Introduction to the Special Issue on Free-Electron Lasers

THIS is the fourth Special Issue of the IEEE JOURNAL OF QUANTUM ELECTRONICS devoted to the topic of Free-Electron Lasers (FEL's). Spaced about every two years (August 1981, March 1983, and July 1985), these issues fairly represent the substantial progress in a field requiring multidisciplinary teams of scientists and engineers. The period since the third Special Issue in 1985 has been especially productive as evidenced by many reports of important experimental achievements, verification of theoretical predictions with experimental results, plus a host of new proposals for advanced devices.

Recent reports of successful laser operation, in chronological order, have included: 1) ~ 3 μm operation of the Stanford University FEL driven by their room-temperature, Mark-III RF linac, 2) 2 percent energy extraction during tapered-wiggler (a.k.a. undulator) oscillator experiments at ~ 10 μm at Los Alamos National Laboratory, 3) ~ 40 percent energy extraction from a tapered-wiggler FEL amplifier at 8.6 mm by Lawrence Livermore National Laboratory, 4) first operation of a Cerenkov FEL tuned between 400 μm and 1 mm by a Dartmouth University/Ecole Polytechnique at Palaiseau team, 5) first visible-wavelength operation (528 nm) of an RF-linac-driven FEL by a Stanford University/TRW team using the Stanford Superconducting Linear Accelerator, 6) coherent harmonic FEL production in the vacuum-ultraviolet at 177 and 106 nm by bunching the electrons circulating in the ACO storage ring (University of Paris at Orsay) with an external 532 nm laser, and 7) 3 percent spectral tuning at 4 μm by use of a H_2-gas-loaded wiggler in the Mark III FEL at Stanford University.

To verify the potential for high-efficiency FEL operation, two experiments were conducted to demonstrate the principle of energy recovery from a recycled electron beam. At Stanford University, a racetrack configuration first accelerated and then decelerated the electrons in the same superconducting traveling-wave linac structure. Energy-recovery experiments at Los Alamos National Laboratory used separate standing-wave structures (room temperature) to accelerate and decelerate the electrons with an RF coupling element between the two to return the recovered energy to the accelerator cavities. While lasing at 10 μm with beam energy of 20 MeV and 0.1 A average current, 70 percent of the residual electron energy passing through the wiggler was recovered.

Major advances in accelerator components have included RF-linac injectors that produced low-emittance beams of unprecedented brightness. With the Mark III Stanford University injector, normalized emittance values as low as 4π mm·mrad (90 percent of electrons) were measured with 20 A peak current by use of a field-emission gun with a LaB_6 cathode. At Los Alamos National Laboratory, a laser-driven photocathode injector also produced beams with very low normalized emittance of $\sim 10\pi$ mm·mrad with substantial micropulse charge of 5 nC. Peak currents to 400 A and average currents to 3 A were reported for the latter injector. These new injectors will lead to vacuum-ultraviolet FEL's, as well as operation in the visible region with higher powers and enhanced extraction efficiency.

We are pleased that a number of the achievements cited above are included in the 26 papers in this Special Issue. The collection begins with four Invited Papers that review substantial experimental progress. Special recognition is given the first paper by Elias, since the FEL research conducted at the University of California at Santa Barbara has led to the first FEL user facility dedicated to scientific experiments in the far infrared (130–800 μm). Official commissioning of the UCSB facility occurred earlier this year. The three following invited papers review the tapered-wiggler FEL results at Los Alamos, the operating characteristics of the new photocathode injector, and details of the tapered hybrid undulator designed and constructed for the Boeing Aerospace Corporation/Spectra Technology visible-wavelength FEL demonstration experiments.

The contributed papers are divided into three categories. The first includes short-wavelength lasers (< 1 mm) which generally operate in the Compton regime, i.e., where electron–electron interactions can be neglected. A second category includes six papers dealing with undulator physics and design which are primarily, but not exclusively, useful for short-wavelength FEL's. The proposed undulator (wiggler) designs include those produced by focused laser beams, plasma waves, electromagnetic standing waves, and a design that both wiggles the electron beam and reaccelerates the electrons as they lose energy to the radiation field. The third category includes FEL's operating in the so-called Raman regime where collective effects within the electron beam are important. For both the Compton and Raman FEL categories, the papers reporting experimental results appear before the more numerous papers concerning FEL theory.

In the next few years, the number of operational FEL's will undoubtedly increase, assisted by the valuable database from existing systems, much of which has been reported in these four JQE Special Issues on FEL's. Although almost all of the FEL research has been conducted by a few nations (U.S.A., France, U.S.S.R., Italy, United Kingdom, and Israel), we expect to hear about experiments in additional countries, including China, Japan, and West Germany, where FEL experimental programs have begun or are planned. The number of user groups devoted to FEL applications will also increase from the one at UCSB to include those being organized now at Stanford University, Los Alamos, NBS-Gaithersburg, Vanderbilt University, and the University of Paris at Orsay. With maturing of this field, the new user facilities should reach shorter wavelengths (even below 100 nm), increased power, and greater reliability. Results of unique applications of free-electron laser radiation should begin to proliferate.

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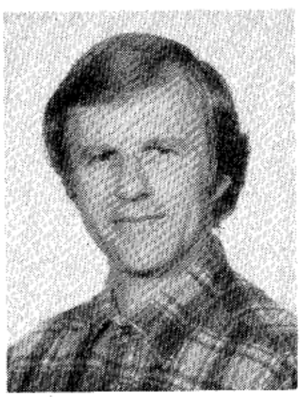
Charles A. Brau received the B.E.P. degree in engineering physics from Cornell University, Ithaca, NY, in 1961 and the Ph.D. degree in applied physics from Harvard University, Cambridge, MA, in 1965.

From 1965 to 1970 he worked at Avco Everett Research Laboratory, Everett, MA, on theoretical problems in chemical physics and vibrational relaxation. Much of this work was in support of the CO_2 gas dynamic laser program. During the academic year 1970–1971 he was in residence at the Kammerlingh–Onnes Laboratory of the University of Leiden as a NATO postdoctoral fellow. Returning to Avco in 1971, he started the excimer laser program which led to the first demonstration of the XeF, XeCl, and KrF rare-gas halide lasers. He joined the staff of the Los Alamos National Laboratory in 1976 becoming the Associate Group Leader for Tunable Laser Development in the Applied Photochemistry Division. For two years, his efforts were largely directed toward development of UV lasers for photochemistry and laser isotope separation. In 1978 he organized the Los Alamos free-electron laser program which he led as Program Manager until 1987. Presently, Dr. Brau is spending a sabbatical year at the Quantum Institute of the University of California at Santa Barbara where his research includes extending the wavelength of the UCSB electrostatic-accelerator-driven FEL into the ultraviolet.



Brian E. Newnam received the B.S. degree in physics from Occidental College, Los Angeles, CA, in 1962, and the M.A. degree in physics and the Ph.D. degree in electrical engineering from the University of Southern California, Los Angeles, in 1966 and 1972, respectively. His dissertation was on high-power, laser-induced phenomena in dielectric films, solids, and inorganic liquids.

From 1965 to 1968, he was a member of the Technical Staff at TRW Systems Group, Redondo Beach, CA where he performed experimental studies of thermal radiation properties of spacecraft surfaces and their ability to withstand the space environment. Since joining the Scientific Staff of Los Alamos National Laboratory in 1972, he has worked extensively on the problems of laser damage to the optical components of inertial-fusion lasers as well as reflectors for free-electron laser resonators. He has been a member of the Los Alamos FEL experimental team since its origin in 1979, being responsible for the various laser and optical aspects of the FEL amplifier and oscillator experiments. During 1982, as a Visiting Scientist at the Max Planck Institut für Quantenoptik in Garching, West Germany, he researched the various schemes for VUV laser generation. In his present role as XUV FEL Project Leader, he is leading R&D studies to determine how to extend FEL's to extreme-ultraviolet wavelengths below 100 nm.

For the last eight years, Dr. Newnam has served as Cochairman and Editor of the Laser Damage Symposia held annually at Boulder, CO.