Integrating Research and Technology

EQEC and CLEO-Europe each have their distinct character, with EQEC covering the fundamental aspects of quantum electronics and CLEO-Europe primarily addressing applied area of lasers and electro-optics. The two distinguished European scientists who spoke during the single EQEC/CLEO-Europe plenary session of the joint conference nicely illustrated the linking of basic research and advanced technology. Both reviewed major recent developments, with H. Walther (Max-Planck Institute, Garching) discussing micro-rasers and associated studies of phenomena in quantum optics while D. Payne (Southampton) spoke on the revolution in telecommunications catalyzed by the advent of high-quality optical amplifiers. These are seemingly well-separated topics. However, over the next decade they will merge as quantum optical effects are predicted to enter the field of optical communication owing to stringent requirements on protocols for secure transmission.

The interplay between fundamental research and state-of-the-art applications was further emphasized in two joint symposia. The one on Quantum Engineering of Photonic Materials featured Y. Yamamoto (Stanford and Tokyo), who spoke on microcavity lasers, and C. Weisbuch (Ecole Polytechnique, Paris) who discussed cavity quantum electro-dynamics in multiple quantum-well structures. Both gave clear evidence that optical microcavities represent a fast maturing field (see page 205) with many potential applications, including noise control in optical communications systems. E. Yablonovitch (Los Angeles) reviewed photonic bandgaps and semiconductor electronics. Among several fascinating topics, he described an intelligent programmable radar reflector that resembled a fence made of chicken wire.

The second joint symposium dealt with the Production and Application of High Brightness Ultrashort Pulses. This field has witnessed a very strong development of both fundamental and applied nature, catalyzed by the advent of new, powerful, short-pulse lasers. S. Sazamari (Göttingen) discussed table-top, high-power femtosecond excimer lasers, while three speakers covered high-brightness X-ray sources, among them E. Turcu (Rutherford Appleton Laboratory) and C. Schenk (Berkeley) who reviewed applications of laser-generated X-rays for lithography and microscopy. This application is potentially very important because it is capable of introducing table-top X-ray sources into the electronics industry. The symposium also dealt with more fundamental issues, notably high harmonic generation in various media. Impressive progress was reported on the generation of tunable XUV radiation featuring parametric mixing. The broad interest in high power and short-pulse lasers, CLEO-Europe included highlights in the fields of waveguide- (fibre-) based lasers, with A.C. Tropper (Southampton) and R. Wyatt (British Telecom) giving invited talks on the rapid developments, including up- and down-conversion. On the EQEC side, the interesting properties embedded in the transverse degrees of freedom of laser fields (i.e., transverse optical pattern formation) was discussed by several speakers, among them G.-L. Oppo (Strathclyde) who showed video recordings of calculated spontaneously generated patterns.

EQEC Symposium Attracted Many

Two EQEC symposia, Cold Atoms and Atom Optics and Interferometry, attracted large crowds on the last day of the joint conference. The leading scientists in these extremely active research areas gave a series of talks of a very high quality. The field of cold atoms is developing rapidly with the custom design of optical lattices for cold atoms. G. Grynberg (Paris) and T.W. Hänisch featured a large technical exhibit in addition to the technical conference itself.

The link between academia and industry has historically been weaker in Europe than in the US. This was the main reason the Quantum Electronics and Optics Division (QEOD) of EPS decided to enter into a collaboration with sister organizations in the US to strengthen the impact of the Divisional EQEC event (organized biannually in Europe since 1986). The success of the Amsterdam meeting shows that this motivation was fully justified.

1994 EQEC/CLEO-Europe
First Event a Landmark Success

With over 2200 participants, the first joint European Quantum Electronics Conference/Conference on Lasers and Electro-Optics (EQEC/CLEO-Europe) held at the RAI Conference Centre, Amsterdam (28 August - 2 September 1994) proved to be a major success.

EQEC/CLEO-Europe is a new initiative aimed at strengthening the interplay between public-sector R&D and industrial development in one of the fastest growth areas of modern technology. In the US, CLEO organized in conjunction with the Quantum Electronics and Laser Science conference, has successfully bridged the traditional gap between private and public R&D, notably by featuring a large technical exhibit in addition to the technical conference itself.

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A full house at the RAI for the 1994 EQEC/CLEO-Europe plenary session. The 1994 EQEC/CLEO-Europe was sponsored by EPS, the IEEE/Lasers and Electro-Optics Society (LEOS), and the Optical Society of America, with the Quantum Electronics and Optics Division (QEOD) of EPS responsible for EQEC '94. The joint event was organized by a LEOS/OSA/QEOD steering committee, and the programme consisted of 8 parallel sessions, 3 EQEC sessions and 5 CLEO-Europe sessions. There were 2200 participants, including some 1500 for the conferences themselves and 300 who visited the industrial exhibition. Conference participants could register either for EQEC (40% chose this) or for CLEO-Europe, but both groups received the technical digests for the two events. A total of 1500 papers (600 for EQEC) were submitted from nearly 50 different countries; some 40% were selected for oral presentation, 30% were given as posters and 30% were rejected. In addition, nearly 90 invited papers in the EQEC part and 90 invited papers in CLEO-Europe ensured a high scientific quality of this first major European event in quantum electronics and lasers. The success of the meeting was greatly enhanced by the early acceptance of many of the invited speakers who thus lent their prestige.
QEOD Board Elects New Chair

M. Ducloy (Paris) and O. Poulsen (Lyngby), on the right. Professor Mlynek reported during the General Meeting of the Division held at the end of the EQEC/CLEO-Europe joint plenary session that Ducloy would be taking over from him next April. He also summarised the Division's wide-ranging activities including: plans for a "who's who" (the last was published in 1984); the Division newsletter in Optics Communications; a possible EPS prize in quantum electronics; conferences, notably the very successful European Research Conference in quantum optics, and of course EQEC in its new format; and finally, efforts to enhance relations with industry, the European Community and with the European Optical Society. Many scientists and engineers working in optics attended the 1994 EQEC/CLEO-Europe, thereby illustrating the optical community's high level of interest.

Garchign discussed in detailed design criteria for the optical potentials in both two- and three-dimensions, and gave examples of unexpected cooperative effects resembling phenomena found in the solid state. The basic physical phenomena behind laser cooling of free and lightly bound atoms were reviewed by M.J. Phillips (National Institute of Science and Technology, Washington), a well-known pioneer of laser cooling, in an exceptionally clear presentation. The EQEC symposium on Atom Optics and Interferometry had the same rare qualities as the symposium on cold atoms by active researchers representing state-of-the-art activities in a rapidly growing field. The world of Newtonian physics was successfully merged with quantum physics by J. Dalibard (Paris), who described the motion of laser-cooled cesium atoms in a gravitational cavity (i.e., a cavity that apparently has no magnetic field present). The extreme precision inherent in using laser-cooled free atoms in combination with atom interferometry was convincingly discussed by J. Heltzcke (Physikalisch-Technische Bundesanstalt), and the fundamental measurement limits were reviewed by T. Pfau (Constance). A highlight of the symposium was an introduction to the (new) topic of non-linear atom optics by P. Meyare (Tucon). The main problem in defining non-linear effects lies in the intricate interaction between atoms in optical fields.

1994 EQEC/CLEO-Europe HIGHLIGHTS

MONOLITHIC MINIATURE RESONATORS
Manipulating the Electromagnetic Field

A major success of quantum optics in the last decade has been the experimental demonstration that the quantum fluctuations of light can be modified: the fluctuations in one quadrature (the amplitude of the cos[qt] or sin[qt] component of the electric field) can be decreased ("squeezed") below the vacuum level, while those in the orthogonal increase correspondingly in order to satisfy the Heisenberg uncertainty relation. Squeezed light can be produced by subjecting a light mode to a nonlinear interaction of the type that gives rise to second-harmonic and subharmonic generation (so-called optical parametric oscillation). Unfortunately, squeezed light is fragile: its nemesis are the ubiquitous propagation losses. To generate strongly squeezed light one must provide an environment in which the nonlinear interaction can act while the losses play a secondary role.

At present, the experimental emphasis relies on developing reliable and efficient sources of strongly squeezed radiation for a number of applications. An "all solid-state" approach has been adopted at the University of Constance by combining diode laser-pumped solid-state lasers and monolithic nonlinear resonators (see photograph). Round-trip losses as low as 0.2% have been routinely achieved.

In a first experiment, a continuous-wave, single-mode wave from a frequency-tunable Nd:YAG laser was resonantly injected into a monolithic nonlinear optical resonator. Shown is a resonator fabricated out of a lithium-niobate single crystal whose ends are accurately polished into a spherical shape. Multilayer dielectric coatings are sputtered directly onto the end faces of the crystal.

1996 EQEC/CLEO-Europe

The 1996 joint European Quantum Electronics/Conference on Lasers and Electro-Optics — Europe will be held in France or Germany in September 1996. In view of rapid developments, there will be two new EQEC session (on atom optics and on cold atoms). The CLEO-Europe general chairs are D.C. Hanna and J.-P. Huignard; the EQEC general chairs are O. Poulsen and E. Giacobino. For information, contact O. Poulsen, Microelectronic Centre, T. Lyngby, DK-2800 Lyngby. Tel./fax: +45 93 46 10/45 88 77 62; op@mic.dtu.dk.

Monolithic nonlinear optical resonator. The high circulating power that builds up within the cavity is converted to the harmonic wave (532 nm wavelength) which immediately escapes from the resonator. When the device is operated in an input-power regime such that the external power conversion efficiency is high, the harmonic wave exhibits intensity noise below the vacuum level. Reduction of 30% has been measured, with more than 50 mW of optical power [Paschotta et al., Phys. Rev. Lett. 73 (1994) 3807]. This source is remarkably stable over many hours, and represents a very simple and reliable way of producing squeezed light.

Besides bright squeezed light, the generation of squeezed vacuum is also of great importance to the optical community's high level of interest.
**FREQUENCY STANDARDS**

**Spectroscopy of a Single Laser-Cooled Indium Ion**

A single laser-cooled ion stored in a radiofrequency trap forms an ideal spectroscopic sample that is practically free of frequency shifts and line broadening mechanisms. Laser spectroscopy of forbidden transitions with natural linewidths in the 1 Hz range therefore offers the potential for very high resolution and might form the basis of a new generation of atomic frequency standards.

The single charged In⁺ ion is an excellent candidate for these applications. We laser-cool it by exciting the intercombination line 5S2 1S0 → 5S5p 3P₁ at a wavelength of 230.6 nm. Presently we reach temperatures of less than 20 mK, but values down to 20 µK should be possible using sideband laser cooling.

The prospective clock transition is the 1S₀ → 3P₁ line at 236.5 nm, a very weak electronic dipole transition induced by hyperfine mixing of 3P₀ with 3P₁ and 1P₁. We recently measured the natural linewidth of this transition to be only 1.1 Hz [1], corresponding to a line Q of 10¹⁵. An excitation of the metastable 3P₀ level can be unambiguously detected as a dark period in the single-ion fluorescence signal on the cooling transition. Samples of fluorescence signal data exhibiting quantum jumps are shown in the figure. The frequency of the 1S₀ → 3P₁ line coincides with the fourth harmonic of a Nd:YAG laser line. Thus an ultrafastable frequency quadrupled diode-pumped Nd:YAG laser operating at 946 nm is used to probe the excitation spectrum of the ion.


**PHOTON CONTROLLED STRUCTURES**

**Breakthroughs at Hand**

The special 1994 EQEC/CLEO-Europe joint session Quantum Engineering of Photonic Materials as well as several presentations indicated that photon-mode control in optical microcavities and bandgap materials has made major advances recently. Claude Weisbuch (Ecole Polytechnique, Paris) reports.

During the 1994 EQEC/CLEO-Europe joint symposium, E. Yablonovitch (Los Angeles) insisted on the huge device applications which can be forecast for the emerging field of photon-mode control in semiconductor microcavities or photonic bandgap (PBG) materials [1]. Moreover, recent implementations which rely on "photonic atoms" have turned out to be easier to fabricate than those originally proposed. It is therefore not surprising that major advances [2] were reported at the 1994 EQEC/CLEO-Europe.

**Couple-Mode Luminescence**

The driving force in the field of photon-mode control is the ability to manipulate spontaneous light emission, photon-matter interaction, beam performance, etc. via the selective enhancement or suppression of photon modes in wavelength-sized, post-nanosecond emission, by the resulting modification of Fermi's golden rule. In the strong-coupling regime, the interaction of a selected and enhanced photon mode with the material's excitations is so strong that the perturbation approach breaks down, the materials system and the photon-mode system interact coherently with one another, giving rise to a Rabi

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**References**

2. E. Piek, G. Hollerman, H. Walther MPI for Quantum Optics, Garching University of Munich
oscillation of the coupled photon-matter system between its two states, where one of the two systems, material or photon, is in the excited state while the other is in the ground state, and vice-versa.

C. Weisbuch (Ecole Polytechnique, Paris) described the strongly-coupled system realized by inserting semiconductor quantum wells in a planar Fabry-Perot microcavity consisting of monolithically-integrated, directly-grown, quarter-wave layer stacks of mirrors (a so-called distributed-Bragg reflector or DBR) sandwiching a spacer layer (Fig. 2a). The most recent work [3] deals with the observation and understanding of coupled-mode luminescence. The in-plane momentum dispersion curves of cavity polaritons (the coupled-mode dispersion) has been determined from a detailed analysis of the angular-resolved emission and is found to agree with the predicted curves (Fig 2b). One therefore now understands the basic aspects of cavity-polariton emission.

There remain, however, some aspects that need further work. In particular, Y. Yamamoto (Stanford and Tokyo) discussed the effects observed at high intensity with strongly-coupled semiconductor quantum wells in microcavities. He modified the usual light-matter Hamiltonian describing the photon field, the material system, and their interaction by inserting boson operators. The solution led to sidebands instead of the usual Rabi doublet. However, this attributing of luminescence sidebands to "Rabi sidebands" originating in the boson nature of the excitons is at variance with the normal fermionic behaviour of electrons in atoms.

But the major issue in the field is to improve light-emitting devices (LEDs). Research is active world-wide and could soon provide a major breakthrough in the high-efficiency generation of light. One of the most desirable devices is the "zero-threshold" laser, where suppression of spontaneous emission in all photon modes but one, i.e., the laser mode itself, allows continuous switching from spontaneous to stimulated emission (photon number in the remaining mode = 0), with a constant quantum efficiency near 100%. The emission process would become fully deterministic, which could lead to photon emission that is limited by Johnson noise instead of the coexistent spontaneous emission with laser emission. De Neve et al. (IMEC, Gent) reported an important step towards the realization of high-efficiency LEDs, possibly zero-threshold lasers, by carefully designing a planar microcavity to give an external quantum efficiency of 6.2% (recently extended to 10.5%).

High Efficiency LEDs

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Austrian Textbook Wins Amaldi Prize

Reconciling our everyday world with the complex logical construction based on empirical principles and mathematics that allows natural phenomena to be modelled is seen by many as the challenge facing secondary school teachers. The winner of the 1993 Amaldi International Prize for a High-School Physics textbook addresses this problem by splitting the physics course into its essential parts (as four, short, compact, volumes on basic knowledge) complemented by series of 12 theme-oriented books dealing with applications in daily life. The books also introduce some novel but useful devices, such as logos asking the student to do something (e.g., "think about ..."), ideas for experiments for the at home, and English translations of technical terms.

The winning textbook is called Physikcompact published by Verlag Hölder-Pichler-Tempel (Vienna), Austria's largest publisher of maths and physics textbooks. The authors are Albert Jaros, Alfred Nussbaumer, Peter Nussbaumer, Hansjoerg Kunze, Leonhard Mathelitsch, Robert Hofstetter, and Hans Haimo Tempert. R. Hofstetter teaches physics and philosophy at Vienna University and in a gymnasium and L. Mathelitsch is Professor of Theoretical Physics at the Technical University, Graz. The other authors are all teachers in gymnasia, with the two Nussbaumers being twin brothers.

Physikcompact was published to coincide with the introduction of Austria's new physics curriculum in 1989, which the authors were heavily involved in drafting. The four basic volumes (Basiswissen) are only sold in Austria, but some 1500 of the theme-oriented books (Themenhefte) have been sold in Germany. The Prize Jury felt the contents were flexible enough to suit curricula in different countries. This may encourage the publication of translations, for which there are no plans at present.

The 1993 Amaldi Prize, the first ever, was awarded by the Edoardo Amaldi Foundation, Piazza, with EPS sponsorship. It comprised 20 000 ECU given to the authors and publishers of a high-school physics textbook first printed in Europe between 1 January 1987 and 30 September 1993. A total of 47 books were submitted out of an estimated 60-70 potential candidates, there being none in French and relatively few in German. The next prize will be awarded in a few years time.