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MICROWAVE OSCILLATIONS OF CURRENT IN III-V SEMICONDUCTORS.

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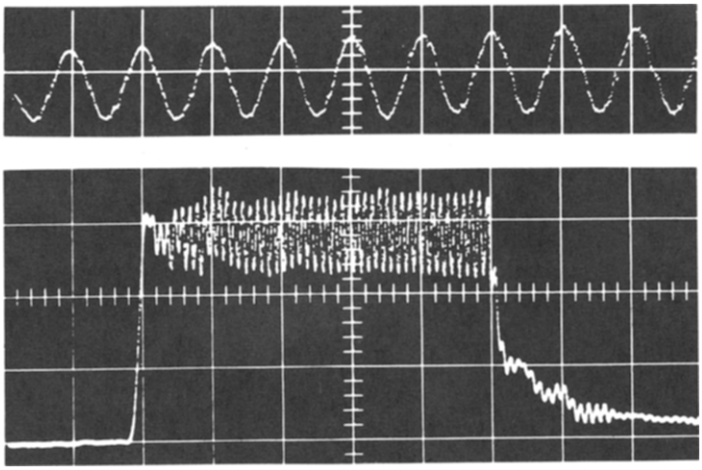
The observation is described of a new phenomenon in the electrical conductivity of certain III-V semiconductors. When the applied electric field exceeds a critical value, oscillations of extremely high frequency appear in the specimen current.

There has been a number of previously reported observations of the generation of electrical oscillations when a current is passed through a homogeneous semiconductor. However, in most of those cases both holes and electrons were present, and in addition a magnetic field,[1] a very low temperature,[2,3] special doping,[4] or a special geometry of specimen[5] was necessary to elicit the effect. In this letter we give a brief preliminary account of a new phenomenon, in which the application of a high electric field to a homogeneous body of a III-V semiconductor gives rise to strong oscillations of current, with frequency in the microwave range. Under the conditions of the experiment (room temperature, zero magnetic field), only electrons are believed to be present.

A number of specimens was made from each of two different crystals of n-type GaAs, and from two of n-type InP. These were cut in the form of thin discs, and "ohmic" contacts were made by alloying a suitable metal (Sn for GaAs, In for InP) to the flat faces of the specimens. The cross section was then reduced somewhat by grinding, leaving a body of semiconductor in the form of a triangular prism about

5×10^{-2} cm on a side, and of length, between contacts on the parallel end faces, from 2×10^{-3} to 2×10^{-2} cm.



Current waveform produced by the application of a voltage pulse of 16 V amplitude and 10 nanosec. duration to a specimen of n-type GaAs 2.5×10^{-3}cm in length. The frequency of the oscillating component is 4.5 Gc/s. Lower trace: 2 nanosec. cm^{-1} horizontally, 0.23 A cm^{-1} vertically. Upper trace: expanded view of lower trace.

The current-voltage characteristics of these specimens, when measured with 10^{-8}sec. pulses, were approximately linear, the resistance rising slightly as the voltage was increased. Above some critical voltage, corresponding to an electric field of 2000-4000 V cm^{-1}, the current in every specimen became a fluctuating function of time. In the GaAs specimens, this fluctuation took the form of a periodic oscillation superimposed upon the pulse current. An example is shown in the figure. The frequency of oscillation was determined mainly by the specimen, and not by the external circuit; values from 0.47 to 6.5 Gc/s were observed on different specimens. It was established that the period of oscillation was usually inversely proportional to specimen length and closely equal to the transit time of electrons between the electrodes, calculated from their estimated velocity of slightly over 10^7cm sec. $^{-1}$.

No significant effects of crystal orientation, resistivity (in the range 0.1 - 5 Ω cm) or temperature were observed. Subsidiary experiments have established that the effect is associated with the bulk semiconductor, and not with the contacts. In most of the InP specimens, only sudden changes or random fluctuations of current were observed, but in one case coherent oscillation at 2.7 Gc/s was observed.

The peak pulse microwave power delivered by the GaAs specimens to a matched load was measured. Values as high as 0.5 W at 1 Gc/s, and 0.15 W at 3 Gc/s, were found, corresponding to 1 - 2% of the pulse input power. These values would appear to be high enough to make the phenomenon of some technological importance.

The mechanism leading to the oscillations is not yet understood. The fact that the critical electron drift velocity is about 30 times the velocity of sound,[6] and the absence of orientation effects, make it unlikely that the amplification of piezoelectrically active acoustical waves[7] is important. It is possible that the fluctuations of current represent non-linear effects of the amplification of polar optical modes,[8] or of a transfer of electrons to higher minima of the conduction band.[9] Calculation suggests, however, that the observed critical drift velocity of about 10^7 cm sec. $^{-1}$ is several times too small to fit either of these mechanisms, and for the present the question remains open.

Some of this work was presented orally at the June 1963 IEEE Conference on Electron Devices, East Lansing, Michigan, U. S. A.

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On décrit l'observation d'un nouveau phénomène dans la conductibilité électrique de certains semiconducteurs du type III-V. Lorsque le champ électrique appliqué dépasse une certaine valeur critique, des oscillations de fréquence extrêmement élevée apparaissent dans le courant dans l'échantillon.