DIAMOND PHYSICS

A CONFERENCE on diamond physics was held during September 22–23 at the J. J. Thomson Physical Laboratory, University of Reading, under the auspices of the Institute of Physics and the Physical Society. More than a hundred delegates attended, and twenty-one papers were presented, most of which originated in Great Britain, but contributions were also received from the United States and one from Stockholm. Most of the contributions were experimental; two theoretical papers on related topics were those of P. Ewald (United States) on the electron density of diamond and of H. Bolton and H. Clark (Newcastle) on the nature of the bond orbitals. It was generally agreed that the electron density is much less concentrated than the word bond might imply, but it still remains very difficult to account theoretically for the intensity of the (222) X-ray reflexion observed in some specimens.

Two papers were devoted to synthetic diamonds. That on their production by E. Lundblad (A.S.E.A., Stockholm) compared different methods of synthesis using various catalysts and conditions of temperature and pressure but no direct transition of graphite to diamond has yet been achieved. The results therefore confirm these of the General Electric Co. (United States).

G. Kennedy (United States) and others, however, pointed out that they were convinced that the pressures at present quoted on the Bridgman scale were about 30 per cent above the true value at pressures greater than 25,000 atm. Consequently diamond formation occurred considerably below the region indicated by the Simon graphite-diamond equilibrium curve, which therefore needed revision.

The diamonds produced synthetically may have either type I or type II characteristics according to the method of production.

The other paper, by S. Tolansky (University of London), on optical and interferometric studies on the surface characteristics of diamonds compared the synthetic products from several different sources. A wide variation in crystal perfection was observed, some batches of specimens consisting of 'hopper-type' crystals whereas other batches were relatively perfect. Growth spirals were detected on specimens from one batch.

There were several contributions on semi-conducting diamonds. H. Farnsworth and J. Marsh (United States), using normal incidence on the (100) face, showed that the electron diffraction pattern below 350 eV. contained no half-integral order surface grating beams, thus indicating that the positions of the atoms in the surface monolayer are not displaced from their 'normal' positions as for silicon and germanium. Changes in the intensity of the diffraction pattern on heating treatment are interpreted in terms of variations in adsorbed oxygen, but there was some disagreement on details of the interpretation.

F. C. Champion and J. Male (London) compared the luminescence excitation spectrum of a semi-conducting specimen with its absorption spectrum and showed that the former method sometimes gave information absent from absorption data. For example, it showed quite clearly a level agreeing with an acceptor-level at 0·35 eV. from the valence band. Measurements of the anisotropy of the magneto-resistance in three oriented crystals of *p*-type semi-conducting diamond by P. J. Kemmey and E. W. J. Mitchell (Reading) were compared with calculations based on the approximate model of two warped and one spherical energy band surface, degenerate at $\mathbf{K} = 0$.

Contributions to the study of graphitization were made by M. Seal (United States) and by T. Evans and C. Phaal, and Evans and H. Sauter (Reading), the two latter emphasizing the aspect of etch-rate determination and etch-pit orientation on diamond surfaces. It was shown that trigons oriented such that the apices of the triangles on the octahedral face were pointed towards the sides of the face, as in naturally occurring trigons, could be produced by etching with an oxygen and water vapour mixture above about 800° C. Below that temperature the trigons had the usual etch orientation with sides of the trigons parallel to the sides of the crystal face. High-temperature and high-vacuum graphitization experiments on diamond were also described by V. Howes (Reading).

Experiments on irradiation damage to diamonds by electrons of energies up to 2 MeV. were described. Changes in the optical absorption of a type II*a* diamond near 2 eV. were compared with the theoretically expected rate of defect production and agreement below 1 MeV., obtained if the displacement energy is $E_d = 80$ eV. Corresponding measurements on the change of resistivity of a II*b* diamond with radiation dosage were in agreement with the absorption data up to 1 MeV., but above this energy C. Clark, P. J. Kemmey and E. W. J. Mitchell (Reading) found poor agreement, the explanation of which is uncertain. D. Palmer and C. D. Clark (Reading) showed from corresponding absorption changes with temperature that complex annealing processes occurred indicating a wide range of activation energies. Tentative models of the various annealing stages over the range 150°–800° C. were proposed. It was suggested during discussion that the interpretation of these experiments would be far more definite if in the first instance the energy of the bombarding electrons was confined to a value just above threshold (say, 0·5 MeV.), so that only one predominant type of defect was produced, namely, close vacancy-interstitial pairs. The number of possible activation-energies required to interpret the annealing data would then be a minimum and the significance of the present results, obtained at bombarding energy up to 2 MeV., could be more fully appreciated.

A two-phonon process was suggested by J. R. Hardy and S. Smith (Reading) to account for specimen-independent absorption between 3·75 and 7·5μ. It confirmed that long-range forces are far less important in diamond than in silicon or germanium. Phonons and also excitons were invoked by F. C. Champion and J. Male (London) to explain specimen-independent broad bands in the luminescent excitation spectrum of all types of diamond except type II*b* at energies greater than 5·45 eV., but bands at 5·25, 5·36 and 5·39 were attributed to some defect other than nitrogen.

J. Male and J. R. Prior (London) also reported the first examples of fluorescent emission in the ultra-violet from diamond at energies near 5·1 and 5·3 eV.

The growing interest in silicon carbide was shown by four papers on practical aspects involving various mechanical properties such as friction and wear of diamond and silicon carbide, by C. Brookes, by D. R. Miller, by L. M. Fitzgerald and by F. Field and N. L. Hancox, all from Cambridge. The steady improvement in the purity control of silicon carbide was described by W. F. Knippenberg (Holland). Using as starting material cubic silicon carbide prepared by decomposition of chlorosilanes, the total content of foreign atoms, which were mostly chlorine, could be reduced to less than 10^{16} cm.$^{-3}$. Using such pure material, H. Daal, W. Knippenberg and J. D. Wassher measured the Hall constant and the resistance of silicon carbide from 80° to 1,400° K. Much lattice imperfection is indicated since the number of acceptors and donors exceeds the number of chemical impurities by an order of magnitude. Occupying as it does a key intermediate position between silicon and diamond, all the properties of silicon carbide are of great interest and importance. However, because of the different possible atomic arrangements such as cubic and such polytypes as 4H and 6H in the hexagonal form, the interpretation of the optical and electrical properties of silicon carbide is complex. D. Hamilton, W. J. Choyke and L. Patrick (United States) have examined the optical absorption and photoluminescence of 4H silicon carbide, extending earlier work on the 6H polytype. A characteristic edge luminescence was observed in the pure 4H crystals and parts of the spectrum were found to have photon energies greater than the energy gap of polytype 6H. Corresponding absorption experiments showed that the 4H energy gap exceeds the 6H energy gap by 0·25 eV. The transitions are indirect and exciton absorption is observed.

The impression gained from the Conference was that although diamond physics is still in its infancy, sufficient experiments have now been performed over a wide range of properties and techniques to indicate that a relatively few well-chosen experiments, such as the investigation of radiation damage close to the threshold energy, should throw real light on fundamental problems in solid state physics. As Prof. R. W. Ditchburn pointed out at the beginning of the Conference, the unique property of diamond is its stability and the simplicity of its composition. These striking advantages compared, for example, with the alkali halides, as set out in a conference on crystal luminescence held two weeks earlier in Turin, seem to me far to outweigh the relative intractability of diamond as a material in that it prevents the overwhelming flood of experimental data which would undoubtedly ensue if simple methods of 'doping' diamond were available. Diamond physics is on an orderly march which should lead to a real advance in our understanding of solid state physics.

Advantage was taken of the opportunity provided by the Conference to present the Duddell Medal to Prof. R. V. Jones, who then spoke on some developments of the optical lever. In an excellent lecture, enjoyed by all, Prof. Jones described in particular the development of the optical lever in the past ten years up to the present stage when the performance approaches the limit set by the statistical fluctuations of photons in the light beam. Applications covered the evaluation of the thermal fluctuation limit for galvanometers, the detection of the change of linear momentum in a beam of light after refraction, and the development of a sensitive infra-red detector based on linear thermal expansion. The method failed to detect any deviation of a beam of light in an inhomogeneous transverse magnetic field of mean value 8,000 oersteds, although a change in the velocity of light of about 70 μsec.$^{-1}$ should have given a deviation equal to the r.m.s. error.

F. C. Champion

THERMAL MOTION IN CRYSTALS AND MOLECULES

The fifth international congress of the International Union of Crystallography which was held recently in Cambridge was followed by two symposia, one of which was devoted to papers on Thermal Motion in Crystals and Molecules. This symposium lasted for two days, August 22–23, apart from an introductory lecture which was given during the main congress in the previous week. It consisted of five invited papers and thirty other contributions, abstracts of which had been published in advance of the meeting by the International Union of Crystallography.

In the early days of crystallographic studies by X-ray diffraction techniques, thermal motion was a disturbing factor for which rather empirical correction had to be made, by means of the familiar Debye–Waller theory, before the crystallographer could make a crucial comparison of his experimental intensity results with deductions from any postulated structural model. Since then the increasing accuracy of measurements and ease of interpretation have permitted the process to be largely reversed and experiment now allows a detailed assessment of atomic motions to be made and analysed into various types of vibration. Investigators are no longer restricted to the use of X-rays for electrons, and neutrons are now being widely used in support. Moreover, further theoretical work on the various scattering processes and improvements in experimental techniques have played their parts in increasing the interest in this field of work. During the past few years it is particularly noteworthy that rather empirical descriptions of atomic motions are being superseded by much more comprehensive descriptions of co-operative motions of molecules and crystals as a whole. To a considerable extent, interest has been fostered by the increasing availability of computing machines and programmes able to analyse the experimental results in terms of the many parameters needed for a full description of thermal motion.

Although receptive of any aspect of thermal motion in crystals and molecules, the symposium was aimed at providing discussion of three particular topics: first, the study of the elastic and inelastic scattering of X-rays and neutrons by solids, as a