HOT-CARRIER InSb MICROWAVE MODULATION

The microwave power absorbed by a rod of $p$type InSb in Qband waveguide decreased by up to 9dB when electric fields of up to 126 V/cm were applied to it, probably owing to a hot-carrier effect.

It is well known that the drift velocity of carriers in germanium virtually saturates above electric fields of about 3kV/cm.[1] This property has been used in experimental bulk-effect microwave modulators.[2] The theoretical response time of such modulators would be limited only by the dielectric relaxation time. The main disadvantage of such modulators is the high applied voltage required. Such modulators would be more practicable if other semiconductors in which the drift velocities of the carriers began to saturate at lower fields were available.

Bulk-effect modulation of 8mm microwaves using $p$type InSb as the modulating material has been observed. A rod of $p$type InSb, approximately $6 \times 1 \times 0{\cdot}5$mm in size, was placed centrally in a slot in Qband waveguide parallel to the narrow dimension. One end was soldered with indium to the floor of the waveguide, and the other end projected out of the roof of the waveguide through a tightly fitting slot insulated with p.t.f.e. and had a pulse contact soldered onto it with indium. The rod was cooled to liquid-nitrogen temperature and had a conductivity of about $2 \times 10^{-2}\Omega^{-1}\text{cm}^{-1}$.

When voltage pulses of up to 78V and of 1μs duration were applied to the rod at a rate of 50 per second, the transmitted-power level was seen to change during the applied pulse. From zero to about 33V/cm the transmitted power fell steadily until it was about 3dB down. When the voltage was increased further, the transmitted power increased until, at about 50V/cm, it became greater than the zero-field level. Finally, at about 126V/cm, the transmitted power was about 9dB above the zero-field level. Fig. 1 shows the transmitted-microwave level during the pulse. It will be noticed that, owing to a mismatch between the rod and the pulse generator, the applied pulse is repeated at opposite polarities and decreasing heights. Also the increase in transmitted power is not instantaneous and there is a gradual increase in the power level. The reason for this is not clear; it may be caused by an injected plasma. The increase in transmitted power also takes place during the two succeeding pulses. The standing attenuation in the rod and the low-temperature waveguide system is 15·5dB giving an effective insertion loss of about 6·5dB. The actual insertion loss in the rod itself, when pulsed to saturation drift velocity, is much less than this and should ideally be zero. The present isolation ratio of about 9dB could be improved by using larger pieces of InSb to produce a greater zero-field attenuation.

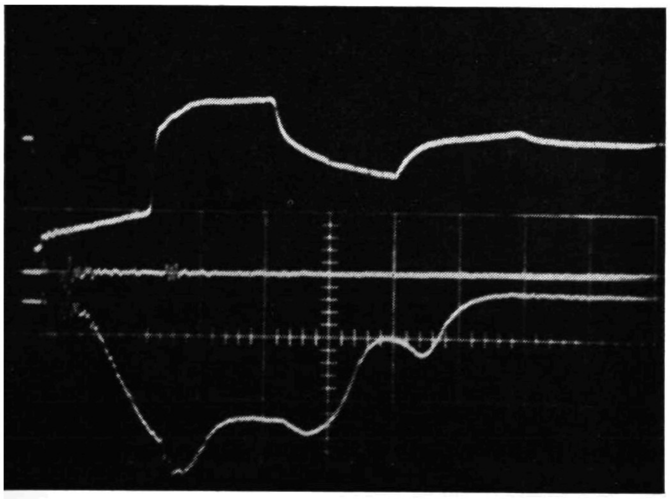

Fig. 1 *Transmitted-microwave level during pulse*

Upper trace: applied voltage pulse; 60V/division
Middle trace: zero microwave level
Lower trace: transmitted microwave level; 0·005 V/division (read downwards for increase)
Time scale: 0·5μs/division

The decrease in the transmitted-power level at the lower voltages could be due to either a warm-carrier effect or an increase of carriers in the rod arising from injection. The polarity of the pulses was negative so that minority-carrier injection would be expected at the contact outside the waveguide. At these low voltages, the injected carriers would not have time to drift into the waveguide before they recombined. If the warm-carrier effect is responsible for the decrease, this would indicate that the dominant momentum-loss mechanism is ionised-impurity scattering.[3] The increase of transmitted power with higher voltages is almost certainly due to a hot-carrier effect. Previous data on high-field conduction in InSb show a possible saturation of drift velocity at about 150V/cm.[4] InSb would thus seem to be a more suitable material than germanium to use as a bulk-effect microwave modulator.

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REDUCTION OF DYNAMICAL SYSTEMS WHEN CERTAIN OF THE ELEMENTS OF THE REDUCED-SYSTEM MATRICES ARE SPECIFIED

The letter describes a method for the reduction of a dynamical system when certain of the elements of the reduced-system matrices are known or specified.

In a recent paper[1] concerning the reduction of dynamical systems it is stated that, ideally, the elements of the reduced-system transition matrix $\phi(T)$ and the driving matrix $\bar{\Delta}(T)$ should be determined so that

$$x^{(r)}\{(k+1)T\} = \bar{\phi}(T)x^{(r)}(kT) + \bar{\Delta}(T)u(kT) \quad . \quad (1)$$

where the vectors $x^{(r)}(kT)$ and $u(kT)$ for $k = 0, 1, 2, \ldots$ are known from the unreduced-system responses. Eqn. 1 is then expanded, for the qth element of the vector $x^{(r)}$ at successive sampling instants, as

$$x_q^{(r)}\{(r+1)T\} = \sum_{i=1}^{r} \phi_{qi} x_i^{(r)}(rT) + \sum_{j=1}^{m} \Delta_{qj} u_j(rT) \qquad (2)$$

in which the ϕ_{qi} and Δ_{qj} are the elements of the qth rows of $\bar{\phi}(T)$ and $\bar{\Delta}(T)$, respectively.

The elements of $\bar{\phi}(T)$ and $\bar{\Delta}(T)$ are then determined from

$$C' = \{\bar{\phi}(T)\bar{\Delta}(T)\} = B'M(M'M)^{-1} \quad . \quad . \quad . \quad (3)$$

where M is a $(k+1) \times (r+m)$ matrix with an $(i+1)$th row given by

$$M_{i+1} = x_1^{(r)}(iT)x_2^{(r)}(iT)\ldots$$
$$\ldots x_r^{(r)}(iT)u_1(iT)u_2(iT)\ldots u_m(iT)$$

and B is formed with columns given by the vectors $b_1, b_2, \ldots, b_q, \ldots, b_r$ where

$$b_q' = [x_q^{(r)}(T)x_q^{(r)}(2T)\ldots x_q^{(r)}\{(k+1)T\}]$$