board rings which they held in their feet and manipulated as if they were running along a twig. Moving targets were used to elicit turns and caused the spider to rotate its ring away from the object. In this way the spider performed the motor patterns of turning but received no visual feedback because the image of the target did not move across the retinae. The angle through which the spider turned its ring was measured and was found to correspond to the angle between target and the axis of the spider's body. The spiders can therefore orient accurately whether or not they receive visual feedback. This means that the angle to be turned through is calculated accurately before the turn is initiated—a remarkable and still poorly understood feat of calibration.

SOLIDS

New Superlattices

from our Materials Science Correspondent

THE term superlattice was coined by an X-ray metallographer many years ago to describe a crystalline solid solution in which, after appropriate heat treatment, solvent and solute atoms are deployed in an ordered manner. In strict semantic terms, the word only makes sense for alloys such as the Cu/Pd series in which "long-period superlattices" occur: the crystal pattern has a structural discontinuity every l unit cells in one particular direction, where l is a small integer, typically 5. Such a superlattice can be described as one-dimensional. Only recently has the work of Sato and Toth at the Ford Scientific Laboratories provided an understanding, in terms of electronic band theory, for the existence of such superlattices.

Work in several unconnected fields of solid state science has now established that long-period superlattices in alloys are not the only exemplars of the species. In recent months, new forms of one-dimensional and three-dimensional superlattices have been described, and a two-dimensional form was predicted and subsequently observed some years ago.

The new one-dimensional superlattice is a man-made semiconductor structure: a silicon monocrystal slice is grown from the vapour phase in an atmosphere which is rapidly and regularly alternated between phosphine-rich and arsine-rich compositions. The slice grows with plane differentially doped layers at a regular spacing, typically about 150 Å (A. E. Blakeslee and C. F. Aliotta, *IBM J. Res. Dev.*, **14**, 686; 1970). Their work was stimulated by a remarkable theoretical paper by L. Esaki and R. Tsu published a few months earlier (*IBM J. Res. Dev.*, **14**, 61; 1970). Esaki and Tsu worked out in some detail the band theory and electron transport properties of one-dimensional semiconductor superlattices. In effect, such materials contain mini Brillouin zones bounded by small energy gaps, all interpolated inside the principal Brillouin zone, and at the same time they embody periodic fluctuations of the main energy gap. The effective electron mass becomes strongly dependent on the direction of motion of the electron, and in the author's words, this "leads to virtually a two-dimensional electron gas system".

An important theoretical consequence of this feature is that the drift velocity along the normal to the superlattice layers passes through a maximum as a function of applied electric field, and so at sufficiently high fields (not enough, however, to cause tunnelling and avalanching) the system has a negative differential conductance. In effect, this happens when the electronic mean free path sufficiently exceeds the superlattice period. Such systems, in which the host crystal and the scale, amplitude and nature of the dopant superlattice are independently disposable variables, should give rise to a novel class of devices and open new areas in semiconductor physics, a field which has lost its first fine rapture. The preliminary experimental work by Blakeslee and Aliotta has now shown that semiconductor superlattices can readily be made with the requisite period and amplitude and with a large number of layers, and so it seems that the new field is wide open.

The new three-dimensional superlattice is a regular array of voids in irradiated molybdenum, recently described by J. H. Evans (*Nature*, **229**, 403; 1971). Voids are small cavities in a crystalline lattice produced by neutron or particle bombardment. In molybdenum bombarded with 2 MeV nitrogen, electron-microscopy showed that the voids were arranged on a regular body-entred cubic lattice aping that of the host metal but with a repeat distance around fifty times larger (220 ±10 Å). This remarkable observation has now been explained by R. Bullough and K. Malen at a recent conference on voids at the University of Reading. They showed that superlattice formation by voids depends on elastic interactions between the voids, which in turn relies on the anisotropic elastic properties of the molybdenum crystal lattice; the theory is able to interpret the scale of the observed periodicity. Presumably the voids migrate by the well-attested process of self-diffusion along their surfaces until the optimum periodicity is established, but this has not been examined. The superlattice contains some vacancies and dislocations, though so far these have not been studied in detail. The nomenclature of a vacancy in a void lattice would seem to offer an intriguing exercise in double negatives.

The dimensional catalogue concludes with the two-dimensional flux-line lattices in type 2 superconductors, predicted in 1957 by Abrikosov and directly observed during the past four years. The lattice consists of normally conducting filaments carrying a magnetic field, and over a range of temperatures below the upper critical field these flux-lines exist in equilibrium and arrange themselves in a two-dimensional lattice with either a triangular or a square unit cell. The important feature of the lattice (which typically has a repeat distance of about 500 Å) is that, in a hysteresis-free type 2 superconductor, the entire flux-line lattice is unstable the moment a finite current flows through a superconductor. The critical field in this temperature range is thus zero unless the lattice can be anchored in some way to the underlying crystal lattice.

A great deal of metallurgical research is currently being devoted to studying anchoring to dislocations and to second-phase particles. Until recently, such studies had to depend entirely on indirect deductions based on measurements of critical currents and fields, but a technique invented by Träuble and Essmann in 1966 has made it possible to observe the flux-line lattice directly. Colloidal particles of iron are allowed to deposit on a superconductor surface, decorate the exits of flux-lines and become fixed in position, so that replicas can later be taken and examined by electron microscopy. A. Seeger has recently published a survey of superconductivity and physical metallurgy (*Metallurgical Trans.*, **1**, 2987; 1970), in which much of the active recent research in this field is summarized and its strategy explained. It seems that flux-line lattices themselves contain all the standard defects—grain boundaries, vacancies, edge dislocations and even disclinations (a species of defect which, though specified by theorists such as Nabarro, has not been observed in crystal lattices). After illustrating all these defects in the flux-line lattice, Seeger goes on to discuss the physical nature of their interaction with defects in the crystal lattice itself and the consequence of such interaction for superconducting behaviour. This article is a particularly readable introduction to a subject which bristles with conceptual difficulties.

It now only remains to seek connexions between these different kinds of macroscopic superlattices. Perhaps void lattices can be created in a periodically doped superconductor and unprecedentedly large critical fields thus obtained?