QUANTUM ELECTRONICS

a report on THE SECOND INTERNATIONAL CONFERENCE

By J. R. Singer

MORE than 500 scientists took part in the Second International Conference on Quantum Electronics, which was held at the Claremont Hotel in Berkeley, Calif., under the sponsorship of the Office of Naval Research and the University of California. Within the three-day conference period (March 23–25, 1961), some sixty papers were presented on recent progress in masers of various types (especially those involving the higher-frequency microwave and optical regions), phonon interactions and relaxation processes in solids and gases, narrow-line optical spectra of solids and gases, optical pumping, and a number of new ideas and accomplishments having to do with the interaction of matter and electromagnetic waves. In addition to those from the United States who attended the meeting, there were delegates from England, France, Germany, Israel, Japan, Switzerland, and the USSR.

The first of the technical papers was presented by C. H. Townes, who outlined five difficult experiments involving the use of optical masers: 1. interstellar communication; 2. frequency multiplication using nonlinear molecular excitation (since carried out by P. Francken and his group at the University of Michigan); 3. spectroscopy by optical masers in the 100-micron wavelength region; 4. mixing of Raman-scattered infrared radiation with the original infrared maser output to obtain outputs in the important wavelengths between the infrared and microwave regions; 5. fundamental experiments, such as the Michelson-Morley experiment performed using optical masers. In addition, Prof. Townes described the work on alkali-vapor infrared masers carried out by Cummins, Abella, Heavens, Knable, and Townes.

A. Javan of Bell Telephone Laboratories presented a description of the remarkable accomplishment of obtaining optical-maser oscillator operation using a helium and neon mixture in a gaseous discharge. This is the most coherent optical source in existence. The most intense output line was found to be the $^2s_2$ to $^2p_4$ transition at 1.15 microns. W. R. Bennett, Jr., a collaborator in the work described by Javan, gave a fundamental paper on radiative lifetimes and collision transfer cross sections of excited atomic states. Both experimental and theoretical aspects were discussed. D. R. Herriott, who had also collaborated in the work, described the experimental characteristics of the helium-neon optical maser.

A. L. Schawlow presented a detailed basic experimental study of the fine structure and properties of chromium fluorescence in aluminum and magnesium oxide. These studies are important for the understanding of optical masers which employ ruby. T. Maiman, who was the first to obtain coherent emission from ruby excited by a flash lamp, described his experimental progress, and I. Wieder and L. R. Sarles reported on the scattering of resonance radiation in ruby.

M. J. Stevenson and P. P. Sorokin reported on their accomplishments in obtaining optical maser action from samarium in calcium fluoride and uranium in calcium fluoride. The output of the latter is at 2.5 to 2.6 microns, and the former at 7082 Angstroms. The characteristic amplitude modulation generally observed in all masers was not seen in the $CaF_2:Sm^{+2}$

J. R. Singer is associate professor of electrical engineering at the University of California in Berkeley. The proceedings of the conference he describes here were published during 1961 by the Columbia University Press under the title, *Advances in Quantum Electronics*. A report by Irving Rowe on the First International Conference on Quantum Electronics, which was held September 14–16, 1959, at Sha-Wan-Ga Lodge, N. Y., appeared in the March 1960 issue of *Physics Today*.

crystals; however, the receiver resolution was not wide band enough to detect such oscillations when they exceeded 10^7 per second, and it seems likely on theoretical grounds that such oscillations are inherent in the system.

A detailed study of the fluorescence and optical-maser effects in $CaF_2:Sm^{++}$ was reported by C. G. B. Garrett, W. Kaiser, and D. L. Wood of the Bell Telephone Laboratories. D. F. Nelson and R. J. Collins, also of BTL, discussed the polarization of the output of a ruby optical maser. For 60° and 90° relative orientation of the c-axis and rod, 100° polarized output was observed. This was not true of 0° oriented rods. G. J. Troup was not able to arrange passage from Australia in time for the conference, but he contributed a very interesting paper on the use of rare-earth ions for infrared masers.

An excellent review of optical-pumping progress was presented by J. Brossel of the University of Paris, followed by another optical-pumping paper given by C. Cohen-Tannoudji, also of the University of Paris. G. W. Series of Oxford presented some new experimental results and interpretations of the properties of modulated light in double-resonance experiments.

The present knowledge and new thoughts regarding the optical spectra of paramagnetic solids was reviewed by W. Low from the Hebrew University of Israel, thus continuing a lecture series he started at the first quantum-electronics conference a year and a half earlier. Much of the work he described was carried out by Professor Racah and the graduate students at the Hebrew University.

H. A. Gebbie of the National Physical Laboratory, England, gave a paper on submillimeter-wave spectroscopy with a Michelson interferometer, in which he pointed out the importance of "light grasp". This term is a measure of the relative quantity of radiation from a source as given by the product of source area and solid angle, assuming a fixed resolution and size for the optical elements.

A very comprehensive paper on spectroscopic observations on maser materials (particularly rare-earth salts) was given by G. H. Dieke of Johns Hopkins University. Many detailed spectral analyses were displayed. This important work, which has been carried on at Johns Hopkins for many years, has now attracted considerable interest.

P. S. Pershan and N. Bloembergen of Harvard presented an account of their recent work on microwave modulation of light. They also summarized work in progress involving high-speed methods of light modulation. In the discussion following this talk, E. H. Turner reported that Ivan Kaminow of Bell Laboratories had been successful in modulating light at 11 kilomegacycles per second, using the linear electro-optical effect; Pershan stated that the Harvard experiments were at 15 kilomegacycles per second, and were close to success.

A novel and intriguing cooling process was described in a paper by S. Yatsiv of the Hebrew University of Jerusalem, who suggested that a process which absorbs phonons and radiates photons would provide a refrigerating system. G. H. Dieke suggested that this idea could be carried to very low temperatures by utilizing Zeeman-splitting levels.

A. L. Bloom and W. E. Bell of Varian Associates described work on modulated light for optical-pumping experiments in which the light is modulated at the Larmor-precession frequency of the pumped spins, and a precession occurs in phase with the light modulation. Some new possibilities for achieving a cyclotron-resonance maser were discussed by B. Lax of Lincoln Laboratories. He reported that the situation has changed from the submarginal outlook of the previous conference because of the use of optical masers for a pumping source, the availability of larger magnetic fields, and the studies made of direct transitions which satisfy the conditions required for operation.

N. G. Basov of the Lebedev Institute presented a paper discussing a negative absorption coefficient at indirect transitions in semiconductors. His calculations show feasibility, and experiments are being carried out. E. Burstein, D. N. Langenberg, and B. N. Taylor of the University of Pennsylvania described prospects for the quantum detection of microwave and submillimeter-wave radiation based on electron tunneling in superconductors. Cross-relaxation and spin-temperature phenomena were reviewed by N. Bloembergen. Experimental data right up to ten minutes before his talk were incorporated into the theory. J. H. Van Vleck reviewed the status of relaxation-time phenomena and continued the lecture started in 1959 at the first Quantum-Electronics Conference. J. C. Gill and R. J. Elliott added their latest results on concentration-dependent relaxation times to round out this topic.

Considerable interest was attached to paramagnetic materials and a number of very interesting paramagnetic resonance studies were reported. R. S. Title of IBM gave a paper describing the use of paramagnetic resonance to detect optical-excitation processes. Specifically, his experiments employed zinc-sulfide photoconductors. W. B. Mims of Bell Laboratories described the use of an electron-spin-echo technique to study the diffusion of excitation through resonance lines. J. G. Castle, Jr., D. W. Feldman, and P. G. Klemens described their experimental studies of spin-lattice relaxation times of chromium ions in MgO. A. Kiel of Johns Hopkins provided a theoretical study of spin-lattice relaxation in excited states of paramagnetic ions. M. Peter, L. G. Van Uitert, and J. B. Mock of the Bell Laboratories described their comprehensive experiments on the paramagnetic spectra of trivalent iron and chromium ions in monoclinic tungstates. S. Geshwind, R. J. Collins, and A. L. Schawlow reported on the optical detection of paramagnetic resonance in an excited metastable state of ruby. E. H. Turner of Bell Laboratories gave a paper on the direct interaction of phonons and spin waves in yttrium-iron-garnet in which acoustic waves of kilomegacycle frequencies were produced.

Willis E. Lamb, Jr., spoke on the problem of angular distribution of stimulated radiation. A number of methods for solving the interaction problems were considered, and various ways of looking at coherent electromagnetic energy interacting with molecules in a resonant structure were discussed. It was pointed out that the interference of the E-M waves should be considered in a realistic analysis.

Daniel Kleppner described his recent work at Harvard with N. F. Ramsey on the atomic-hydrogen maser. The concept of using a storage-box technique to trap atoms in a particular state for prolonged times while interactions occur will undoubtedly be extended to a great number of new experiments. The experiment utilized the hyperfine transition $F = 1$, $m = 0$ to $F = 0$, $m = 0$ at 1420 megacycles per second. Storage times of as much as 0.3 seconds were obtained.

A paper showing a fundamental limitation on the amplitude stability and coherence of all maser emission because of the precession of the electric or magnetic dipoles around the radiation field was presented by J. R. Singer and S. Wang. In addition, the possibilities of a π-pulse electric-dipole optical maser were mentioned. The authors are presently doing experimental work on such a system. A. G. Fox and T. Li of Bell Laboratories presented the results of some lengthy theoretical calculations of the characteristics of resonant structures at optical frequencies. Energy losses and the sources of losses were carefully evaluated for each mode with a digital computer. G. D. Boyd of Bell Laboratories presented some results showing that a confocal spherical resonator has lower diffraction losses, and hence a higher Q for the same volume as that of a Fabry-Perot structure. W. G. Wagner and G. Birnbaum of Hughes Research Laboratories presented a theory of an ideal optical maser operating in a multimode resonator, and R. W. Hellwarth of Hughes suggested some novel switching schemes for changing the reflectivity of the optical-maser resonator. L. D. Shearer of Texas Instruments gave a paper on the polarization of metastable helium atoms by means of optical-pumping techniques.

The properties of optical dielectric waveguides were reviewed by E. Snitzer of the American Optical Company, who showed slides of the field configuration of light leaving the ends of the fibers. A millimeter-wave CW maser was described by S. Foner, L. R. Momo, J. B. Thaxter, G. S. Heller, and R. M. White of Lincoln Laboratory. This maser uses Fe^{3+} in titanium oxide as the active material and operates within the band from 26 to 48 kilomegacycles. Different approaches to millimeter-wave generation were taken by J. B. Newman (Johns Hopkins) who discussed a two-millimeter-wavelength gas-beam maser, and Paul D. Coleman (University of Illinois) who described a Čerenkov radiation approach to the submillimeter-wave generation problem. J. S. Thorp (R.R.E.) described the operation of an 8-mm maser amplifier. T. Yajima and K. Shimoda of the University of Tokyo provided a paper which described the theory of multiple quantum transitions in gas masers. Experimental results of their studies using HCOOH molecules were in reasonably good agreement with the theory.

Information theory was applied to the description of optical maser communication possibilities in papers by J. P. Gordon (Bell Laboratories) and G. J. Lasher (IBM). The paper by J. P. Gordon was read by A. Yariv of Bell Laboratories. J. Weber of the University of Maryland described some fundamental gravitation experiments which could be performed using maser techniques, and H. Gamo (IBM) gave a comprehensive paper on the intensity interferometer with a coherent background.

Flashlamps as intense sources for optical pumping were thoroughly discussed by H. E. Edgerton (MIT). The beginning of his talk was incidentally accompanied by the fortuitous click of a photographer's flash, which Professor Edgerton then described in terms of the energy stored and emitted. D. Mergerian and J. J. Markham of the Armour Research Foundation presented an idea regarding use of F centers in KCl as a Stoke's-shift light amplifier. S. A. Colgate and A. W. Trivelpiece (University of California) described the progress of their experimental studies using a dynamic pinch as a source of optical pumping for a ruby optical maser. I. R. Senitzky (US Army Signal Research and Development Laboratory) presented a paper on quantum-mechanical incoherence and on noise in a coherent amplifier. H. Statz, C. Luck, C. Shafer, and M. Cifton of Raytheon gave a paper on the observation of oscillation spikes in multimode optical masers.

The photodetection and mixing of optical-maser outputs in a photoelectric detector was described by A. T. Forrester who pointed out that this may be the only practical means of measuring maser oscillator bandwidths. Spin-wave spectroscopy utilizing spin waves generated through use of the magnetic gradient of a long rod subjected to uniform rf fields was reported by E. Schömann of the Raytheon Corp. An analysis of the relaxation of inhomogeneously excited spin systems was provided by R. F. Soohoo of Lincoln Laboratory.

N. S. Shiren of General Electric described a new detector of pulsed microwave ultrasonics using double quantum transitions. J. Fontana, R. Pantell, and R. Smith provided a paper on a proposal for the generation of high-power, high-frequency (mm-wave) harmonic generation using multiple quantum transitions, elaborating on a proposal of E. Jaynes. A report of the experimental data and details of the operational 21-cm Harvard radiotelescope using a maser preamplifier was given by J. Jelley and B. F. C. Cooper who are currently at Harwell.

The session chairmen (William Gwinn, E. Hahn, A. Kip, S. Silverman, J. H. Van Vleck, and John R. Whinnery) deserved a very large vote of thanks for managing to keep the program nearly on schedule; there were no parallel sessions and careful timing was needed to meet the schedule.