/QELS 2002) colocated with QELS 2002
Conference Dates: 19-May-2002 to 24-May-2002
Long Beach Convention Center, Long Beach, CA USA
Conference URL: www.cleoconference.org
Conference Email: custserv@osa.org

International Workshop on Laser and Fiber-Optical Networks Modelling (LFNM 2002)
Conference Dates: 3-Jun-2002 to 5-Jun-2002
V. Karazin Kharkov National University, Kharkov UKRAINE
Conference URL: www2.kture.kharkov.ua/LFNM

IEEE Workshop on Fibre and Optical Passive Components (WFOPC 2002)
Conference Dates: 5-Jun-2002 to 6-Jun-2002
University of Glasgow, Glasgow, Scotland UK
Conference URL: http://www.leos-scot.ac.uk/WFOPC/

International Quantum Electronics Conference
Conference Dates: 22-Jun-2002 to 28-Jun-2002
Russian Academy of Sciences, Moscow RUSSIA
Conference URL: www.ilc.msu.su/iqec/
Conference Email: iqec2002@comsim1.phys.msu.su

Venice Summer School on Polarization Mode Dispersion
Conference Dates: 24-Jun-2002 to 26-Jun-2002
Instituto Veneto di Scienze, Venice, ITALY
Conference URL: vss2002.dei.unipd.it

Int'l Symposim on Optical Memory (ISOM) and Optical Data Storage Topical Meeting (ODS) 2002
Conference Dates: 7-Jul-2002 to 11-Jul-2002
Outrigger Waikoloa Beach, Waikoloa, HI USA
Conference URL: http://www.ieee.org/organizations/society/leos/LEOSCONF/ISOMODS2002/isomods.htm
Conference Email:

Opto-Electronics and Communications Conference
Conference Dates: 8-Jul-2002 to 12-Jul-2002
Pacifico Yokohama, Yokohama JAPAN
Conference URL: http://www.bcasj.or.jp/oecc2002/
Conference Email: oecc@bcasj.org.jp

IEEE LEOS Summer Topical Meeting Series
Conference Dates: 15-Jul-2002 to 17-Jul-2002
Fairmont Tremblant, Mont-Tremblant, Quebec CANADA
Conference URL: http://www.ieee.org/organizations/society/leos/LEOSCONF/SUM2002/sum02.htm
Conference Email: summertopicals@ieee.org

International Optoeletronics Exhibition 2002 (InterOpto 2002)
Conference Dates: 16-Jul-2002 to 19-Jul-2002
Makuhari Messe, Chiba JAPAN
Conference URL: http://www.oitda.or.jp
Conference Email:

International Conference on Optical Internet (COIN 2002)
Topical Meeting on Photonics in Switching (PS 2002)
Conference Dates: 21-Jul-2002 to 25-Jul-2002
Hyatt Regency Hotel, Cheju Island KOREA
Conference URL: http://www.coin-ps2002.org/
Conference Email: coin-ps2002@icu.ac.kr

Int'l Conference on Optical MEMs (MOEMS 2002)
Conference Dates: 19-Aug-2002 to 23-Aug-2002
Hotel de la Paix, Lugano SWITZERLAND
Conference URL: http://www.fzk.de/imt/optmems2002/

European Conference on Optical Communication (ECOC 2002)
Conference Dates: 8-Sep-2002 to 12-Sep-2002
Bella Center, Copenhagen DENMARK
Conference URL: www.ecoc.dk/

Conferences between 1-Mar-2002 and 1-Dec-2002 (cont'd.)
For further information please see the LEOS conference calendar at www.ieee.org/leos

International Conference on Molecular Beam Epitaxy (MBE XII 2002)
Conference Dates: 15-Sep-2002 to 20-Sep-2002
Renaissance Parc 55 Hotel, San Francisco, CA USA
Conference URL: http://www.ieee.org/organizations/society/leos/LEOSCONF/MBE2002/mbe02.htm

Symposium on Optical Fiber Measurements (SOFM 2002)
Conference Dates: 24-Sep-2002 to 26-Sep-2002
NIST, Boulder, CO USA
Conference URL: http://www.boulder.nist.gov/blconf.htm

IEEE International Semiconductor Laser Conference
Conference Dates: 29-Sep-2002 to 3-Oct-2002
Kongresshaus Garmisch-Partenkirchen, Garmisch GERMANY
Conference URL: http://www.ieee.org/organizations/society/leos/LEOSCONF/ISLC2002/islc02.htm

International Symposium on Compound Semiconductors
Conference Dates: 7-Oct-2002 to 10-Oct-2002
Hotel Alpha, Lausanne, SWITZERLAND
Conference URL: http://iscs2002.epfl.ch/

International Conference on Optics-Photonics Design & Fabrication (ODF 2002)
Conference Dates: 30-Oct-2002 to 1-Nov-2002
National Museum of Emerging Science and Innovation, Tokyo JAPAN
Conference URL: http://annex.jsap.or.jp/OSJ/meet/ODF2002/index.html
Conference Email:

International Topical Meeting on Microwave Photonics (MWP2002)
Conference Dates: 5-Nov-2002 to 8-Nov-2002
Awaji Yumebutai Int'l Conference Center, Hyogo JAPAN
Conference URL: http://www.ieice.org/~mwp/mwp2002/
Conference Email:

IEEE LEOS 15th Annual Meeting (LEOS 2002)
Conference Dates: 11-Nov-2002 to 14-Nov-2002
Scottish Exhibition and Conference Centre, Glasgow, Scotland UK
Conference URL:
Conference Email:

President's Column

Continued from page 1

of you about your needs, and your willingness to actively participate in LEOS activities.

FYI, Jim Coleman championed a program for primary and secondary school teachers to do research in universities. This is a trial program to be funded by LEOS for three years, with up to three grants with a maximum of $10,000 each. You may want to get together with a local teacher to apply for it. In 2002, the deadline for submissions will be 25 April, and awards will be decided and announced by 16 May. This program triggered an idea that to get more young people interested in science and technology could be the noble goal needed to rally our members. Maybe we can take on a project to make it easy for LEOS members to promote science and photonics to K-12 students through the Chapters, hopefully with the active participation of retired members. What I've learned from Jim is that most high school science teachers do not have much more than sophomore college physics. So it is hard for them to make science interesting. That's something most of us are good at, especially if we can get a few pointers from a colleague. I personally have avoided touching the K-12 science education issue because as an individual I do not know how to get my hands around such a big problem. A little help from the LEOS "mother ship," such as having available a collection of simple demonstrations, or pointers to the organizations that already have similar efforts underway may just be enough to set some of us into motion. We can then make a meaningful personal contribution in our own way to fulfill some particular local needs. Some of us may choose to develop a mentor relationship with a student or a teacher, to give a lecture at a local science museum, to help a student do a science project, or whatever. None of these are new ideas, but the point is with a little "lubricant", we can help our members make laser electro-optics topics interesting to spark student interests. What do you think? Please write me of any successes and failures you have had in these activities and any help you wish you had and I will compile your experiences to share with everyone.

I will now report on OFC 2002. Total attendance was down slightly from last year, 15 % to 32,000. Technical registration was just over 7,700, down nearly 30% from last year. On the other hand, total booths sold were 1241, up over 25% from last year, although 37 booths were paid for but the companies chose not to exhibit. As I reported last time, paper submissions were at a record high, but to maintain quality standards, the number of papers presented was about the same as the previous year. Given that OFC is by far one of the most important sources of income for LEOS, please do what you can to help make OFC 2003 a big success.

I will report, for the last time, on the IEEE budget. I brought it up because I felt you ought to know. But this is also something LEOS, as a Society, has essentially no control over. The good news is IEEE is working towards a balanced budget, cutting staff and expenses. Just imagine, sending us the IEEE membership cards, which I trash, costs IEEE about $1 Million a year. What impacts LEOS directly is the "infrastructure tax." In the past this tax was based on the cash reserve of each Society. For 2001, that amounted to $2.48 Million for LEOS! Now since they have adopted a "pay-by-the-drink" formula, our tax in 2002 is projected to be $881,000 and will decline each year to $484,000 in 2005. Given that our reserve now stands at a healthy $5.4M, which is the third largest among IEEE Societies, there is no guarantee they won't somehow tap into it. In the meantime, keep your fingers crossed on the outcome of OFC 2003.

LEOS Mission Statement

LEOS shall advance the interests of its members and the laser, optoelectronics, and photonics professional community by:

- providing opportunities for information exchange, continuing education, and professional growth;
- publishing journals, sponsoring conferences, and supporting local chapter and student activities;
- formally recognizing the professional contributions of members;
- representing the laser, optoelectronics, and photonics community and serving as its advocate within the IEEE, the broader scientific and technical community, and society at large.

LEOS Field of Interest

The Field of Interest of the Society shall be lasers, optical devices, optical fibers, and associated lightwave technology and their applications in systems and subsystems in which quantum electronic devices are key elements. The Society is concerned with the research, development, design, manufacture, and applications of materials, devices and systems, and with the various scientific and technological activities which contribute to the useful expansion of the field of quantum electronics and applications.

The Society shall aid in promoting close cooperation with other IEEE groups and societies in the form of joint publications, sponsorship of meetings, and other forms of information exchange. Appropriate cooperative efforts will also be undertaken with non-IEEE societies.

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THE INSTITUTE OF ELECTRICAL
& ELECTRONICS ENGINEERS, INC.
445 Hoes Lane
Piscataway, NJ 08855-1331, USA
www.i-LEOS.org