heat of crystallization should agree approximately. In the light of Mozzi and Warren's larger mean deviation of ~15° for Si–O–Si, this value of 10°–11° seems by no means excessive. This suggests that amorphous germanium, and no doubt glasses in general, do not adopt the least disturbed configurations compatible with non-crystallinity and, in view of the drastic conditions in which glasses such as amorphous germanium are formed, this seems quite reasonable.

POINT DEFECTS

New Role for Dislocations

from our Solid State Physics Correspondent

A NEW way of studying point defects in solids using variations in the mobility of dislocations has been suggested. F. J. Wagner and A. Seeger (*Phys. Lett.*, **30**, 274; 1969) have recognized the similarity between the interactions of a domain wall with a point defect and a dislocation with a point defect, and have suggested that the amplification effects of domain walls in magnetic materials, known as a magnetic after-effect, can be translated to non-magnetic materials in the form of a dislocation or mechanical after-effect. They tested this idea by measuring the variation of the elastic modulus of nickel under strain, and found that an appropriate time constant predicts an activation energy for the interstitial defects in the metal in agreement with that deduced from annealing experiments.

Wagner and Seeger considered the simple case of dumb-bell shaped interstitial defects. Mobile dislocations act so as to lower the elastic modulus of the solid, and when the solid is put in tension the dumb-bell defects orient themselves so as to lower the interaction with the dislocation strain fields and so the measured elastic modulus gradually increases. This is sometimes viewed as a decrease in what is called the modulus defect, and the time constant for the decrease is the relaxation time for the reorientation of the dumb-bell axes.

High purity nickel wires were strained in tension at room temperature, and it was found that the increase in the elastic modulus could be described by a superposition of two exponential functions. Wagner and Seeger associated one time constant with the activation energy of rotation of the defect and the other with the activation energy of migration between sites. They deduced that the beginning of migration towards the dislocation is described well by an exponential time dependence.

Wagner and Seeger suggest that this mechanical after-effect technique can be applied to different types of crystal and to different point defects. They are now engaged, they say, on a more detailed investigation which includes measurements on copper.

INTEGRATED CIRCUITS

The Electromigration Problem

from our Materials Science Correspondent

AN essential constituent of integrated circuits is the thin film of aluminium through which gold wire leads are connected to various points in the circuit. The whole industry has by now standardized on aluminium for this purpose, in spite of several metallurgical problems in ensuring the integrity of the contacts when first manufactured. Other metals pose even more difficult problems. As integrated circuits become more elaborate (through "large-scale" integration in particular) the unit size of active devices, already minute, must be further diminished, and this implies higher current densities at the contacts and in internal leads. This development has brought with it a new metallurgical disease, the "high current density problem". After some hours of operation, an aluminium connecting strip or contact layer may suddenly become open-circuited. This has been traced to electromigration, which could perhaps be described as a special form of radiation damage. The impinging particles are not neutrons or photons, but electrons. At a d.c.-biased a.c. contact, the net momentum of drifting electrons is transferred to the metal atoms which progressively diffuse out of the film, forming cavities or whiskers and eventually causing loss of electrical continuity.

During the past two years an intensive programme of research has been mounted to define the problem and estimate the mean lifetime of aluminium films as a function of current density and structural parameters such as crystallite size and impurities, but a recent survey (Spitzer and Schwartz, *J. Electrochem. Soc.*, **116**, 1368; 1969) indicates that a great deal more research urgently needs to be done if the necessary confidence in the design of integrated circuits is to be maintained. It is not always possible to design circuits to by-pass the electromigration problem, and because extreme reliability is probably the central advantage of integrated circuitry over conventional circuits, this problem is plainly being taken very seriously by the manufacturers. There is scope here for research in universities, which are not subject to the extreme time pressure characteristic of the microelectronics industry. The problem is squarely metallurgical in nature: for example, the mean life until failure depends on the operating temperature through an activation energy which is intimately related to the way the film was made, because the various forms of diffusion in the bulk, at grain boundaries and at the surface, determine how quickly metal atoms can electromigrate. Some of the research quoted by Spitzer and Schwartz shows that dielectric overcoatings on the aluminium retard electromigration and increase lifetimes, but it is not clear why this happens.

ENZYMES

Nomenclature Reform

BIOCHEMISTRY grew up with some picturesque names for the enzymes—"old yellow enzyme", "Zwischenferment", and so on—but names that were satisfactory in the days of Warburg are not necessarily acceptable today. The picturesque has had to make way for a colourless and systematic codification of enzyme reactions, which now number almost a thousand, and the abandonment of many trivial designations. In 1955 the International Union of Biochemistry set up a commission to examine the problems caused by diversity of practice in enzymology, not only in the