THE EFFECT OF TEMPERATURE ON L S A OSCILLATIONS BETWEEN 26-40 GHz.

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Investigations have been carried out on the effect of temperature upon L.S.A. oscillations, in the band 26 to 40 GHz. Measurements on n^+-n^{++}-n-n^{+} GaAs 'sandwich' devices have been made over a range of ambient temperatures -50°C to +100°C. To avoid significant temperature gradients within the active 'n' region the pulse length was chosen to be short compared with the thermal time constant of the device (about 1µs) and the mean input power was maintained at a low level.

The results are interpreted with the aid of a computer analysis of the interaction between device and circuit. The simulation considers a realistic device with doping contacts and various random doping fluctuations and attempts to explain some of the essential elements of the experimental performance.

Experimental Results

The n^+-n^{++}-n-n^{++} layers used were made from vapour-phase grown GaAs. The epitaxial layer had a thickness of 9.5 µm, a mean carrier concentration of $2.3_{10}15$ cm^{-3} and a low field mobility of 6160 cm^2/v.s. at 20°C. The material was cut into approximately 0.1mm x 0.1mm squares, giving devices of about 5 ohms low field resistance.

These unencapsulated devices were placed across a ridge section waveguide cavity and pressure contact was made (fig1a). The complete microwave circuit is shown schematically in (fig1b). In some of the ridge cavity configurations used the devices could be mechanically tuned over the range 26-40 GHz by short circuit adjustment.[1] In these non-localised circuits the loading was optimised by an E-H tuner placed many wavelengths from the device. The mode of operation has previously been shown to be a fundamental space charge control mode.[2]

A bias pulse of length 300nS and PRF 100 pps, was applied to the device. When this was increased above the threshold point $V_{th}I_{th}$ (fig2) the sample switched to point V_1I and started oscillating at frequency f. V_1/V_{th} was typically 3 and the current drop $\frac{I_{th}-I}{I_{th}}$ about 0.2 to 0.3.

Fig.2 shows how, as the bias voltage was increased the efficiency increased to a maximum value; further increase of voltage caused a fall off until at voltage V_2 the device stopped oscillating. The values of V_1 and V_2 were to some extent dependent upon the circuit load which was adjustable mainly by the E-H stub tuner. When the sample was at point

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V_2I and just going out of oscillation at frequency f; further adjustment of the E-H tuner caused a switch to a 10% higher current level and oscillation at a lower frequency f′. The efficiency in this new mode was low but comparable with that for the previous frequency signal, at V_2.

As the Ambient temperature was increased V_1, V_2, V_2-V_1, and the maximum efficiency all decreased; whereas the low field resistance increased. (Fig3) shows the variation of these parameters at different temperatures. As the bias voltage approaches the lower cut off point V_1, from above, the frequency drops by typically 50 to 100 MHz and then goes out of high frequency oscillation and switches back to V_{th}. At lower temperatures, i.e. higher values of low-field mobility this frequency fall off occurs at higher voltages. The measured mobility varies from 4600 $cm^2/V.S.$ at 100°C to about 8000 $cm^2/V.S.$ at -50°C.

Computer Analysis - An Interpretation of the Experimental Results

A computer analysis of a device in a simple LCR parallel resonant circuit was programmed for various low field mobilities [3,4] and various doping profiles n(x) were specified as shown in (Fig4). There are two conditions necessary for the L.S.A. mode of operation.[5,6]

(1) Small Signal Condition - that the space charge accumulated per cycle does not exceed a certain value.

(2) Space Charge Control Condition - that there is no net space charge accumulated at the end of each r.f. cycle.

These general conditions will apply whatever the doping profile, however any profile other than uniform will modify the initial space charge accumulation at the start of each cycle. This modifies the allowed values of the growth and decay factors, to maintain conditions (1) and (2), hence the bias voltages and r.f. voltages required for successful operation are also changed. Hasty et al [7] have shown that a profile with a high resistivity layer can modify the I-V characteristic of the device. In many of our devices similar effects were observed; such profiles were analysed and found to modify the operation characteristics in the desired way.

Frequency Variation with Bias Voltage - (fig5)

For lower bias voltages there is a higher space charge growth per cycle - the r.f. voltage is predominantly in the steep negative mobility portion of the v-F. characteristic - resulting in an increased average device capacitance and a fall off in frequency. As the bias increases the frequency rises and levels off at about 36 GHz.

High Current Mode f^1

If the circuit Q is reduced such that the r.f. voltage no longer swings below threshold for a sufficient time to satisfy condition (2). Then the sample no longer oscillates in the 36 GHz mode, but at some lower frequency f^1 in this case 28 GHz. (Fig5) shows this change in operation and it will be seen that the mean current is now about 10% higher. The efficiency is low and probably exists together with a 14 GHz signal as well.

Efficiency Variation with Mobility

(Fig6) shows the variation of efficiency for 3 values of μ_o. It is assumed that these correspond to device temperatures of -30°C, 25°C, and 110°C. The doping profile used here had a 10% random doping fluctuation about a mean of $2_{10}15$. The maximum efficiency attained was about 13% at a bias voltage of 9.5 volts at μ = 7500 cm^2/volt sec. as μ is decreased the maximum efficiency drops and the operating voltage range diminishes.

The effect of larger doping inhomogeneities in the sample is too cause an even higher initial space charge accumulation. In practice this means that operation is not obtained until the circuit Q is high enough to limit the space charge growth to a reasonable value required by condition (1). (Fig7) summarises the basic limiting factors of the effect of doping profile on output. Superimposed on the curve is the experimental one showing that a high Q is needed before successful operation is attained.

Conclusions

It has been shown that the combined effects of uniform temperature and doping fluctuations can severely limit the efficiency and mode of operation. The high ambient temperatures cause a reduction in the peak to valley ratio and thus maximum attainable efficiency - however this now occurs at a lower bias voltage.

The doping fluctuations aggravate the situation by requiring a high bias voltage before a high frequency control mode is possible - and then at a much reduced efficiency. This means that even under pulsed conditions breakdown may occur before output is achieved. The cavity Q must be sufficiently high to ensure control of space charge.

With such doping profiles; CW operation not only causes reduction in the peak to valley ratio because of device heating, but the irregularities would enhance the already significant temperature gradients across the active layer. Further, the higher bias voltages required increase the heat sinking problems.

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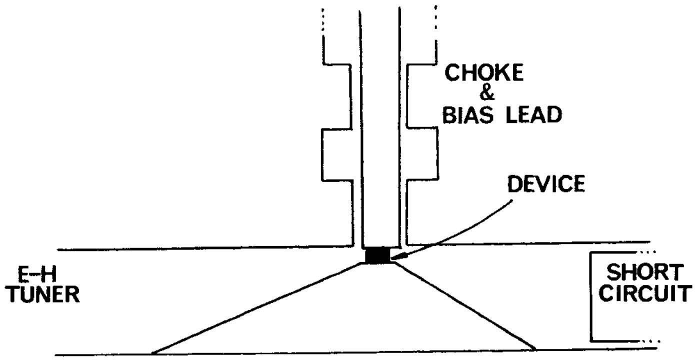


FIG 1a

TUNABLE RIDGE CAVITY

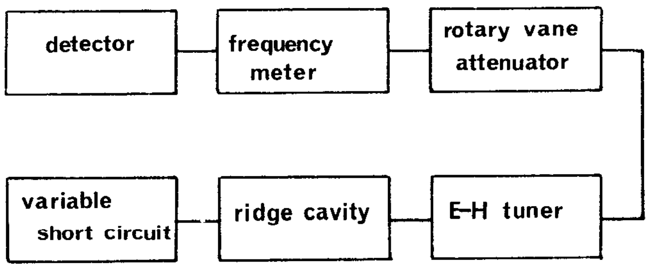


FIG. 1b

COMPLETE CIRCUIT

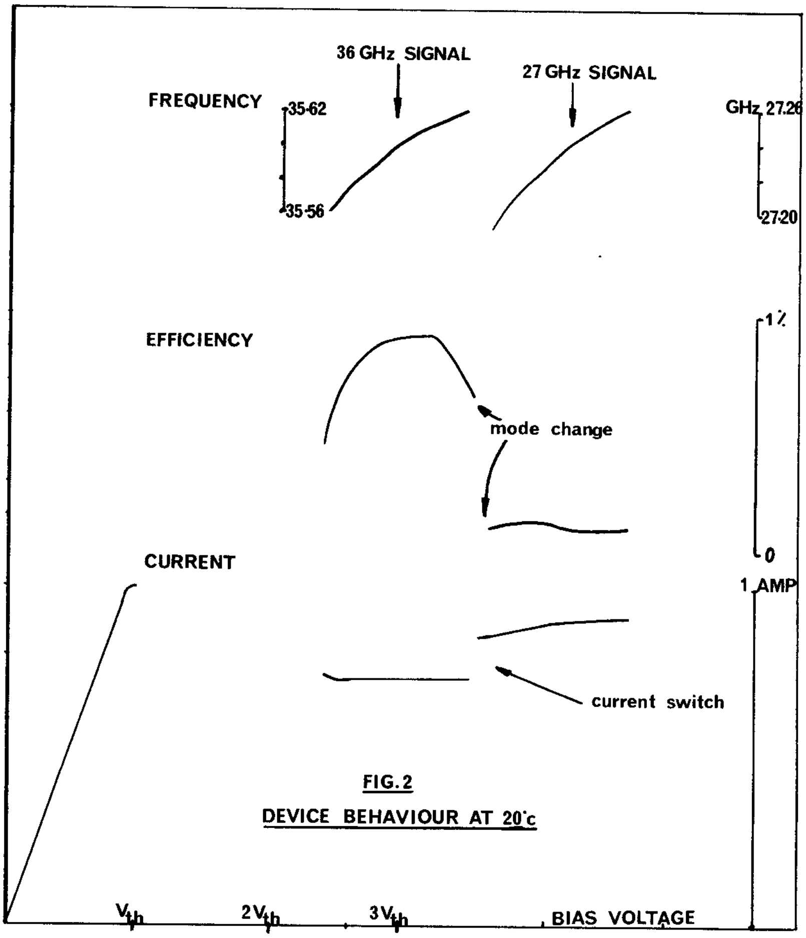


FIG. 2

DEVICE BEHAVIOUR AT 20°c

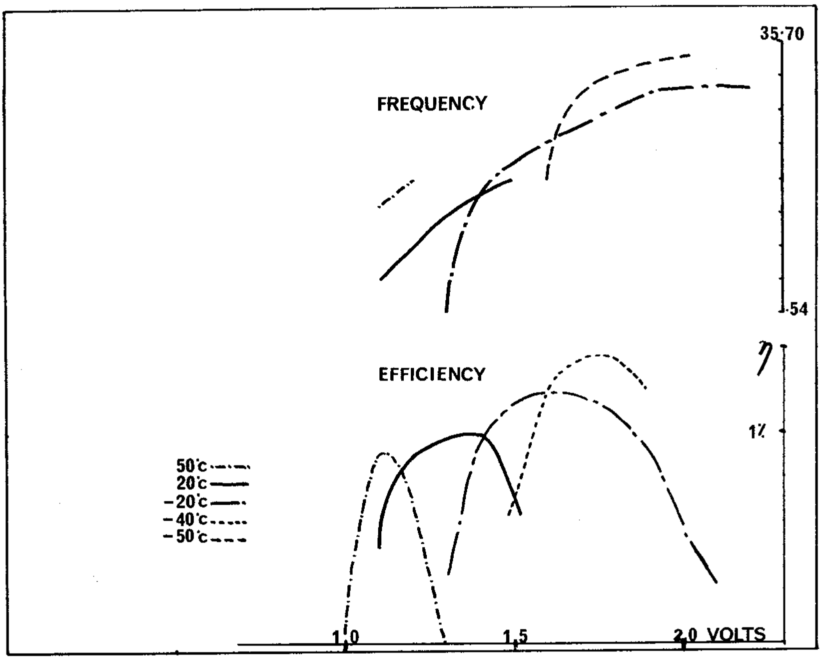
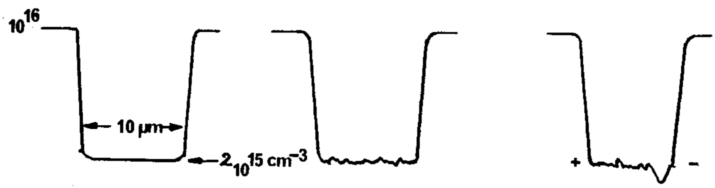


FIG. 3 THE VARIATION OF FREQUENCY AND EFFICIENCY WITH TEMPERATURE



(a) Uniform n (b) 10% Random Fluctuation (c) Doping Notch

FIG. 4 FORM OF N(x) CONSIDERED IN THE ANALYSIS

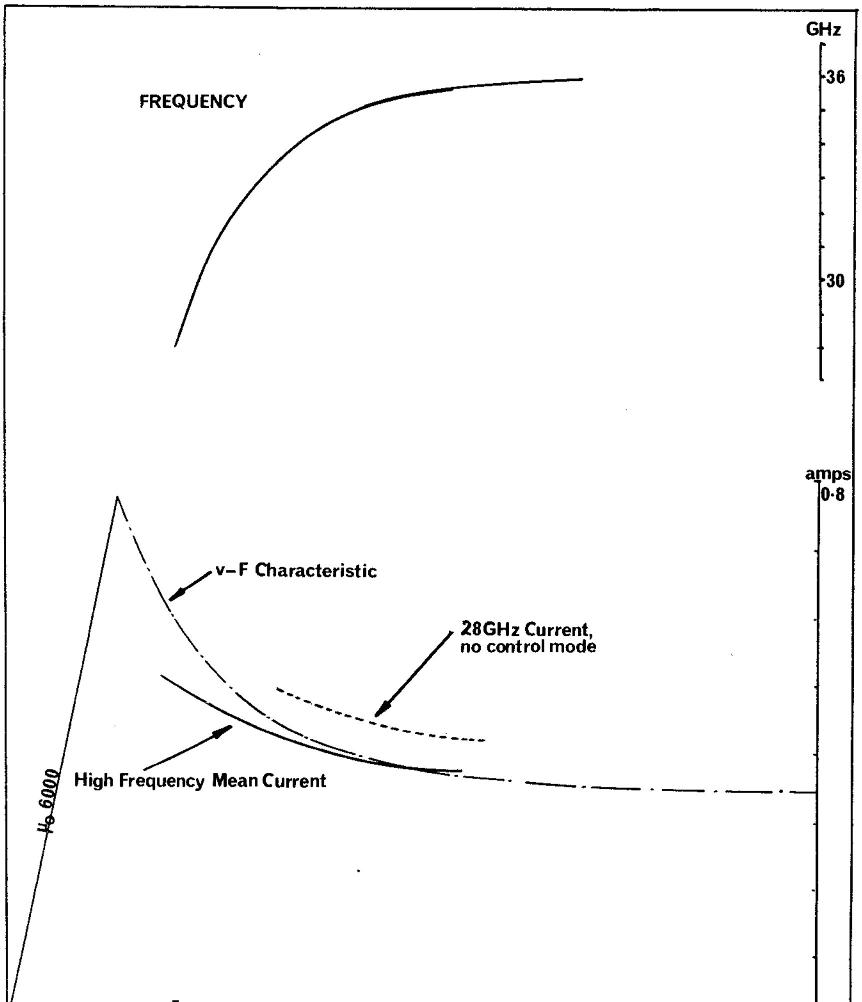


FIG. 5 COMPUTED RESULTS OF FREQUENCY & MEAN CURRENT $\mu_o = 6000$

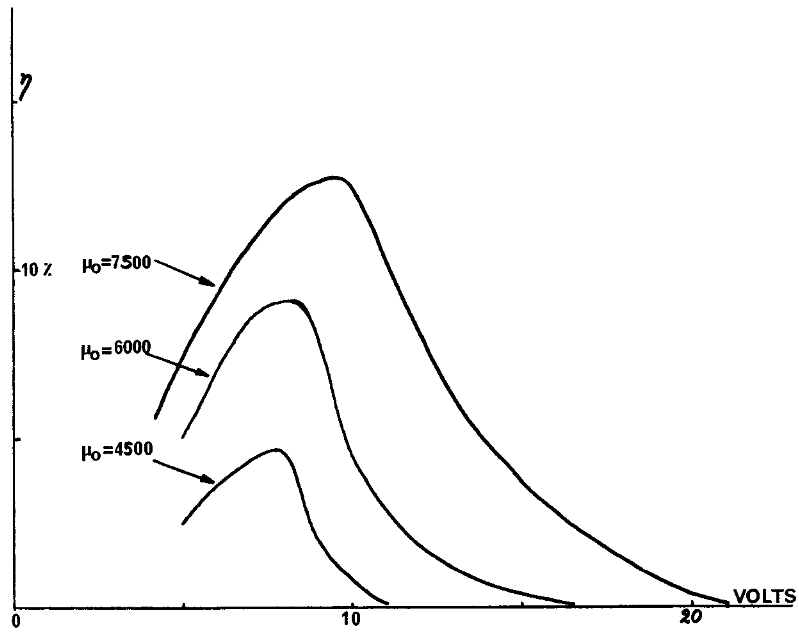


FIG. 6 COMPUTED EFFICIENCY Vs MOBILITY

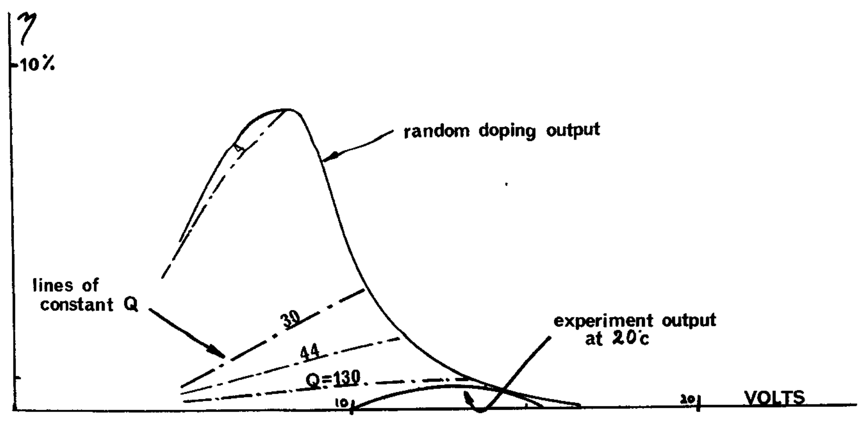


FIG. 7 A COMPARISON OF COMPUTED AND EXPERIMENTAL RESULTS