Artificial Semiconductors

IN 1968 while spending a sabbatical period at the Allen Clark Research Centre I worked on an idea for making artificial semiconductors and did a few preliminary experiments. It seems worth recording these because, due to the interest of colleagues, we are about to continue the work; and a comparable scheme has been proposed by distinguished scientists at IBM[1].

The basic idea is to make a multilayered structure of alternate thin films of metal and insulator. The resulting potential diagram (Fig. 1) is similar to the Kronig-Penney[2] representation of a crystalline solid. In a solid, of course, the potential barrier is the effort an electron has to make to get from one atom to the next and its width is entirely governed by the crystal lattice spacing, a very inflexible parameter. Because nearly all lattice spacings are between 3 and 5 Å, it follows, from solving the Schrödinger equation with barriers of this periodicity, that the energy spread of a band is a few electron volts. The limits of the band occur when the periodic distance, $(a+b)$ in Fig. 1, is an integral number of half de Broglie wavelengths for an electron.
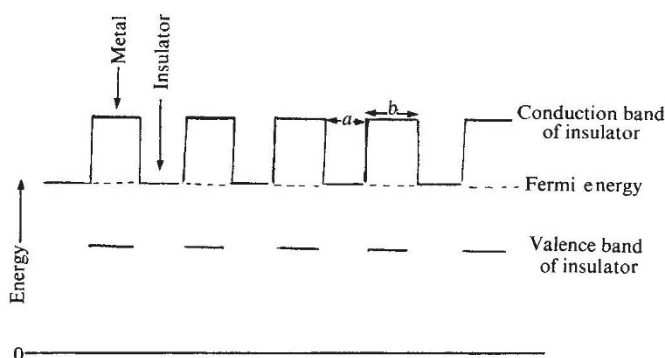

Fig. 1 Potential diagram of a multilayered structure.

If one applies this model to dimensions that are just practicable for an artificial semiconductor, say, sputtered layers of 20 to 30 Å, a great difference occurs. The solution of the Kronig-Penney problem simplifies to an approximate equation

$$\alpha_n a = K \pm n\pi$$

where $\alpha_n = (2mE_n)^{1/2}/h$, E_n is the energy of the nth allowed level, a is the thickness of the metal and K is a constant for a particular structure.

The values of α_n represent allowed energy levels. The allowed band is very narrow, a physical consequence of the wide barrier which holds the electrons to the metal layers. Consequently, once the values of the Fermi level of the metal and the energy gap of the insulator are known it is easy to calculate the energy gap corresponding to, say, the transition from $n=0$ to $n=1$. For a Au–SiO$_2$ multilayer with $a=30$ Å this comes to about 1.0 eV.

In the experiments I was associated with in 1968 we used an r.f. sputtering set with a rotating electrode, one half SiO$_2$ and the other half Au. Each side could be made to sputter on to substrates separately. The sputtering rates were determined in the usual way by measuring long exposures, then the times were scaled down so that a thin layer of each material was obtained. Typical runs were made in which about twenty layers each of Au and SiO$_2$ were sputtered on to glass or 'Irtran' substrates.

Of course a 30 Å layer even by r.f. sputtering must have many voids and islands. Electrical resistance measurements

on a forty-four layer structure, showed an ohmic characteristic with a resistance of only $\sim 10^{-2}$ Ω. This was presumably the path of lowest resistance through the layers and may well have been shunting some more interesting characteristics. A more promising diagnostic method is infrared absorption. At the infrared wavelength corresponding to an energy gap electrons should be excited across it, with the corresponding absorption of radiation. Two runs of multilayered structure were therefore sputtered on to an 'Irtran' substrate which has a good transmission characteristic. Infrared from a hot source and a grating monochromator was split into two equal beams one of which was transmitted through the specimen and the other through a blank 'Irtran' substrate. The two beams were detected and the difference signal fed on to a pen recorder. The pen recorder was driven by the same motor that operated the monochromator. The first specimen tested was a forty-four layer structure with nominal 30 Å Au separated by nominal 20 Å SiO$_2$. An absorption edge well above noise level was found at 9.5 μm with smaller edges at 7.9 μm, 4.3 μm and 3.05 μm. The second specimen, which had only eighteen layers, showed less marked effects. The large discrepancy between the calculated value of 1.0 eV and the measured value of 0.13 eV for the principal absorption edge indicates either that the simple theory is inadequate or perhaps that it is wrong to take a value for the bulk Fermi energy of gold (5.6 eV) in considering thin layers. The value of the calculated energy gap is sensitive to this value, decreasing to 0.04 eV if the Fermi energy is zero.

In spite of this limitation of theory the prospect of achieving man-made semiconductors is an exciting one. These structures are difficult to make, so it is too early to be definite about their application. The idea of tailoring a photoconductor for specific narrow band infrared detection is, however, attractive. It is also likely that negative resistance characteristics could be created if a higher uniformity could be achieved. Further experimental and theoretical work is needed to explore these possibilities.

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BIOLOGICAL SCIENCES

Role of ATP in DNA Replication

THE bacterial chromosome replicates in a semiconservative manner[1]. This process may occur at the cell membrane[2,3]. Efforts to study replication by means of purified DNA polymerases have failed to elucidate the mechanism of the *in vivo* process. Therefore, recent attempts have been made toward isolation of membrane-containing systems which more nearly approximate the properties of *in vivo* replication. Two different procedures have been used. One relies on hydrolysis of the cell wall by lysozyme, followed by gentle disruption of the spheroplast membrane so as to avoid shearing the replication apparatus[4,5]. In a different approach, cells have been made permeable to nucleotides and other small molecules by treatment with toluene[6-8] or ether[9]. This permits incorporation studies with little alteration of the cell interior. Both of these procedures yield preparations that replicate bacterial or phage