ELECTRONICS

Improving Charge-coupled Devices

from our Solid State Physics Correspondent

THE concept of the charge-coupled device (CCD) emerged from Bell Telephone Laboratories about three years ago (Boyle and Smith, *Bell Syst. tech. J.*, **47**, 587; 1970) and several groups have been working hard to bring this very simple but very useful device to fruition. One example was given at a recent European Device Conference (Tompsett *et al.*, *Institute of Physics Conference Series*, No. 15, 174 and 175), where a solid state television camera using a 128×106 element array of these devices was described. Some significant development work is also going on in Britain (and was reported at an Institute of Physics meeting on charge transfer devices held on June 11—see *Nature*, **244**, 11; 1973).

An interesting new concept for operating CCDs has recently emerged from Mead's group at the California Institute of Technology (Mohsen *et al.*, *Appl. Phys. Lett.*, **22**, 172; 1973), where some advanced thinking on device physics and detailed analyses of circuits has indicated that the use of "push clocking" must have many advantages over the conventional "drop clocking", which essentially has to do with the sequence and levels of pulsed voltages applied to the electrodes of the CCD.

As the CCD is not yet widely familiar, a brief description will be given here. The device can be thought of as a line of rectangular metal-oxide-semiconductor capacitors placed edge-to-edge and as close as possible together. Simple theory says that if a voltage is applied to the metal electrode, the silicon energy bands will bend and minority carriers will invade the surface region from the bulk of the semiconductor. In other

words, the potential well at the surface fills up with charge. The higher the applied voltage, the deeper the well and the more charge injected.

The concept is illustrated in Fig. 1, the well being formed in the x - ϕ plane between the oxide surface and some outer plane, which is in fact less well defined than that shown. The situation in a plane at right angles to that of Fig. 1 is shown in Fig. 2(a). By applying different potentials at the surface by means of different plates in the array this potential well can be bound in the z direction. In Fig. 2(a) the electrodes A and C are further away than electrode B but the same well geometry could be obtained if they were coplanar, with different voltages applied. In either situation the result is an electronically bounded and controllable charge packet. The packet can be moved along the chain of electrodes by suitably raising and lowering these potential walls and essentially pouring the packet of charge from one well to the other.

The "conventional" method of moving the packet is to lower one wall of the well, as in Fig. 2(a), allow the charge to move two places (step (1)) and then re-erect the wall behind it (step (2)). The sequence of electric pulses which carries this out can be termed "drop clocking".

The new approach suggested by Mead's group is shown in Fig. 2(b). Instead of lowering a wall the voltages are so arranged that the charge is tipped over the existing wall into the next well. The rising floor of potential well B can be thought of as a piston which pushes the charge over wall C into the next well. Mead and his colleagues call the operation "push clocking" for obvious reasons.

Push clocking has many advantages, the chief of which stems from the fuller use of the power supply voltage available for making the potential wells. The "stroke" of the "piston" in the push clock case (Fig. 2(b)) corresponds to the full 15 V, whereas in the equivalent drop clock case (Fig. 2 (a)) only half the swing is used for the same purpose.

Fig. 1 Concept of the CCD.

The result is that the efficiency of charge transport, which essentially determines the signal-to-noise characteristics of the device, is increased. Also a great impediment to the efficient transfer of charge—the holding up of carriers in interface traps—is ameliorated and the time taken to raise and lower the walls is, as it happens, more efficiently used in shifting the charge. This improves the performance of the device at low frequencies—an important feature. These conclusions by Mead and his colleagues seem to be sound for two-phase clocking. Stanley Brotherton, of the University of Southampton (work to be published) finds, however, that the same advantages do not apply for three-phase clocks. Here, the most important factor for efficient charge transfer is the shape of the rising and falling edges of the clocking pulse waveform.

Fig. 2 a, Drop clocking; b, push clocking.