Spotlight on Quantum Electronics and the Use of Dye Lasers

For the past several years, the accusation has been made that quantum electronics in no longer an exciting field, having matured in the 22 years since the invention of the laser. But one must not forget that a fruit grows most rapidly early in its period of maturation, its growth slowing markedly as it reaches maturity. This is the time of ripening, and it is not to be confused with stagnation. I am happy to report that the fruit of quantum electronics is now ripe, tastes delicious, and decay is nowhere in sight. In fact, the process is self-renewing, and seeds are being sown in lots of other fields.

At the XII International Quantum Electronics Conference, held in Munich from June 22-25, 1982, I learned about:

(1) how lasers can produce pulses only 30 femtoseconds long (3×10^{-14}s), an incredibly short time by any standards,

(2) detailed laser spectroscopic studies of the chemical equilibrium between Na and Na_2,

(3) absolute wavelength measurements of the fine structure of Li^+ ions using laser-microwave double resonance spectroscopy,

(4) detection of adsorbed monolayers on surfaces by nonlinear optical spectroscopy of the surface,

(5) the observation of optical excitation of positronium by two photon spectroscopy,

(6) the measurement of H atom concentration and velocities at the edge of a tokamak plasma,

(7) a microscope with high spatial resolution and molecular specificity based on nonlinear optical spectroscopy, and

(8) dynamical studies of optical bistability using a Doppler-free, two-photon resonance excitation.

These topics are representative of the astounding progress that continues to be achieved in quantum electronics and show how the field is proliferating in its impact on other scientific fields. A striking aspect of each of the above topics is that they were carried out using dye lasers, the workhorse of laser spectroscopy.

The conference featured a plenary session with talks by Arthur Schawlow and Nicolaas Bloembergen who shared, with Kai Seigbahn, the 1981 Nobel Prize in physics. Bloembergen and Schawlow who were cited for their contributions to the development of laser spectroscopy, each gave a talk about lasers and spectroscopy, and, once again, dye lasers were prominent in the experimental studies that formed the substance of their presentations. Both men have been involved in quantum electronics since its founding in 1959, and they have made substantial and continuing contributions to laser science from that time right up to the present.

It was particularly interesting for me to hear back-to-back talks by Fritz Schaefer and Peter Sorokin on their latest research in the area of laser studies of chemical physics. Schaefer and Sorokin are generally recognized as the independent co-discoverers, in 1966, of lasing from organic dyes, and they have continued to be active in dye laser research and in laser spectroscopy, the field that has mushroomed up around their discovery.

The conference had over 1000 participants, and talks were presented in four parallel sessions over four days. In addition, nearly 70 post-deadline papers were presented on the first night of the conference. With such a wealth of new results, it is impossible for this review to do justice to everything worth reporting. Therefore, I shall concentrate on the above eight topics, all of which generally fall under the heading of laser spectroscopy, the field I know best.

On the short-pulse frontier, several groups from the United States, one at Bell Labs., Holmdel, N.J., one at the Laboratory for Laser Energetics, Rochester, N.Y., and one at Cornell University, Ithaca, N.Y., reported on the generation of 70 femtosecond long pulses from mode-locked dye lasers. Charles V. Shank, the leader of the Bell Labs. effort, gave an invited talk entitled "Progress in Ultrashort Optical Pulse Generation", in which he reviewed the latest dramatic advances. He described how the 70 fs pulse could be further shortened to 30 fs, using a technique devised by a group at IBM Research, Yorktown Heights, N.Y. In this technique, the short input pulse is first sent through a length of single-mode optical fibre where linear and nonlinear propagation effects serve to broaden the frequency spectrum of the pulse and cause it to be chirped. The resulting pulse can then be recompressed using a linear, dispersive delay line, the recompressed pulse ending up shorter than the starting pulse. Shank and co-workers thereby produced a pulse which, incredible as is may seem, was only ~ 12 optical cycles in duration and covered a distance of a mere ~ 10μm in space. It seems clear that such short pulses will be used to probe dynamical behaviour on this unprecedented time scale (sub-picosecond spectroscopy), and there is certainly going to be great activity to see how the pulses themselves behave, as well as to shorten them further. (What do you call a pulse that is shorter than a femtosecond?)

On a different front, J.P. Woerdman of Philips Laboratories in Eindhoven presented an invited talk entitled "Chemical Accommodation of Na_2 Wall Collisions Studied by Laser Spectroscopy." He studied the spatial distribution of the two species Na and Na_2 over a glass cylinder subject to a temperature gradient which created a stationary non-equilibrium distribution of the two species. His studies revealed that the sticking coefficient of the species upon collision with the cylinder walls was of the order of unity. Additional studies revealed the velocity distribution of the species and showed an asymmetry that was also a consequence of the temperature gradient. Studies such as this will provide important information about the nature of chemical reactions occurring at the gas-surface interface.

High-resolution laser spectroscopy was represented by a group from the Physikalisches Institut, Heidelberg University, who presented a talk entitled "Laser-Microwave Spectroscopy and Absolute Wavelength Measurements in Helium-Like Li^+ Ions." The authors, M. Englert, J. Kawalski, F. Mayer, R. Neumann, S. Noehte, R. Schwarzwald, H. Suhr, K. Winkler, and G. zu Putlitz, used a specially-built travelling wavemeter to make absolute wavelength measurements to an accuracy of 1 part in 10^8, thereby measuring the $2\,^3S_1$ - $2\,^3P_0$ transition in $^6Li^+$ and $^7Li^+$ to unprecedented accuracy. These measurements are important experimental tests for the most precise calculations based on theoretical models for the two-electron system.

An invited talk entitled "Nonlinear Optical Detection of Adsorbed Monolayers and Monolayer Spectroscopy" was presented by T.F. Heinz, C.K. Chen, D. Ricard, and Y.R. Shen of the University of California, Berkeley. They reviewed advances in using second harmonic generation to detect adsorbates on surfaces. By studying the spectrum of the second harmonic generated light as the dye laser wavelength was tuned, monolayer coverages of several different organic dyes on smooth fused silica substrates were identified. Such techniques have the promise of being able to identify the species on the surface of a substrate undergoing a chemical reaction with an adjacent fluid.

Turning to fundamental scientific questions, a beautiful scientific investigation of the electronic structure of positronium was presented by Steven Chu and Alan Mills of Bell Labs., Murray Hill, N.Y. In an invited talk entitled "Observation of the $1\,^3S_1$ - $2\,^3S_1$ Energy Splitting in Positronium", they described an experiment in which resonance-enhanced ionization of positronium was detected as a dye laser was tuned into resonance with the two photon transition. The experiment required the synchronization of a pulsed laser with a pulsed positron source and the use of single atom detection techniques. Their data showed clear resonances when they counted for sufficiently long times, (since the peak count rate was only 5 counts per 200 laser shots above the background noise count rate). Experiments such as this show the unique power of spectrally-narrow, tunable lasers for investigations of fundamental interest.

While positronium is an exotic "unique" atom, hydrogen is just as unique, if not exotic. In a talk entitled "Atomic Hydrogen Concentrations and Velocities Measured with Harmonically Generated Lyman-α (1215 Å) Radiation", Russell Dreyfus, P. Bogen and H. Langer reported their latest results aimed at measuring the H-atom concentration and velocity distribution at the boundary of a hydrogen-plasma within a tokamak discharge. This work was the result of a collaboration between the KFA at Jülich and the Max-Planck Institute for Plasma Physics at Garching in association with Euratom. Using state-of-the-art techniques, dye laser radiation tuned to 3646 Å was frequency tripled to produce Lyman-α radiation, bright enough to detect H atoms by laser-induced-fluorescence techniques, even in the presence of background Lyman-α produced by a tokamak dischage. These measurements represent an important step toward experimentally characterizing the transport of H atoms in the plasma boundary of a tokamak.

In the field of biophysics, M.D. Duncan, John Reintjes and T.J. Manuccia of the Naval Research Laboratory, Washington DC, described "A Scanning CARS Microscope", a technique which allows both molecular specificity and high spatial resolution by using Coherent Anti-Stokes Raman Spectroscopy (CARS). The characteristic Raman scattering spectrum gives the technique molecular specificity, and the spatial coherence of the generated signal provides the high spatial resolution. The technique has been used to obtain images from a variety of organic liquids and from onion skin cells containing deuterated water. Since the technique used picosecond pulses from dye lasers, time-resolved studies of dynamic biological systems should be possible.

The last item on my menu deals with a post-deadline paper presented by E. Giacobino, S. Cribier, G. Grynberg and F. Biraben of the Laboratoire de Spectroscopie Hertzienne de l'E.N.S., Paris, entitled "Study of Transients in Intrinsic Optical Bistability." The topic of optical bistability has been fashionable for several years because of possible technological applications to switching. Devices featuring optical bistable behaviour might feature very short switching times. In this paper, the authors studied the temporal behaviour of an intrinsic bistable Fabry-Perot device as it switched from low to high transmission, and vice-versa. Their study featured the use of rubidium vapour as the nonlinear medium filling the Fabry-Perot. A dye laser was tuned to a two-photon transition so that the excitation of the rubidium was Doppler-free (the light was naturally counterpropagating within the Fabry-Perot cavity), thereby enabling all the atoms to respond in the same way, independent of velocity. Their experimental results were shown to be in good agreement with theoretical calculations for the transient behaviour where the relaxation times of both the nonlinear material and the cavity were taken into account.

These laser spectroscopic results are just some of the exciting things I heard and saw at the conference. I must also mention startling new results in the study of the transition from stable to chaotic behaviour, a field known as period-doubling bifurcation to chaos. In essence, a system can make a transition to chaotic behaviour in an orderly manner. One Italian speaker on this topic concluded his talk by saying that this type of work is very important to the Italian physicists because it gives them hope that there may be some order in chaos. There was also a wealth of new results on laser-assisted studies of chemical physics, new laser-like sources in the vacuum ultraviolet, phase conjugation, picosecond pulse applications, laser-produced plasmas, and nonlinear optical processes. An exhibit of commercially available laser equipment could best be described as making me want to throw out all my old instruments and start anew.

Finally, the arrangements of the conference provided an atmosphere that optimized the exchange of information. The conference organizers and the programme committee deserve our thanks for putting together an excellent meeting. The programme and summaries of the papers presented at the conference are published in *Europhysics Conference Abstracts*, Volume 6B and in *Applied Physics*, **B28** (June/July 1982) 2/3, pp. 81-310.

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