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Among those taking part in the International Conference on Quantum Electronics were (a) R. H. Dicke, (b) John R. Pierce, (c) M. W. P. Strandberg, (d) A. L. Schawlow, (e) Willis E. Lamb, Jr., (f) J. H. Van Vleck, (g) Hubert Heffner, (h) William Low, (i) J. R. Singer, (j) Profs. Prokhorov, Townes, and Basov, (k) Koichi Shimoda, (l) Helmut Friedburg, (m) Charles H. Townes.

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an international

conference on

QUANTUM ELECTRONICS

By ***Irving Rowe***

QUANTUM electronics may be loosely defined as the areas of concern to both electronics and physics which deal with atomic, molecular, or nuclear resonance phenomena. It combines the techniques of electronics and of spectroscopy, and it examines the resonant behavior of individual atoms or molecules by the utilization of coherent electromagnetic radiation. It has resulted in the invention of the maser, with its subsequent development in varied forms and for varied applications, ranging from commercial communications to erudite investigations of cosmological theory.

The idea for calling an International Conference on Quantum Electronics originated with members of the staff of the Office of Naval Research, who realized the growing significance of the field of quantum electronics and of the revolution that it is producing in microwave techniques and in physical science. It was felt that the research stemming from the development of the maser and from related resonance phenomena had reached a degree of maturity where an international scientific meeting would be well justified. It was hoped that such a conference would consolidate current knowledge and would be a springboard toward further advances. Charles H. Townes of Columbia University, the inventor of the maser, was invited to be chairman, and he formed a planning committee to arrange the program. In addition to Professor Townes, the committee consisted of G. Birnbaum, N. Bloembergen, R. H. Dicke, C. Kittel, R. Kompfner, B. Lax, I. Rowe, A. E. Siegman, G. J. Stanley, and M. W. P. Strandberg.

Held September 14–16, 1959, the conference had as its setting Sha-Wan-Ga Lodge in the Shawangunk Mountains of New York State. Perched on a peak, the Lodge affords a magnificent view which extends over thirty miles of lush countryside to the range of hills bordering the Hudson River. These surroundings contributed to the general sense of satisfaction of the conference members.

The topics discussed included masers of all types, experimental and theoretical work concerning resonant interactions and relaxation processes, noise in quantum-mechanical amplifiers, the generation and detection of electromagnetic energy (including the millimeter and infrared wavelengths) by atomic or molecular phenomena, and the potentialities, limitations, and applications of electronic devices using resonant quantum electronics to fundamental experiments in physics and other fields.

The emphasis was on the basic, underlying science involved and not on the engineering design of devices. The conference was planned to afford an opportunity for those active in the field to hold informal discussions and to permit a thorough exploration of ideas which were, perhaps, not yet ready for formal presentation. With this in mind, the locale was set in a resort hotel away from a city where there would be competing distractions. The conferees dined together, but changed tables and table-mates at each meal to insure free discussions—a procedure which was very puzzling to the dining room staff. In order to make this person-to-person contact more effective, the committee at first decided to send out a maximum of 75 invitations. However, there is now so much interest in this field,

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and so many active scientists and engineers involved, that it became necessary to raise this quota. As a result, 162 persons actually registered their attendance at this meeting, not counting the wives and children who accompanied some of the men. (At least one of the conferees was a woman, and she, in turn, brought her husband.) The committee regretted that, in spite of this increase, it was unable to invite all those who expressed their desire to come.

The meeting was truly international in character, with scientists from many different lands coming to contribute the results of their research. The foreign countries represented included Canada, England, France, Germany, Holland, Israel, Japan, Russia, and Switzerland.

Fourteen invited papers, thirty minutes each in length, were presented, and fifty papers were contributed. Of the latter, nineteen were read by title only to conserve time. However, a discussion period was allowed for all papers, including the latter category, and the complete text of all will appear in the published proceedings. Because of the heavy schedule, an evening session was held on Tuesday. The social graces were not forgotten, and our hosts of the hotel management provided a gala cocktail party on Monday evening. This was enlivened by our Russian guests, who brought with them gifts of vodka and caviar. A banquet followed, with humorous comments by the chairman and an after-dinner speech by J. R. Pierce (Bell Laboratories), who poked some good-natured barbs at some of the wilder claims of our outer-space enthusiasts. Dr. Townes reported a rumor that the Mayor of the near-by village of Bloomingburg was prepared to change its name to Bloembergen to honor that scientist's notable contributions to the solid-state maser!

The general plan of the conference was to introduce a given area of discussion by presenting an invited paper which surveyed that particular aspect of research. This was then followed by short contributed papers on the same topic. Ample time was allowed after each paper for discussion. Each question and answer in the discussion period was immediately written down and collected by student ushers for inclusion in the printed proceedings.

AFTER a brief welcoming address by Irving Rowe, representing the sponsoring agency (ONR), the conference was opened by Professor Townes who defined quantum electronics, gave a short history of the field, and indicated its future potential. J. P. Gordon (Bell Laboratories) gave the first formal paper, a survey of beam-type masers, thereby introducing a group of six contributed papers dealing with beam techniques. Gordon pointed out that in 1951, Dicke and Newell had built a beam-type spectrometer for ammonia, and Basov and Prokhorov in Russia had published in 1954 a discussion of the possibility of making a molecular amplifier at about the same time that the Columbia University group reported the first operation of a beam-type maser. The currently used 3–3 line of ammonia is subject to fluctuations of one part in 10^9 or 10^{10} because of temperature, pressure, cavity pulling, and other effects. The frequency stability can be improved by slowing down the beam so that the resonating molecules will spend more time in the microwave cavity. C. V. Heer (Ohio State University) followed with a proposal to mix the molecular beam with cold helium gas at 1.5°K to reduce the beam velocity to 1/50 of the usual value. The low temperature also permits the use of a superconducting cavity. A manyfold improvement in stability is predicted.

In the same vein, Basov and Prokhorov (Lebedev Institute, Moscow) suggested the use of an electrostatic field type of mirror to separate slow molecules from the fast ones in a beam. With the beam directed at the mirror, the fast molecules will go through and be lost, whereas the slow molecules will be reflected and focused into the resonant microwave cavity.

Koichi Shimoda (University of Tokyo), reporting on maser research in Japan, announced the use of the 3–2 line of ammonia, instead of the more customary 3–3 line, to produce a frequency standard 100 times more stable. This improvement is due to the absence of quadrupole hyperfine interference with the former line. He also reported on the high-resolution spectroscopy of OCS and of formaldehyde using beam maser techniques. Thaddeus, Loubser, Javan, Krisher, and Lecar (Columbia) also reported on the precision spectroscopy of heavy water, deuterium sulfide, and formaldehyde and discussed the possibility of analyzing a number of cyanides and organic molecules. The high resolution permitted the measurement of hyperfine splittings and the calculation of hyperfine coupling constants. Some of the transitions indicated promise as frequency standards. Frank S. Barnes (Colorado Research Corporation) explored the feasibility of building masers for submillimeter use. By using a molecular beam passing perpendicularly through a Fabry-Perot interferometer as the resonant structure, it seems practical to build a maser operating at 3.4 mm using HCN and at 0.126 mm using NH_3 in the $J = 4 \rightarrow 3$ mode, both with a frequency stability of a few parts in 10^{11}. Giordmaine and Wang (Columbia) and Helmer and Jacobus (Varian Associates) both discussed techniques for focusing molecular beams. The latter paper described a parabolic focuser with a point source effuser which doubled the power output for the same rate of molecular flow.

Jean Brossel (Ecole Normale Supérieure, Paris) reviewed optical pumping and related effects. Optical detection of magnetic resonance was initiated by Bitter at MIT in 1949. Soon afterward, Kastler in Paris proposed the scheme known as optical pumping. Brossel himself was a heavy contributor to the field. The process depends on the use of circularly polarized light beams of opposite orientations which are absorbed to different extents by different atomic energy levels. Levels must be chosen for an optimum rate of excita-

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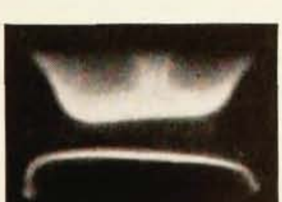
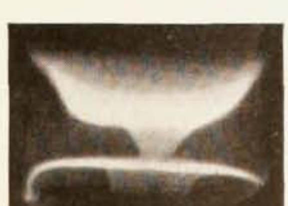


Iron carbonyl, an antiknock



Ethyl nitrate, a proknock

Iron carbonyl retards, ethyl nitrate accelerates central portion of cool flames.

tion versus radiation. Suitable rates can result in maser action. Some of the fundamental problems that can be studied with optical pumping techniques include studies of the imprisonment of radiation, electron exchange cross sections, and paramagnetic absorption as a function of lattice arrangements. Continuing the discussion of optical effects, Lambe and Baker (University of Michigan) described the irradiation by green light at liquid helium temperatures of KCl crystals having a strong concentration of *F* centers. The result seemed to indicate an increase in the spin temperature of the *F* center, although there was no evidence of heating of the rest of the crystal. This might be called optical spin heating rather than optical pumping. R. S. Title (IBM) reported that the excitation by light of phosphors containing europium and samarium results in the trapping of an electron and in the reduction of the paramagnetism of the europium ion. This he has verified by paramagnetic resonance techniques. I. Wieder (Westinghouse Research Laboratories) described an attempt to extend optical pumping techniques to solids, specifically to ruby. Optical pumping has not yet been observed, but in the course of the investigation, he developed a source of resonance radiation emitting 100 milliwatts at 6920°A and at 6934°A. This radiation source, in turn, is being used to excite ruby crystals for further evidence of optical pumping.

ATOMIC clocks and frequency standards were next on the program. This field was reviewed by P. Bender (National Bureau of Standards). He pointed out the keen interest in this application of quantum electronics because of the need to provide the stable frequencies required for sophisticated and difficult communication and navigational problems, to solve the question of ether drift, and to obtain answers to gravitational questions. At the Bureau, differential resonance absorption in the hyperfine levels of rubidium vapor provided lines with a width of 20 cps at 7000 Mc, or one part in 10^9. Using a double-beam maser with the N^{15} isotope in ammonia, Mockler at NBS has developed a frequency standard with a potential accuracy greater than 10^{10}. For short-time stability the ammonia maser seems best, although cavity pulling is a problem over long periods of time. Gas cell and cesium-beam standards are limited by the stability of the associated quartz oscillator. However, future refinements should make stabilities of one part in 10^{11} feasible. Kalra and Bailey (National Research Council of Canada) and Mockler, Beehler, and Barnes (NBS) presented data on the evaluation of cesium-beam frequency standards, indicating that accuracy is of the order of one part in 10^{10}. C. O. Alley (Princeton) proposed an atomic clock based on the intense optical pumping of rubidium. A program of magnetic pulses is applied and a spin-echo phenomenon takes effect. If microwave radiation at the $0 \leftrightarrow 0$ hyperfine frequency is applied, the final result is a quantum state completely different from the initial one, making possible a large optical detection signal. Chamberlain, Hughes, and Zorn (Yale) are developing a molecular frequency standard for the millimeter range based on the electric resonance method. The 100 kMc transition between the $J = 0$ and $J = 1$ rotational states of $Li^6 F^{19}$ seems particularly promising, since this transition is relatively insensitive to external electric and magnetic fields. Electric quadrupole transitions have been observed in RbF. In the final paper of this group, Professor Bloembergen (Harvard) suggested the use of a zero-field solid-state maser as a time standard. Such a system would have the advantages of (a) no frequency pulling by a cavity or external oscillator, (b) very good long-term stability obtained from operation at liquid-helium temperature, and (c) relatively large power output. Nickel and chromium ions in many compounds have a narrow line width and a magnetic moment operator having no diagonal matrix elements, thereby being insensitive to broadening effects due to internal or external fields. The most bothersome factor may be stress inhomogeneity in the crystal.

J. Combrisson (French Centre d'Etudes Nucleaires) discussed the polarization of nuclei and the generation of radio-frequency energy by nuclear precession. This is an application of the Overhauser effect. In particular, there is great enhancement in the nuclear polarization of the protons of water in which is dissolved the free radical, peroxylamine disulfonate. At very low magnetic fields, such as that of the earth, the zero-field splitting of the electronic lines of the free radical produces a maser-like action in the protons. The latter precess at the Larmor frequency corresponding to the magnetic field of the earth. An extremely sensitive magnetometer is obtained in this way, which should be very valuable for geophysical explorations. J. Winter of the same laboratory showed that a similar effect can take place in solids. The polarization of nuclear spins can be greatly enhanced by irradiating a crystal containing paramagnetic impurities by an external radio-frequency field. This effect is caused by a forbidden transition which mixes slightly the electronic and nuclear levels. Two papers from the Rice Institute continued the discussion of nuclear effects. Rorschach and Low discussed radiation damping in liquid He^3. Squire and co-workers found two nuclear spin-lattice relaxation times in a crystal of KI^{127}, one of 560 minutes and the other of 213 minutes. Which one was observed depended on the initial magnetic conditions.

SINCE low-noise operation is one of the major benefits of the maser, it is only natural to inquire whether there are any theoretical limitations on noise level. This problem was considered by a number of conferees. Helmut Friedburg (Karlsruhe) attacked the problem by analyzing an amplifier matched to a transmission line and capable of measuring the amplitude and phase of an incident electromagnetic wave. He applied the uncertainty principle $\Delta n \Delta \phi \geqslant 1$, which means that the phase and the number of quanta arriving during a finite time cannot be measured exactly and

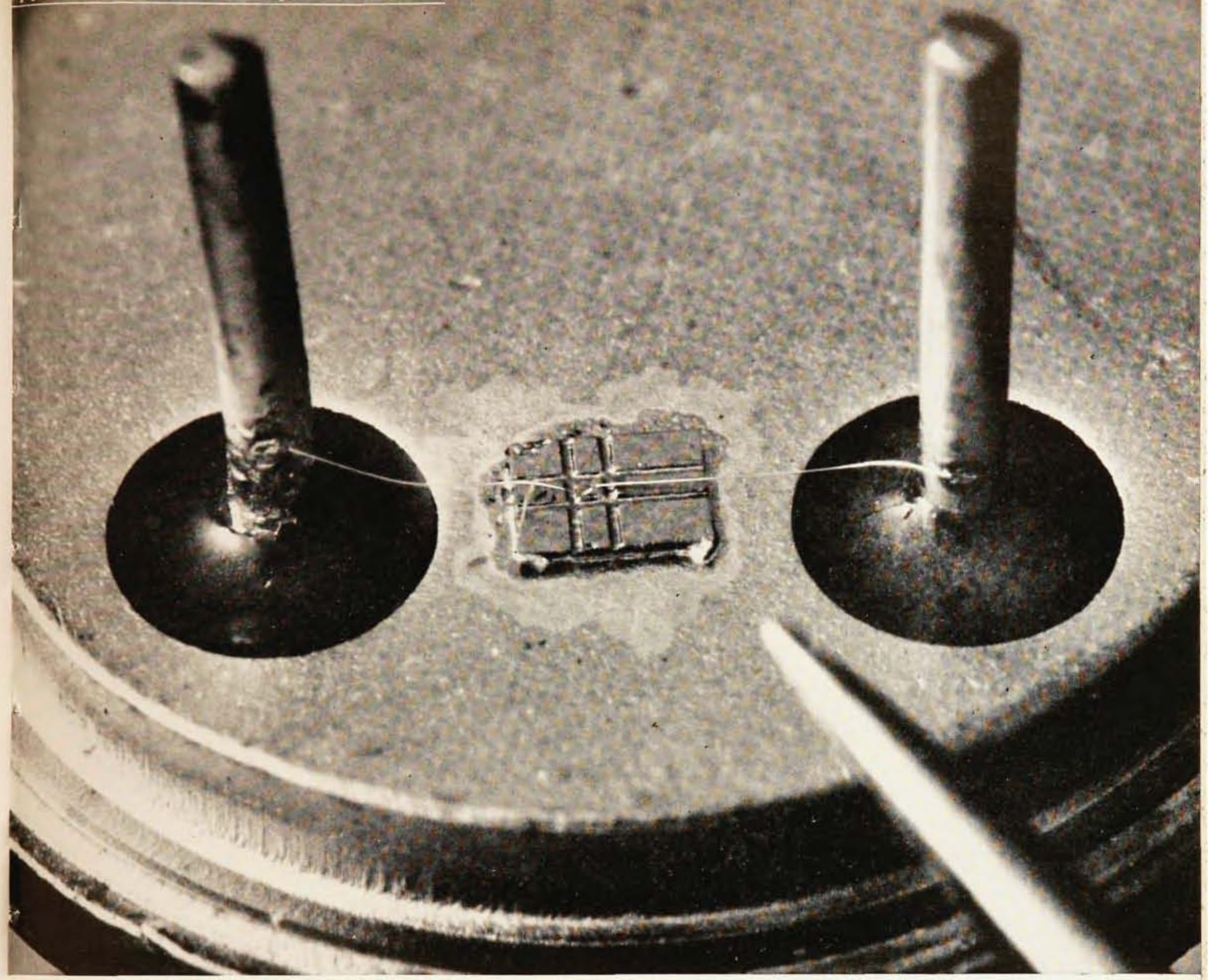
simultaneously. The only way a phase-sensitive amplifier can fulfill this condition is to have noise. The minimum effective noise power corresponds to one quantum in a time t which is defined as the resolution time of the amplifier. This is exactly the theoretical noise limit of the maser amplifier, which is caused by spontaneous transitions. He concluded that it is impossible to construct a phase-sensitive amplifier with background noise lower than that of the ideal maser. Serber and Townes (Columbia) presented conclusions essentially similar, but generalized to include devices which measure electromagnetic waves with varying relative accuracy in phase and intensity. P. N. Butcher (Royal Radar Establishment) considered the relation between noise and absorption spectra, and showed that the noise temperature is determined by the ratio of stimulated absorption to stimulated emission. For crystalline maser materials, noise temperature is independent of frequency. For gases and liquids, noise temperature is frequency-dependent and at a minimum at the resonant frequency. I. R. Senitzky (US Army Signal Research and Development Laboratories) presented two theoretical papers in which he discussed the induced and spontaneous emission in a coherently driven cavity and the noise from incoherent pumping.

The practical application of very-low-noise amplifiers to radio astronomy was described by T. Matthews (California Institute of Technology). Low noise is particularly important at the higher frequencies since above 2000 Mc the chief limitation is the inability to detect antenna temperatures below 0.01°K. Radio astronomy may deal either with discrete sources yielding thermal radiation or with spectral line sources. For the first type one needs a broad bandwidth to reduce noise. Here again stability for at least a 20-minute observation period is important. For spectral line sources an amplifier having a narrow i.f. frequency is necessary to explore in detail the shape of the line. The most obvious advantage of the increased sensitivity obtainable with low-noise amplifiers would be an increased accuracy of position determination and of brightness contours, providing the possibility of a detailed comparison between optical and radio sources. It would also permit detection of extremely weak sources, such as the more remote planets. Decrease in receiver noise would allow a detailed knowledge of the motions of interstellar hydrogen clouds, give information on the spin temperature of the gas, and give a direct determination of the interstellar magnetic fields through observations of the Zeeman splittings. In another application of low-noise receivers, J. R. Pierce showed that transmission of data by a satellite, using a good conventional receiver on the earth, would require 8 kilowatts of transmitter power—hardly practical with present satellite technology. However, if a low-noise receiver is employed, the satellite's transmitter power can be reduced to 80 watts, which is entirely feasible. Still greater reductions of power are possible if practical ways can be found to apply the more sophisticated forms of modern information theory.

IS the operation of the parametric amplifier the same as or different from that of the maser in principle? This question was tackled by a number of speakers. A. G. Fox (Bell Laboratories) reviewed the generation and amplification of microwaves by parametric amplifiers (paramps). Garnets are promising as a paramagnetic material for this purpose, probably because they are packed with unpaired spins and have low loss. Even so, they require high pumping power because of the strong exchange forces between these spins. Diodes are more efficient because of their filling factor. All of the energy in the circuit is stored in the diode for at least one point in the cycle. Roberts, Ayres, and Vartanian (Microwave Engineering Laboratories) pointed out a new method of operation of ferrite paramps by using a nonlinear dielectric mode. Hubert Heffner (Stanford University) also reviewed the paramp situation. He mentioned the difficulties with the ferrite and electron beam types and agreed that the diode version is the most practical at the present time. The diode paramp has low noise, needs little pump power, and requires neither refrigeration nor a magnetic field. As for the theory of operation, Professor Heffner pointed out that the same expressions can be written for the paramp and the maser. There is one important practical difference in the gain behavior of the two devices, however. The maser is insensitive to the level of pumping power, since the power is always sufficient to saturate the transition. In the paramp, there is no similar saturation effect so that gain instability is a more serious problem. Expanding the theoretical discussion, E. T. Jaynes (Stanford) showed that the basic equations of motion for the two devices are identical. The resemblance is not superficial: the Schrödinger equation describing the change in state of a molecule perturbed by electromagnetic fields can be transformed into the equations of motion of a parametric system. To every kind of level scheme in a maser, there corresponds a purely classical parametric system which would behave in just the same manner. Hence the decision whether to use a maser or a paramp for a given purpose depends on the practical questions of the availability of materials with the appropriate characteristics, the efficiency, and the cost.

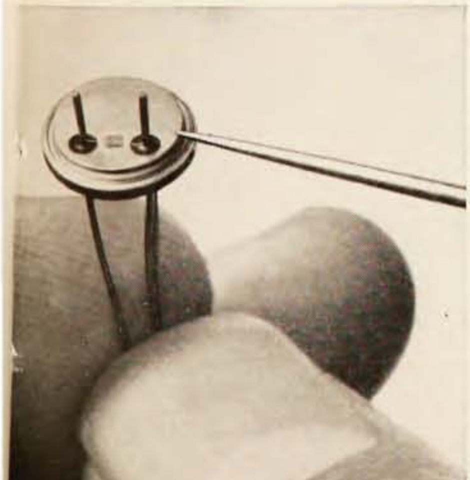
In the active discussion which followed, one comment was that the maser utilizes the diagonal elements of the density matrix, whereas the paramp makes use of the off-diagonal elements. Senitzky pointed out that the maser is a system of many loosely coupled molecules, but that the paramp consists of a single resonant idling circuit. Another participant thought that an essential difference is that the maser can be pumped with incoherent radiation, whereas the paramp requires coherent radiation.

Fundamental to the operation of masers and similar resonant systems are the various phenomena of relaxation. Under study in many laboratories is a variety called cross relaxation—an exchange of energy between two or more sets of resonances, illustrated by a cooperative flipping of spins which conserves energy.



Actual size of this germanium, NPN, all-diffused transistor as delineated by the etched trenches, is 6 mils square.

Developing all-diffused NPN germanium transistors for UHF



IBM semiconductor specialists have developed this all-diffused NPN germanium mesa transistor which has a frequency cutoff greater than 600 megacycles.

The basis for this development is a process in which a mask of silicon monoxide permits the diffusion of desired "P"-type elements into regions of minute dimensions. This new device, designed for high-speed switching applications, has also been made possible by important advances in germanium "P"-type diffusion processes achieved by IBM engineers and scientists.

The processes used in making this device permit close control of electrical characteristics, high electrical performance and low fabrication costs. This project is typical of the many challenging assignments in IBM's expandi semiconductor programs.

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Sorokin, Laser, and Gelles (IBM Research Laboratory) found from a double resonance experiment that the paramagnetic nitrogen centers in diamond exhibit cross relaxation, and that in special cases use can be made of this phenomenon to produce CW maser operation. Nash and Rosenvasser (Columbia) found that cross relaxation in copper Tutton salt makes it possible to operate a maser with an emission frequency higher than that of the pump. This may lead the way to efficient masers for the millimeter and submillimeter wavelengths. By increasing the concentration of chromium doping in a ruby crystal, T. H. Maiman (Hughes Aircraft) was able to design a compactly packaged maser with liquid nitrogen as the refrigerant, rather than liquid helium. Operation at the higher temperature with heavier doping is apparently due to the decrease in relative importance of cross relaxation compared to ordinary relaxation processes.

Experiments made by B. Bolger at Leiden confirmed that cross relaxation makes it possible to use concentrated maser materials at higher temperatures. He showed that the cross relaxation rate is independent of the lattice temperature, but this is not the case for spin-lattice relaxation rates. Using a traveling wave ruby maser at Stanford University, W. S. C. Chang found a variation of cross relaxation due to harmonic coupling. If the idling transition frequency is a harmonic or subharmonic of the signal frequency, the relaxation time is greatly shortened. Harmonic coupling is an effective way to modify relaxation rates to achieve a high inversion ratio in a three-level maser. Chester, Wagner, and Castle (Westinghouse Research Laboratories) explored relaxation processes in dilute potassium chromicyanide as a function of concentration. With less than 1% of chromium, relaxation appeared to be a single phonon process at the lowest temperatures and a Raman process at about 4° K. For higher concentrations, there is an increase in rate of relaxation as the transitions approach each other in frequency. Shapiro and Bloembergen presented similar conclusions.

The Tuesday evening session was devoted largely to a free discussion of these and other aspects of relaxation phenomena. J. H. Van Vleck (Harvard) led the discussion after reviewing possible causes for the discrepancies between observed and theoretical relaxation times. He introduced the new concept of "exchange pockets" to account for these differences. These pockets may be analogous to lattice defects. They might have a large exchange coupling between them, even though the average exchange coefficient is very small. He arrived at this concept that very day, after hearing the above-mentioned papers on relaxation phenomena.

CONSIDERABLE curiosity exists about the status of quantum electronics in the Soviet Union. Although not on the formal program, A. M. Prokhorov, of the Lebedev Institute in Moscow, was prevailed upon to give a brief review of this subject. The suggestion to improve frequency stability by the use of slow molecules, obtained by the technique of an electrostatic mirror, has already been mentioned. He also stated that he has considered obtaining a slow beam of ammonia molecules by collisions with liquid helium, as had been suggested by Heer. An interferometer using parallel plates is being considered to obtain generation of millimeter and submillimeter waves. The Q of this apparatus may go up to 7000 and depends on the cleanliness and parallelism of the plates. Much work in this field is going on in Kharkov, Gorki, and other cities. Resonance is being studied in aluminum oxide and in the ions of Cr, Fe, Co, Va, and Ti. The Radioelectronic Institute in Kharkov has built a chromicyanide maser operating at 10 cm. A radiotelescope 22 meters in diameter is being planned which will use a maser amplifier. Maser spectroscopy has been explored, with internal rotation and quadrupole interactions being investigated. Fundamental work on clocks, ether drifts, and gravitational experiments has been discussed at length but not undertaken. Amidst much laughter and applause, Professor Prokhorov suggested that it may soon be possible to send a man to the moon, so why bother with difficult experiments—a reference to the Russian rocket which was reported to have struck the moon that day.

The optical properties of paramagnetic solids were reviewed by W. Low (Hebrew University), who showed how the energy level schemes for ions of the transition elements can be calculated for various crystal symmetries. Fluorescent decay times and intensities of absorption lines can be computed with good accuracy. A. L. Schawlow (Bell Laboratories) discussed the experiments under way to produce coherent optical and infrared oscillations with maser techniques. Attempts are now underway using gases and vapors, but it should be possible to construct a solid optical maser having a very simple structure. The output of an optical maser should be powerful, monochromatic, coherent, and unidirectional radiation. The narrowness of the emitted line would make it an attractive wavelength standard and would permit a precise determination of the velocity of light. The high-energy density might be useful in promoting chemical reactions. Ali Javan of the same laboratory discussed the possibility of using electron impact to produce an optical maser.

Benjamin Lax (MIT Lincoln Laboratory) reviewed cyclotron resonances and impurity levels in semiconductors and G. C. Dousmanis (RCA Laboratories) reported on the negative effective mass found by cyclotron resonance in germanium. E. H. Jacobsen (General Electric Company) reviewed the production of ultrasonic vibrations at microwave frequencies in quartz. This makes possible the investigation of phonon-phonon scattering caused by the anharmonic forces between atoms, which shows up when attenuation is measured as a function of temperature. Shiren and Tucker of the same laboratory reported on the effects of ultrasonics on electron-spin resonances in quartz. S. Foner and co-workers at the Lincoln Laboratory and Hoskins and Birnbaum of Hughes Aircraft discussed pulsed-field solid-state masers—a technique for the generation and


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*The Rubáiyát of Omar Khayyám

amplification of microwaves at a frequency higher than that of the pump. M. W. P. Strandberg of MIT presented a number of considerations for the design of parametric amplifiers.

In the final session of the conference, J. R. Singer (University of California) described amplitude modulation effects in masers. W. H. Wells of Caltech discussed the quantum theory of coupled systems based on Feynman's space-time approach and Wigner's probability density of position and momentum. K. W. H. Stevens (Nottingham) presented a theoretical discussion of spin systems coupled to cavity modes, and V. W. Hughes (Yale) indicated how very narrow line widths, and hence high-frequency precision, can be obtained by passing a beam of fast hydrogen atoms through a pair of separated oscillating fields. W. E. Lamb (Oxford) showed that it may be possible to use highly monochromatic gamma rays for microwave spectroscopy. The line width is such a small fraction of the frequency that the effective Q is 20×10^9, making it feasible to resolve the hyperfine structure corresponding to the orientation energies of nuclear states in suitable crystalline environments. A. Lubin (MIT) describes a gaseous quantum counter utilizing the singlet metastable level in helium. A. E. Siegman (Stanford) reviewed recent developments in traveling-wave techniques and showed their usefulness for studies of line shapes, adiabatic fast passage, spin diffusion, cross relaxation, and optical irradiation of samples.

The extension of quantum electronic techniques to cosmological problems was discussed by R. H. Dicke (Princeton). An artificial satellite at a height of several thousand miles could be used as a gravitational timekeeper. Comparison with an atomic clock would help determine the value of the gravitational constant. Use of the techniques suggested by Hughes to make precision hyperfine structure measurements on hydrogen would yield better values of the fine-structure constant, which is a factor in the theories which state that gravitational interaction depends on the structure of the universe. The fine structure constant could also be checked by comparing atomic clocks of different types, the frequencies of which depend on that constant in different ways. The experiment by Cedarholm and Townes to check relativity by observing the frequencies of two oppositely directed ammonia beam masers is also a contribution to cosmological research.

Obviously this report cannot do justice to the wealth of information presented at the conference. Those interested in having the complete text of all the papers and discussions will be pleased to know that the *Proceedings of the Conference on Quantum Electronics* will be published early in 1960 by the Columbia University Press.

At the meeting's conclusion, a number of persons expressed the wish that a similar conference would be held in the near future. That wish is both an indication of the great activity in this field and a tribute to the scientists who contributed so brilliantly to the conference.