High Uniaxial Stress on Germanium Causes Gunn-Effect Oscillations

By applying 10 000–20 000 atmospheres along the [111] axis of n-type germanium at room temperature, John E. Smith Jr at IBM Watson Research Center has produced microwave current oscillations. Smith attributes the oscillations to bulk negative differential conductivity.

Bulk negative resistivity, predicted by B. K. Ridley and T. B. Watkins in 1961 and predicted (by Cyril Hilsum in 1962) to occur in n-type gallium arsenide, was found in 1963 by J. B. Gunn. To produce the effect in gallium arsenide one applies an increasing electric field. At a threshold of 3000 V/cm, electron drift velocity decreases with increasing field.

Gunn showed experimentally that beyond threshold a high-field domain forms near the cathode that reduces the electric field in the rest of the sample and causes the current to drop. Then the high-field domain drifts with the carrier stream across the sample and disappears at the anode. To keep voltage constant, electric field and current rise again to the threshold value. Then a new domain forms at the cathode and the cycle repeats. The frequency is the ratio of the distance between the two contacts and the drift velocity of the domain (constant for a given material).

This mechanism modulates the generating microwave power. One finds that the alternating component of current is out of phase with the voltage and the material has a negative resistance.

In the model of Ridley, Watkins and Hilsum, the conduction band has two valleys with different energies and mobilities. Three conditions must be satisfied: Electrons in the lower valley have much higher mobility; the energy difference between valleys is several times greater than thermal energy, and the energy difference between valleys is smaller than the energy difference between the conduction and valence bands. Then as one applies more electric field, the electrons transfer from the lower valley to the upper where they have much less average velocity.

By applying a uniaxial stress to the germanium, Smith explains, he alters its many-valleyed conduction band so that the transferred-electron effect can occur. He believes that the same technique may work in other semiconductors with many-valley conduction bands, such as silicon, lead telluride and gallium phosphide.

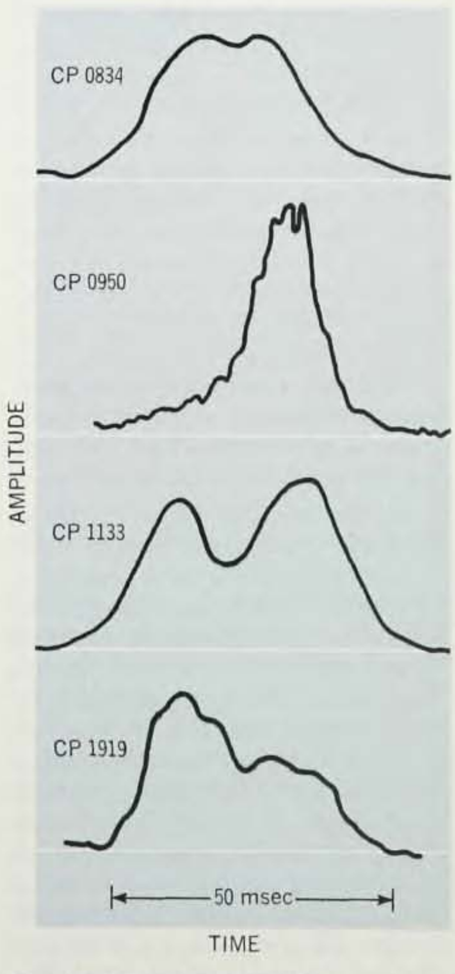
In addition to gallium arsenide, bulk negative differential conductivity has been found in several polar semiconductors, and, by lowering the temperature to 120 K, in n-type germanium. Several theorists have proposed mechanisms other than transferred electrons to explain the results in cooled, unstrained n-type germanium. —GBL

Astronomers Need More Observations to Explain Pulsars

More information is available now on the four pulsed radio sources discovered last December at Cambridge, but no new ones have been found and theoreticians still argue about what they are. Called "pulsars," these sources emit pulses at radio wavelengths with remarkably constant repetition intervals that range in the four known cases from 0.25 to 1.33 sec (PHYSICS TODAY, May, page 75). We recently visited the Mullard Radio Observatory at Cambridge and the Nuffield Radio Observatory of the University of Manchester at Jodrell Bank to talk to astronomers engaged in these observations.

At Cambridge, Anthony Hewish stressed the need for further observation of the four original pulsars and for a careful search for others before conclusions are drawn concerning their nature. "We need accurate positions, optical identification, spectra," he said, but admitted that their current program consisted partly of catching breath after the hectic period following the original discovery last December. Particularly desirable would be searches in the southern hemisphere, Hewish thinks, perhaps by copying the new phased array at Cambridge, which was built quite cheaply in twelve months with student labor.

This new antenna array, with its 21 000-m^2 collecting area, is a very sensitive instrument for rapid searches, and its electronics can be arranged to track four beams at once. The current search with this array could find pulsars with repetition intervals between 0.05 sec and 1 min. Once found with this antenna a pulsar can be tracked and studied with a pencil-beam dish telescope for periods of up to about half an hour. The phased array, which lies in a fixed horizontal plane, loses sensitivity for objects close to the horizon, and Jodrell Bank has been helping with the search in those parts of the sky that are at too low a



MEAN PULSE PROFILES for the four pulsars. These pulses were received at 408 MHz and averaged over 8 min.

declination for the Cambridge instrument.

At Jodrell Bank, John Davies with his students Andrew Lyne and Barney Rickett talked to us about their work. Apart from a search for more sources, which has covered "a fair area of the sky, not too thoroughly," they have concentrated on the pulse shape of the four known pulsars. Although the shapes vary from pulse to pulse, the mean pulse profile averaged over a few minutes turns out to be characteristic for each pulsar (see figure). Surprising similarities show up when the four are compared; each pulse has two components, approximately Gaussian curves 20 milliseconds wide and 20 msec apart, with the overall extent of the emission 50–60 msec for all four. Individual pulsars differ only in the relative amplitudes of the two parts of the pulse. The most extreme case is CP 0950 (CP stands for "Cambridge Pulsar," and the four numbers that follow give the right ascension to the nearest minute). This one has the fastest repetition rate, 0.25 sec, and its average pulse shape shows a long initial slope or "slow rise" instead of the double peak seen in the other three. Polarization measurements at Jodrell Bank show that the two halves of each pulse are differently polarized and presumably originate in different parts of the star. Dispersion curves show that the pulses are all emitted as single broad-band bursts, and give estimated distances of the objects between 30 and 100 parsecs (1 parsec = 3.26 light years).

What are they? While Hewish's original suggestion included the possibility of both white-dwarf and neutron-star oscillations, Davies at Jodrell Bank inclines towards white-dwarf star explanations; his colleague at the University of Manchester, theoretical astronomer Franz Kahn, has a detailed white-dwarf theory and an engaging manner sufficient to convince anyone. The theory follows a suggestion by Richard James and Eric Graham that, at a late stage in its development, a white dwarf may have most of its mass concentrated in an inert helium core, with a hot shell of hydrogen and helium covering the surface. If such a shell oscillates almost adiabatically, thermonuclear reactions proceed faster during the compressed phase than during the expanded phase. The oscillation therefore picks up additional energy because expansion and contraction occur under conditions of excess and defect pressure relative to the adiabatic values. Kahn estimates the buildup time of these oscillations to be 10^{13}–10^{14} cycles. If the boundary conditions for stable oscillations are met, says Kahn, we are left with a very narrow range of values for the total mass of the star, the temperature of the shell and the frequency of the oscillations. The range of allowed pulse rates is a few seconds with a minimal period of 0.1 sec—a range that includes the four observed pulsars.

Kahn has also worked on the transducing mechanism whereby these oscillations are converted into radio signals by interaction of a collisionless plasma shock in the hot shell with the star's magnetic field. He believes that the emission spectrum cuts off in the radio region before reaching the visible. An oddity of white dwarfs, not previously explained, is the relative absence of visible cool ones; if they represent the last stage of stellar evolution, in Hewish's words "we would expect the sky to be littered with them, but it's not." Perhaps Kahn's stars are a later development of nearly burnt-out white dwarf stars that have become optically invisible.

At Cambridge, Hewish refuses to write off neutron-star theories of pulsars. He thinks that the various theories are still too vague to offer any definite observational test. His parting words were, "This is a good time to be a theoretician." —JTS

Floating Rings Extend Plasma Observation Time

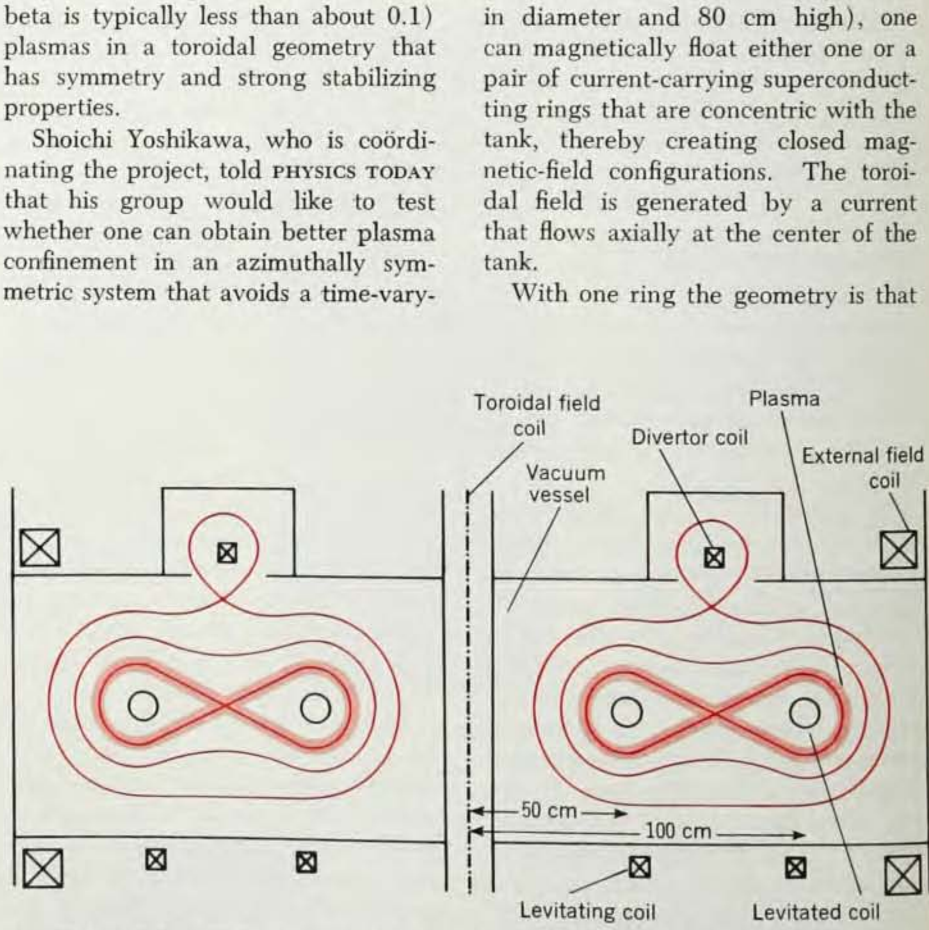
A superconducting toroidal quadrupole is being built at the Princeton Plasma Physics Laboratory. The floating multipole experimental facility will be used to study confinement of low-beta ("beta" is the ratio of plasma pressure to the confining magnetic field pressure, and a low beta is typically less than about 0.1) plasmas in a toroidal geometry that has symmetry and strong stabilizing properties.

Shoichi Yoshikawa, who is coördinating the project, told PHYSICS TODAY that his group would like to test whether one can obtain better plasma confinement in an azimuthally symmetric system that avoids a time-varying magnetic field, attempts to minimize field imperfections and minimizes neutral gas background.

Expected to cost approximately \$2.5 million, the quadrupole device should be ready for experiments at the start of 1970, Yoshikawa said.

Inside the vacuum tank (300 cm in diameter and 80 cm high), one can magnetically float either one or a pair of current-carrying superconducting rings that are concentric with the tank, thereby creating closed magnetic-field configurations. The toroidal field is generated by a current that flows axially at the center of the tank.

With one ring the geometry is that



SUPERCONDUCTING TOROIDAL QUADRUPOLE, being built at Princeton, has two rings that are levitated in equilibrium by a feedback-controlled magnetic field. The device will provide several magnetic-field geometries to test plasma confinement.