editorial

Quantum electronics—25 years of achievement

For over twenty-five years quantum electronics has provided a striking example of scientific creativity, technological impact, and cross-fertilization between physics and numerous other fields. The origins of quantum electronics coincided with the intense activity in microwave and magnetic resonance spectroscopy as klystrons and other high-frequency radio technology became available following World War II. An outgrowth of this work was the realization that transitions between molecular rotational/vibrational states in gases and magnetic states in solids could act as a fundamentally new type of microwave circuit element. The uniquely quantum-mechanical features of negative temperature, inverted population, and net stimulated emission of radiation, together with well known electronic concepts such as feedback, led to the maser and laid the groundwork for the laser.

The quantum-electronics articles in this issue, as well as the new results to be presented at the Tenth International Quantum Electronics Conference to be held later this month in Atlanta, Georgia, reflect a remarkable combination of physics, electronics, materials and even computer-science activities very much in the tradition of the first Quantum Electronics Conference held in 1959 in High View, New York.

The pace in the control and utilization of electromagnetic radiation since the 1960 demonstration of the ruby laser is suggested by the subsequent increase by 10^{10} in optical power, from kilowatts to tens of terawatts; the increase to a part in 10^{11} in spectroscopic resolution; the decrease by a factor of 10^7 in pulse duration, from microseconds to tenths of picoseconds. Also impressive has been the change in simple physical volume of lasers in comparison to the ruby laser: a factor of 10^8 decrease in volume for semiconductor communication lasers and 10^8 increase in volume for fusion lasers.

A different measure of the pace of activity is our comfortable familiarity with concepts that seemed less than self-evident as recently as the first observations of coherent laser light. Examples that come to mind include open optical resonators bounded by end mirrors, optical modulation and sidebands, nonlinear optical properties of matter, and the differences between the statistical properties of laser radiation and incoherent light.

The appearance of new lasers continues, based in part on familiar materials but also on wholly new systems such as the excimer rare-gas halides discussed in this issue. The excimer transitions, between unstable ground and stable excited states, emit very efficiently in the ultraviolet and were unknown only a few years ago. An interesting example of a new group of semiconductor lasers is the system of quaternary gallium, indium, arsenide, phosphide III–V alloys. This composition is of special importance for optical communications because it emits near 1.3 microns where optical fibers have minimum wavelength dispersion and transmission losses. Another example, embodying a novel emission mechanism, is the broadly tunable free-electron laser in which gain arises from transfer of power to optical radiation from an electron beam traversing a synchronously periodic, spatially varying magnetic field. In parallel with the development of new lasers has been the dramatic scaling up to higher peak powers of CO_2, neodymium:glass and other potential laser drivers for inertial-confinement fusion.

An important scientific return from the laser has been its use in high resolution and high-speed spectroscopy. The discovery of doppler-free resonant nonlinear laser spectroscopy has led to improvements of 10^5 in resolution, to values midway between doppler widths of 10^{-6} and an ultimate goal of 10^{-15} set by the natural width of the laser line, a regime accessible now only in Mössbauer systems. New processes, such as cooling and trapping of atoms by laser radiation now under active study, could allow detection of minute effects such as the difference in energy levels of mirror-image molecules due to parity nonconservation.

Another return has been high-speed optical pulse spectroscopy, recently extended into the subpicosecond regime by passively mode-locked, continuously operating dye lasers. Pulses of this duration consist of only a few hundred optical cycles. Achievements to date of picosecond and subpicosecond techniques include the first direct observation of nonradiative electronic relaxation processes in semiconductors, identification of the pathways of electronic energy transfer in organic and biological molecules, and resolution by a fast two-photon process of the broad, featureless absorption bands of polyatomic molecules.

Laser radiation has led to important new photochemical and analytical techniques. As discussed in this issue polyatomic molecules can absorb about 30 infrared photons to form highly excited vibrational states. The resulting highly isotope-selective, infrared photochemistry has obvious applications to synthesis, isotope separation, purification and catalysis. Fundamental understanding of these processes remains incomplete. On the analytical side, the combination of multiple-photon absorption and sensitive ion detection has made possible the tagging and detection of single atoms.

Other active quantum-electronic areas include astrophysics and infrared astronomy, the extension of coherent optical sources into the far uv and x-ray region by laser and optical harmonic generation, as well as important medical and computing applications.

As its potential for major impact on the transmission of information and generation of energy becomes clearer, quantum electronics promises continuing opportunity for both technical innovation and fundamental new physics.

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Tenth International Quantum Electronics Conference