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STABLE AMPLIFICATION AND HIGH CURRENT DROP BISTABLE SWITCHING IN SUPERCRITICAL GaAs TEDs

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ABSTRACT

Bistable switching with current drops of 40% and switching times of 100 ps are obtained in pulsed operation of 10μm supercritically doped n^+nn^+ GaAs Transferred Electron Devices (TEDs). When CW-operated the same devices exhibit a 5-17 GHz bandwidth for the stable negative resistance.

1. INTRODUCTION

The purpose of this paper is to demonstrate theoretically and experimentally that the same 10μm supercritically doped n^+nn^+ GaAs TED can be CW-operated as a stable reflection type amplifier and a well-behaved oscillator or in pulsed operation as a fast bistable switch. The paper emphasizes that bistable switching with current drops of 40% and negative resistance bandwidth from 5-17 GHz have been obtained from GaAs TEDs that 1) have n^+nn^+ sandwich layers grown by liquid phase epitaxy 2) active layer thicknesses about 10μm and 3) doping densitites in the 2-4 x $10^{15}cm^{-3}$ range.

2. BISTABLE SWITCHING

Bistable switching has been predicted theoretically [1], and verified experimentally [2]. In the interest of clarity Fig. 1 shows results obtained from a large signal computer simulation of a device having the lattice temperature T_o = 300°K, the doping level n_o = 4.0 x $10^{15}cm^{-3}$, the active layer length L_a = 10μm, the low field resistance R_o = 5Ω and a flat doping profile. When the device voltage exceeds the threshold

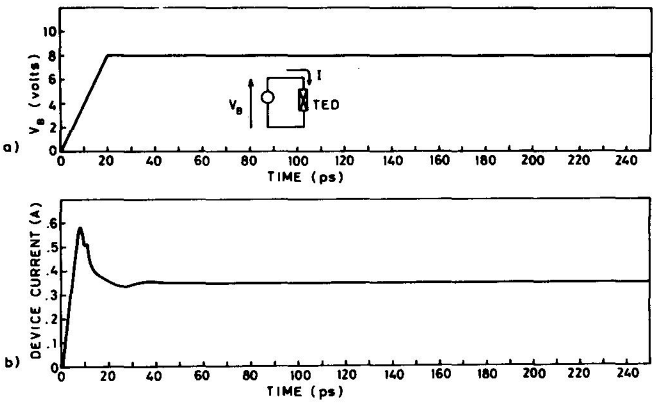

Fig. 1. (a) Applied voltage vs. time used in computer simulations of n^+nn^+ TED. (b) Corresponding device current I vs. time. Device data: T_o=300°K, n_o=4.0 x $10^{15}cm^{-3}$, L_a=10 m, R_o=5Ω, flat doping profile.

voltage a fast current drop occurs due to the formation of a stable anode domain.

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The calculation suggests that for a doping level of $4 \times 10^{15} cm^{-3}$ and doping gradients smaller than 30% current drops of 40% are possible. Moreover, for these high doping levels the domain tends to form right at the anode implying that switching times of 30 ps - i.e. substantially smaller than the domain transit time [3] - should be possible.

In the experiments packaged devices were mounted in the center conductor of a 7 mm coaxial air line and operated into a series coupled resistive load. The current and voltage waveforms were displayed on an 18 GHz sampling oscilloscope. The devices were operated pulsed and in order to avoid heating pulse lengths of 20-100 ns at repetition rates of 50-100 Hz were used. Fig. 2 shows a block diagram of the circuit used to measure the device current and the voltage across the device and the load. This voltage will in the following be denoted by the total voltage. For a 25Ω resistive load measured waveforms are shown in Fig. 3, where the current switches to a value 41.5% lower than the maximum current of 400 mA at threshold. The measured switching time was about 110 ps. The device remains in the high voltage-low current state throughout the pulse. In this state a high field domain is frozen at the anode as discussed above.

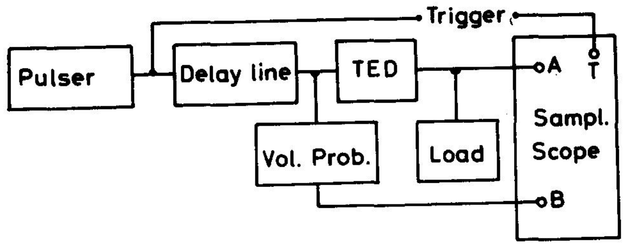

Fig. 2. Circuit block diagram for measuring waveforms of bistable n^+nn^+ TED. Channel A records device current, channel B total voltage across TED and load.

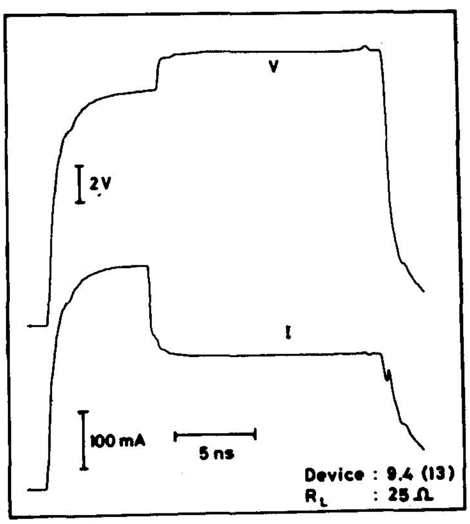

Fig. 3. Measured waveforms for device current and total voltage for the case of 41.5% current drop using the circuit in Fig. 1.

It is well known that the average current in a transferred electron device drops when the device starts oscillating. However, in the measurements described above no microwave oscillations were observed on the extended time scale of the sampling oscilloscope in the high voltage-low current state. Consequently no large amplitude current oscillations - with a non sinusoidal waveform resulting in a 41.5% decrease of the average current - are present. The possible existence of small amplitude oscillations at the transit time frequency or any higher frequencies up to 18 GHz was investigated using the circuit shown in Fig. 4. In the set-up in Fig. 2, 30 dB of attenuation in front of channels A and B was necessary because of the dc components of the signals. Improved RF sensitivity is obtained from the set-up in Fig. 4, where 18 dB, 3-18 GHz directional couplers D.C. 1 and D.C. 2 were used to decouple the dc components and to couple the RF components of the device current and the total voltage to the sampling oscilloscope.

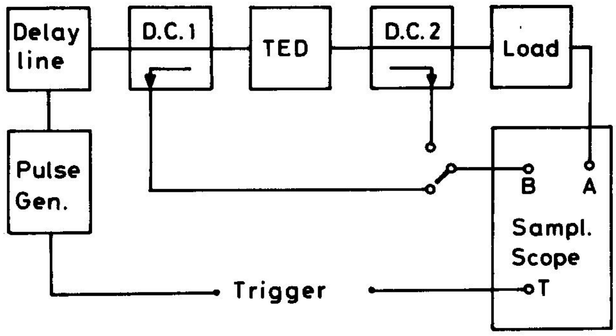

Fig. 4. Circuit block diagram for stability check. Channel A records device current, channel B RF voltage from D.C. 1 or RF current from D.C. 2.

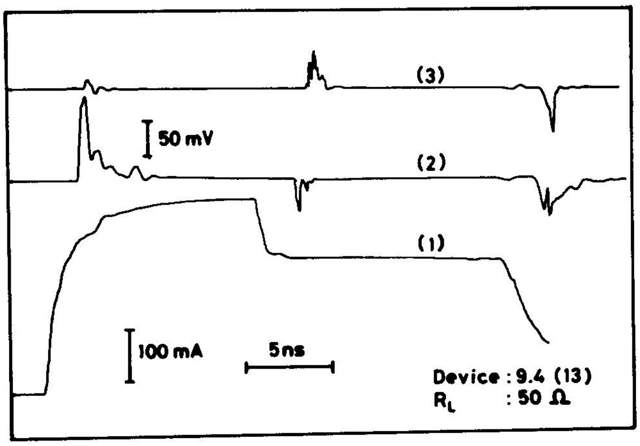

Fig. 5.
Typical recorded waveforms from stability check using the circuit in Fig. 3. (1) Device current at channel A, (2) RF current from D.C. 2 at channel B and (3) RF voltage from D.C. 1 at channel B.

The results are illustrated in Fig. 5. Here trace (1) shows the device current as discussed above. In trace (2), illustrating the RF current from D.C. 1, the positive spike to the left is a replica of the bias pulse rise-time and the negative going spike in the middle of the trace indicates the switch-on of the device to the high voltage-low current state. The fall of the bias pulse is shown by the negative going spike to the right, where the superimposed small positive peak indicates the switch-back of the device to the low voltage-high current state as was discussed in the above section. No other RF signal is detected and hence no microwave oscillations exist in the high voltage-low current state. Trace (3) illustrates the RF voltage obtained from D.C. 1. The presence of only two opposite polarity spikes occuring at the switching instants gives further evidence for the stability of the state above threshold.

3. STABLE AMPLIFICATION, OSCILLATION AND BISTABLE SWITCHING

Typical 10µm n^+nn^+ GaAs TEDs doped in the 1-2 x $10^{15}cm^{-3}$ range have been CW-operated as stable reflection type amplifiers and - when the device is loaded with a resistance less than the small signal negative resistance at the series resonant frequency of the packaged device - as a well behaved oscillator the properties of which can be derived from the amplifier characteristics [4]. Further experiments with those moderately doped devices have shown, that they also exhibit bistable switching with a 10% current drop, which is in good agreement with theory for these doping levels. The presence of the bistable switching marks the differenc between the n^+nn^+ devices used in this work and the large doping notch devices, that are also being used in stable amplifiers [5], [6].

When the doping level is increased from 1-2 x $10^{15}cm^{-3}$ and up to 4 x $10^{15}cm^{-3}$ the current drop associated with bistable switching increases theoretically and experimentally from 10% to 40% as discussed above. The small signal admittance of such a high current drop switch has been measured in CW-operation on an automatic network analyzer. A typical chip admittance corrected for package parasitics is shown in Fig. 6 for a bias voltage $V_B = 9$ V. A ratio of 3.5:1 between upper and lower frequency for the negative conductance is observed. Such new, broad experimental bandwidths agree well with the large bandwidths that have been predicted theoretically for stable n^+nn^+ devices having a high field domain at the anode [7], [8].

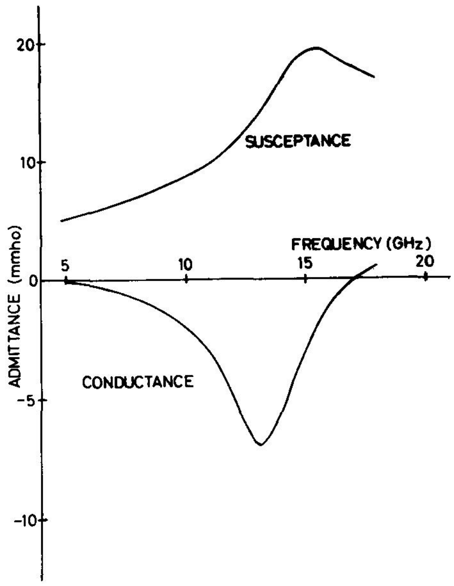

Fig. 6. Measured small signal chip admittance vs. frequency of n^+nn^+ TED in CW-operation.
Device data:
$n_o = 4 \times 10^{15} cm^{-3}$, $L_a = 10 \mu m$,
$V_B = 9V$, $R_o = 10\Omega$, cathode at substrate.

4. CONCLUSION

In the present investigation of 10µm, n^+nn^+ GaAs TEDs it has been shown experimentally and theoretically that:

1. Bistable switching with 40% current drop and 100 ps switching time can be achieved experimentally and interpreted theoretically for heavily doped devices. These new high current drops and the short switching times should contribute to the usefulness of the bistable switch in high speed pulse applications such as optical PCM systems [9].
2. The same moderately doped device can be operated as a stable reflection type amplifier, a well-behaved oscillator or a low current drop bistable switch. The close amplifier-oscillator relation allows the oscillator behaviour to be predicted from the amplifier characteristics - a feature that facilitates the design of TEOs.
3. Heavily doped devices possess a negative resistance in bandwidths of about 3.5 octaves. Such new, broad bandwidths may be of interest for applications in ECM systems and in low cost, multi-octave sweep oscillators.

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