

THE 1958 INTERNATIONAL CONFERENCE on SEMICONDUCTORS

A report by W. Crawford Dunlap, Jr.



Strong Auditorium, where technical sessions were held.

THE first international conference on semiconductors to be held in the United States took place on the University of Rochester campus during the week of August 18-22, 1958. This conference was the fourth in a series sponsored by the International Union of Pure and Applied Physics; previous conferences were held at Reading, England, in 1950, at Amsterdam in 1954, and at Garmisch-Partenkirchen in 1956.

The international character of the meeting is indicated by the fact that representatives from fifteen nations were on hand. The meeting was of interest in that it marked the first visit to the United States of a group of important semiconductor scientists of the Soviet Union. The Soviet delegation was headed by Academician A. F. Joffe, director of the Institute of Semiconductors at Leningrad. Others in the group included E. F. Gross of the Physicotechnical Institute at Leningrad, S. G. Kalashnikoff, head of a semiconductor group at the University of Moscow, V. S. Vavilov of Moscow University and the Electrotechnical Communications Institute of Moscow, E. G. Miselyuk, associate director at the Institute of Physics of the Ukrainian Academy of Science at Kiev, and L. S. Stil'bans and Mrs. A. F. Joffe, associates of Prof. Joffe at the Institute of Semiconductors in Leningrad.

Among the representatives of other nations were L. Sosnowski of the Polish Institute of Physics at Warsaw; Jan Tauc of the Institute of Technical Physics, Czechoslovak Academy of Sciences, Prague; T. Muto of the University of Tokyo; Pierre Aigrain of the Ecole Normale Supérieure of Paris; Georg Busch of the ETH, Zurich; H. Welker of Siemens, Erlangen, Germany; R. A. Smith of the Royal Radar Establishment, Great Malvern, England; L. W. Davies of the Commonwealth Scientific Organization, Sydney; S. Amelinckx of the University of Ghent, Belgium; F. R. N. Nabarro of the University, Johannesburg, South Africa; D. Polder of the Philips Laboratories, Eindhoven, The Netherlands; F. Bassani of the Uni-

versity of Pavia, Italy; and numerous representatives of organizations in Canada and the United States.

A total of 490 individuals were registered at the conference, not including family members. There were twenty sessions, with a total of 160 papers. At any one time during the meetings there were one, two, or three papers being given simultaneously, depending upon the day and even the hour, since usually at the beginning of each session period there was only a single session in action, the others being delayed for an hour or so to permit all conferees to hear papers of general interest.

The opening session was distinguished by papers given by John Bardeen, the conference chairman, and by Joffe, as a distinguished representative from abroad. Bardeen's paper, besides reviewing the present status of semiconductors, contained a tribute to the late K. Lark-Horovitz, who had died four months earlier while at work in his office at Purdue University. A native of Vienna, Prof. Lark-Horovitz had been chairman of the Purdue Physics Department for 27 years and had brought it to a position of being one of the nation's leading centers for semiconductor research, in addition to its excellent reputation in other fields.

Band Theory vs. the Atomic Approach

THE 1958 conference came at a time when a "plateau" might be said to have been reached in semiconductor physics, and a "where do we go from here" attitude was evident in the atmosphere of the conference. The major advances of the "germanium" period, dating perhaps from the discovery of the transistor in 1948 to 1956, when new discoveries, major theoretical advances, and new device concepts were coming thick and fast, have died down to a steady series of contributions on an increasingly sophisticated level.

The participation of the Russian workers led by Joffe also injected a theme of the different approaches to semiconductors inherent in the work of the two countries. This difference was outlined by Prof. Joffe in his opening address. In this talk he summarized the position he has taken in written papers, some of

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which have been in print for three years, that the band theory, derived for metals, is actually inadequate for the study of many important semiconductors.

Prof. Joffe feels that the characteristic semiconductor phenomena are really characteristic of short-range order and do not require the existence of large perfect crystals. As evidence for this point he discussed the properties of several liquid and amorphous semiconductors such as selenium and others, whose properties are not widely different in the amorphous and in the crystalline states. A theory more closely related to that of atomic bonding and the theory of insulators, Prof. Joffe feels, will be of more general value for the future of semiconductors than the band theory.

Implicit in the position of Prof. Joffe and the Russian workers is the belief that the study of a wide-ranging group of semiconducting compounds is likely to prove more rewarding for the future of solid-state physics than undue emphasis on the monatomic semiconductors such as silicon and germanium, important as these materials undoubtedly are.

Excitons

REVIEWS of the properties of excitons and experimental and theoretical studies of their properties formed an important aspect of the new material appearing at the conference. Typical of the surprising situations which sometimes arise in fields such as this was the case of a paper by M. Balkanski of the Ecole Normale Supérieure which dealt with the theory of the exciton phenomena in cadmium sulfide. It was presented on the heels of another paper by his former collaborator in Berlin, I. Broser, who attempted to prove that the phenomena taken for granted by Balkanski did in fact not exist.

A partial resolution of this situation was given by Diemer of Philips who had carried out very much the same sort of experiment, dealing with the possible diffusion of excitons in cadmium sulfide, and who found that although he agreed with Balkanski that such a phenomenon as described by Balkanski did exist, the effect still showed up in only a small fraction, perhaps five percent, of the crystals studied.

Other reviews of exciton phenomena were given by Gross, who has stressed the use of magnetic fields and Zeeman-like effects on the exciton bands as means of analyzing and characterizing these effects. Similar work was also reported on by Nikitin of Strasbourg, France, who has dealt primarily with the absorption spectra at low temperatures of the alkali halides, and similar materials.

"Hot Electrons"

ANOTHER topic which received considerable attention at the conference was that of "hot electrons". These electrons have been accelerated by electric fields until they are no longer in thermal equilibrium with the lattice; that is, their effective



Prof. A. F. Joffe leading discussion after a paper.



T. Muto (Japan), W. C. Dunlap, Jr., and Jerome Rothstein (USA).

temperature is greater than that of the rest of the sample. Study of hot electrons gives us new information about electron lattice interactions.

One of the interesting papers in this session was that of Sasaki, Shibuya, and Mizuguchi, who have shown that in germanium, when the field and current are sufficiently large that electrons "warm up", the current and electric field no longer remain in the same direction because of the anisotropy of the energy band structure for such a situation.



R. A. Smith (England), Malcolm Hebb (USA), Jan Tauc (Czechoslovakia), L. Sosnowski (Poland), Walter Brattain (USA), and H. Welker (Germany).



S. G. Kalashnikoff, E. G. Miselyuk, E. F. Gross, Viktor Vavilov, and L. C. Stil'bans all of the USSR.



Richard Longini (USA) and F. W. Smits (USA).

The effect is similar to the Hall effect, since it shows up in the form of a transverse electric field. The effect may be characterized by a "Hall angle" θ , where $\tan \theta = E_t/E_l$ and where the E 's are the transverse and longitudinal components. This angle is measured with respect to variations of field intensity, angle between crystallographic axes and current, and related parameters.

Since the effect depends upon the nonequilibrium resulting in the various ellipsoids of the conduction band of n -type germanium, and the various effective masses resulting from acceleration of electrons in the various directions, the effect gives means of gaining additional information about the details of the conduction band structure.

The complete program, including manuscripts of papers and summaries of the discussion, is scheduled to appear in a single issue of the *Journal of the Physics and Chemistry of Solids*, of which Harvey Brooks, Harvard, is editor.

Personal Reminiscences and Reflection

IT is appropriate that personal contacts be emphasized here, since they really form the important part of such meetings, and I shall conclude this report on the Rochester Conference in a more personal vein. Trite as it is, to be sure, one realizes more than ever on talking with people from all over the world that, regardless of their political or economic backgrounds, the factors that divide people from one another are few and weak compared to the bonds that should keep them together.

The scientific sessions were held at Strong Auditorium where the facilities proved to be more than adequate for the meetings. The Women's Residence Hall at Rochester University was an excellent site for the social part of the conference, having not only fine accommodations but also a swimming pool. Only a few mixups were occasioned by the fact that the pool is generally used for ladies only and the locker facilities are not divided. Besides swimming, numerous conferees took advantage of the proximity of good golf and tennis facilities to keep themselves in shape during the meeting.

The Russian visitors were the center of attention, socially speaking, and I saw little of Prof. Joffe. We did have occasion to chat in the dressing room one morning when he and I appeared for shaving at the same time. I introduced him to American canned lather and he was very pleased with it.

His wife and collaborator A. V. Joffe is a sophisticated woman with an excellent sense of humor. Many of us were dismayed to see in one of the Rochester newspapers an interview with Mrs. Joffe which did little but stress the fact that she does not use lipstick and prefers working in a laboratory to cooking and washing dishes at home.

At one of the sessions, when L. S. Stil'bans of Joffe's institute was delivering a paper to the conference, a movie cameraman appeared and proceeded to

take pictures of Dr. Stil'bans lecturing, including close-ups, with the camera only feet away, lights bearing down, and Stil'bans manfully trying to enjoy it. He continued to talk with a big grin on his face, sweat pouring down his forehead, at which point Mrs. Joffe whispered in Russian to one of her colleagues, "They are making a new motion picture. It's called 'The Leningrad Smile!'"

Prof. Gross of the Physicotechnical Institute at Leningrad proved to be a likable person who brought great credit to himself and his country with his interesting English and charming personality, expressed as much in his manner of speaking as in its substance. I had the pleasure of cochairmaning a session with him on Friday morning. Prof. Gross, who is about 5 feet 2 inches tall, was at one point faced with the task of putting the chest microphone about the neck of Murray Lampert of RCA Laboratories, who is about 6 feet 4 inches in height. After succeeding in the task he turned to the audience, beaming, and announced, "My, my, such a high speaker!"

It was interesting to me to note the very respectable English spoken particularly by Stil'bans and Prof. Kalashnikoff. When I visited them last fall, neither spoke English at all, and, for example, when Prof. Kalashnikoff and I put his English and my Russian together we decided to speak German. At this meeting he not only read his paper (on recombination due to 3-5 impurities in germanium) in English, but also carried on long conversations in English with other conferees.

Viktor Vavilov of Moscow University speaks English very well. At one point I invited him to take a ride around Rochester in my airplane, which I had brought to the conference from our summer place at Lake George. He said he would think it over and after a few other remarks came out with, "Of course, you know I was with the air force for several years during the war." I spent quite a few minutes after that trying to decipher the implications, one of which might have been, "I've done my part", or "Oh, well, having been through that I am ready for anything."

I had invited Jan Tauc of Prague to fly with me to Lake George for the weekend since he was to be in Schenectady the following Monday. It should, of course, be added that I had received my license to fly passengers only the week before. Although Tauc appeared to be agreeable, various people thought it might not be politic, and Walter Brattain, I am told, took him off in a corner and asked him not to risk any international complications by flying with Dunlap. We compromised by getting Art Tweet of GE to drive him to the lake.

The conference supplied an ideal opportunity to make new friends and to become reacquainted with old friends from abroad whom we had not seen for some years. Good weather prevailed through most of the week, and the tours of Corning Glass Works and of Niagara Falls permitted many foreign delegates to improve their knowledge of the area.



A. V. Hensley (USA), E. G. Mielzok (USSR), P. R. Ruscel (USA), and I. Beagelsdorf (USA).



S. G. Kalashnikoff (USSR) and Bernd Ross (USA).

As a forum for the discussion of old and new ideas in the rapidly growing solid-state physics and semiconductor fields the conference was a great success. Also, it is to be hoped, the contacts made at international meetings of this type may lead to improved personal, scientific, and political relations among the scientists and peoples of the world. It is my opinion that the organizers of the conference and particularly Malcolm Hebb and David Dexter are to be congratulated on a splendid job. The conference owes much in the way of financial and other support to the International Union of Pure and Applied Physics, to the Atomic Energy Commission, the Air Force Office of Scientific Research, the National Science Foundation, and the Office of Naval Research, as well as to a number of industrial organizations.

The next conference in this series is scheduled to be held at Prague in 1960.