you current oscillations that are nonsinusoidal. In gallium arsenide, electrons are transferred within the conduction band from a low valley to an upper valley; the transfer is responsible for the negative differential conductivity.

Two-level oscillators have some inherent problems, Hilsum told us: the effect is not very pronounced because the peak-to-valley ratio is not very high; because the material automatically breaks into domains you can't use all of the negative resistance available.

Hilsum had observed that certain semiconductors would permit electron transfer from a low-energy valley to an intermediate-energy and also a high-energy valley. If the energy differences are suitable the peak-to-valley ratio may be much higher than in a two-level system; so the oscillation may be more pronounced. Domain formation is also suppressed; so the frequency can be controlled by the circuit itself. Although LSA-(limited space-charge accumulation) mode devices also suppress domains and thereby give you a higher frequency in the same sample, Hilsum remarked that the devices tend to oscillate at the Gunn frequency as soon as anything goes wrong in the circuit. The Malvern group has made an indium phosphide oscillator with 7% efficiency and a wide tuning range.

In the discussion following Hilsum's talk, Esther Conwell (General Telephone and Electronics) commented that the three-level structure itself was not sufficient to suppress domain formations, that low-field contacts such as Hilsum presumably used were also required.

Hilsum thinks indium arsenide phosphide and some alloys of indium gallium antimonide should also work as three-level devices. Indium phosphide, however, is easier to make, and because it's a good thermal conductor, you can put a lot of power in. Hilsum foresees extensive applications in radar and general microwave instrumentation.

In J. B. Gunn's original paper in 1963, he reported sinusoidal oscillations in indium phosphide but attributed them to another mechanism. The effects were much less pronounced than in gallium arsenide, probably because of the poor quality crystals available at the time. —CBL

A Mott transition? It all depends on what you mean . . .

One of the most talked-about talks at the International Conference on the Physics of Semiconductors (held in Boston in August) was that given by Maurice Rice of Bell Labs. The discussion period lasted longer than the talk itself. It was part of a year-long controversy over whether or not the metal–insulator transition in V_2O_3 should be regarded as a Mott transition.

Part of the problem is in defining the transition that was first discussed twenty years ago by Sir Nevill Mott (Cavendish Laboratory). The Bell group defines the Mott transition roughly as the path a system of electrons and ions will take as a function of interatomic distance in going from the metallic state for small distances to a highly correlated insulating state for large separations. This path of transition is determined by electron–electron interactions and was originally suggested by Mott to be discontinuous—that is, a first-order transition. Some people now believe, based on experience with doped semiconductors, that the transitions should occur in a continuous fashion, as has been proposed by Walter Kohn (University of California, La Jolla).

The Bell workers say that to observe such a transition one must be able to vary the lattice parameters continuously. This is experimentally impossible, as there will usually be an excluded volume region. However, the Bell Labs experimenters choose to call experimental transitions in which the system transforms from localized to nonlocalized states "Mott transitions."

Last December Dennis McWhan, Rice and J. P. Remeika reported that they had found a sharp first-order transition in chromium-doped V_2O_3 at room temperature with no apparent change in symmetry from a metal to an insulator. The transition occurs either as a function of pressure or chromium doping. McWhan explains that by observing this transition they deduce a phase diagram that includes the well known metal - to - antiferromagnetic - insulator transition at lower temperatures in pure V_2O_3. This phase diagram led the Bell workers to claim that the metal-insulator transition is a Mott transition.

Because there is no change in symmetry across the high-temperature metal-to-insulator transition it can and in fact experimentally does terminate at a solid–solid critical point. At certain pressures and compositions the material goes from antiferromagnetic insulator to paramagnetic metal and then back to paramagnetic insulator as the temperature is raised, Rice says.

In the early work only electrical resistivity and x-ray measurements were reported. Since then Bell workers and others have done optical, nuclear magnetic resonance, susceptibility and Mossbauer measurements on V_2O_3, which, according to McWhan, support their original findings.

One major objection to the work, raised by John Goodenough (Lincoln Lab), William Paul (Harvard), David Adler (MIT) and others, is that electron-lattice interactions have been largely ignored in the interpretation of the transitions by the Bell workers. There are several oxides of vanadium that have first-order semiconductor-to-metal transitions associated with lattice changes, and none of these represent a Mott transition.

Goodenough, who spoke next at the meeting, pointed out that a significant band crossing is associated with the crystallographic changes across the high-temperature transition; band splittings are associated with the symmetry changes across the low-temperature transition. Although he agrees that electron–electron Coulomb forces play an important role in these two transitions, he felt that the Bell workers had not adequately defined what they meant by electron localization in the so-called "insulator phases."

Paul emphasizes the need to consider dynamical motion of the lattice, the actual vibrations of the lattice in the transition. Furthermore he argues that the d electrons may produce a large effect by modifying the vibration spectra; so the frequency of the vibrations would be different in the two phases. He feels that the effect should be examined experimentally before final conclusions are drawn.

Adler points out that amorphous films of V_2O_3 fail to exhibit the conductivity jump, which indicates that inhibiting the change in short-range order that is represented by the lattice change suppresses the transition. He feels that this is strong evidence that the transition is driven by the electron–lattice interaction rather than electronic correlations and thus is not a Mott transition. Another objection raised by him is that in the Bell data the "metallic" phase has lower conductivity than the "insulating" phase near the supercritical transition, an unusual result. McWhan feels that such behavior is not unreasonable near the critical region and at the same time points out that at low temperatures the two phases are in fact well characterized.

What does Mott himself say? He thinks that there are many kinds of metal–nonmetal transition, some due to electron–electron interaction and some not. He thinks that V_2O_3 is probably in the former class and is therefore a kind of Mott transition, but that the crystal structure and electron–lattice interaction both play an essential part in making possible the observed behavior. —CBL □