# A STUDY OF HIGH POWER PULSED LSA GaAs DEVICES*

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## Introduction

Some properties of high power pulsed GaAs diodes operated in the LSA-mode [1] have been investigated. The present study involves both boat grown, here referred to as "bulk", as well as epitaxial GaAs. The quality of epitaxial GaAs is higher than the quality of bulk GaAs, especially with respect to random doping fluctuations and compensation of carriers. In the case of LSA operation fluctuations in doping density requires light loading of the oscillator in order to prevent formation of high field domains resulting in lower efficiencies. The compensation of bulk GaAs gives rise to a negative temperature coefficient of resistivity which severely limits the operation at high duty cycles or over wide temperature ranges. However, as of yet no epitaxial GaAs is available with thicknesses suitable for very high peak power LSA diodes, bulk material has been partly used in the present investigation to demonstrate the power capabilities and operating conditions of LSA diodes. Some recent results with epitaxial GaAs diodes operated in thick waveguide iris circuits are discussed in the latter part of the paper.

## Bulk LSA Diodes In High Impedance Circuits

Diodes of bulk GaAs were operated in the long post structure across the X-band waveguide shown in the upper part of Fig. 1. The diodes were mounted near the broadband low impedance wavetrap, i.e. flush with the top of the waveguide wall. This wavetrap presents a good short to frequencies below L-band. A slide screw tuner and a sliding short were used for optimization of power at X-band frequencies.

It was observed by Chilton and Kennedy [2], when operating LSA diodes in X-band that simultaneous subharmonic oscillations occurred below the cut off of the waveguide. These low frequency oscillations were investigated by using a coupling loop through the waveguide wall near the diode. The dependence of os-

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cillation frequency on bias voltage were studied and this voltage dependence is shown in the lower curve in Fig. 2. The curves in Fig. 2 are plotted for a 7Ω diode, 150 μm thick, (corresponding to a threshold voltage of 50 volts), and with a doping density of $5x10^{14}cm^{-3}$.

It is seen that the frequency increases very fast with increasing voltage but tends to saturate at about 5 times the threshold voltage. It should be noted already here that at a bias voltage around 125 volts the fourth harmonic of this low frequency oscillation gets above the cut off of the X-band waveguide. This will be discussed in more detail later.

The geometry of the waveguide was varied and the frequency versus voltage curves were measured. As is shown in Fig. 2, it was found that decreasing the width as well as the height of the waveguide moved the curves up to higher frequencies. The width was decreased by 17% and 33% and the height was reduced by 33% in the respective curves shown in Fig. 2.

The waveguide is below cut off for the low frequency oscillation, which thus is unaffected by any movable short circuit or other variable impedance circuit. Consequently, the electric fields are confined within a short distance of the cross section of the post across the waveguide. Then the post supporting the diode forms an inner conductor and the two side walls of the waveguide form a slab line. This slab line is short circuited by the bottom of the waveguide. An equivalent diagram of the waveguide circuit below cut off is shown in the lower portion of Fig. 1. The LSA diode is in series with the impedance of the wavetrap, $Z_{WT}$, and the resonant circuit is formed by a short circuited transmission line which is a quarter wavelength long at 7.5 GHz. The characteristic impedance of this transmission line in an unmodified X-band waveguide is about 200Ω.

LSA oscillators operated in high impedance transmission line circuits have been simulated in a digital computer by P. Jeppesen and the author [3] showing excellent agreement with the above presented results. The oscillations exhibits the properties of relaxation oscillations and are similar in nature to tunnel diode relaxation oscillations in high impedance circuit.

I was shown in Fig. 2, that in the case of a 150 μm, 7Ω diode the fourth harmonic of the low frequency fundamental LSA oscillation could be raised above the cut off of the waveguide for a certain voltage. Limitations in contact and material quality has prevented enough bias voltage to be applied on 4-5Ω diodes above a thickness 500μm for this shift of harmonic to occur. Recently however an improved contacting procedure made it possible to apply voltages up to nine times the threshold voltage across thick bulk diodes of resistivities below 2Ω cm. A summary of the best results obtained to date with bulk diodes in L-band (fundamental frequency), S-band (second harmonic) and X-band (fourth harmonic) when operated in the circuit of Fig. 1, are shown in Table 1.

TABLE 1

| f (GHz) | P (W) | $V_B/V_T$ | n/f ($x10^5 s/cm^3$) | nxL ($x10^{13} cm^{-2}$) | tp (ns) | η (%) |
|---|---|---|---|---|---|---|
| 7.0 | 1450 | 8.2 | 1.5 | 5.3 | 100 | 5.1 |
| 7.0 | 2100 | 6.9 | 1.0 | 4.6 | 100 | 4.0 |
| 1.75 | 6000 | 7.8 | 3.6 | 3.5 | 50 | 14.6 |
| 3.50 | 3000 | 7.8 | 1.8 | 3.5 | 50 | 7.3 |

Here f = operating frequency, P = output power, $V_B$ = applied voltage, $V_T$ = threshold voltage, n = doping density, L = sample thickness, tp = pulse length and η = DC to RF conversion efficiency. The power in the low frequency oscillations was obtained by coupling out through the waveguide wall and using a double stub tuner as a matching element.

## Some Aspects on Operating Conditions for LSA Diodes

It should be noted that the doping to operating frequency ratios, n/f, for the diodes presented in Table 1 are all substantially higher than the normally considered upper limit of $2x10^5$ $s/cm^3$ for LSA operation [1]. The ratio of n/f for the diode yielding 1450W at the fourth harmonic is as high as $6.0x10^5 s/cm^3$ at the fundamental LSA frequency. However it has been shown by P. Jeppesen and the author in a computer simulation of twice oversized LSA diodes operated in a multi-resonant circuit that the LSA mode can be extended to n/f ratios as high as $10x10^5$ $s/cm^3$ [4]. The important conclusion being that efficiencies and ranges of n/f for LSA operation are strongly determined by the RF voltage wave shape across the diode. Circuits supporting the odd harmonics of the fundamental frequency provide a fast rise-time RF square wave voltage across the diode. In such a case the electric field in the diode very fast passes the region of the velocity-field curve with high negative differential mobility and effectively prevents formation of high field domains even for high ratios of n/f.

In the mode of oscillation for bulk diodes described above in high impedance circuits the growth of high field domains is prevented by a fast varying voltage across the diode. The high impedance short circuited transmission line is a suitable circuit for operation of many times oversized bulk diodes with high nxL products and with random doping fluctuations. As the impedance of the transmission line determines the dynamic load line for the diode, the RF voltage across the diode increases fast to a high value, where the negative differential mobility is zero, as soon as the applied voltage reaches threshold. The wave that is sent out on the line at this moment will be reflected at the short and when it again reaches the diode the voltage across the diode will be swept down below threshold. The voltage must stay below threshold long enough for any accumulated space-charges to decay. This time period is controlled by the applied DC voltage and the mismatch between the diode low field impedance and the impedance of the line.

An important conclusion is that the starting conditions for the LSA diodes are primarily set by the dynamic impedance of the circuit. Thus LSA-oscillations will start as soon as the applied voltage across the diode reaches threshold. The rise-time of the pulser becomes less important, which also has been experimentally verified by using a Velonex pulser with a rise-time above 25 ns.

Epitaxial LSA Diodes

Results obtained with epitaxial LSA diodes in coaxial double slug resonators for L-band and waveguide iris-circuits for X- and $K_A$-band are summarized in Table 2.

TABLE 2

| f (GHz) | P (W) | n/f ($\times 10^5$ s/cm$^3$) | nxL ($\times 10^{13}$ cm$^{-2}$) | $\eta$ (%) |
|---|---|---|---|---|
| 1.6 | 130 | 3.5 | 0.3 | 16.5 |
| 9.3 | 20 | 2.0 | 1.2 | 10.0 |
| 33.0 | 20 | 0.6 | 1.2 | 5.0 |

The waveguide iris circuit is schematically shown in Fig. 3. By contacting these diodes by the solution regrowth method efficiencies were improved and average powers up to 75 mW have been obtained.

References


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4. P. Jeppesen and B.I. Jeppsson, "Computer Simulation of LSA Oscillators with High Doping to Frequency Ratios," Proc. IEEE, to be published.


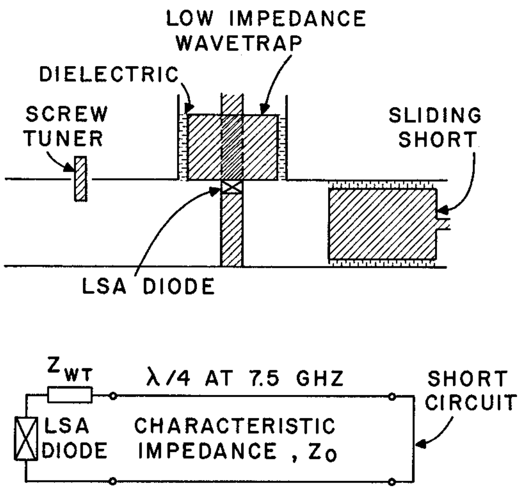


Fig. 1 X-band waveguide circuit used for operation of thick bulk GaAs diodes, upper part. Simplified equivalent circuit for oscillations below cut off of the waveguide, lower part.

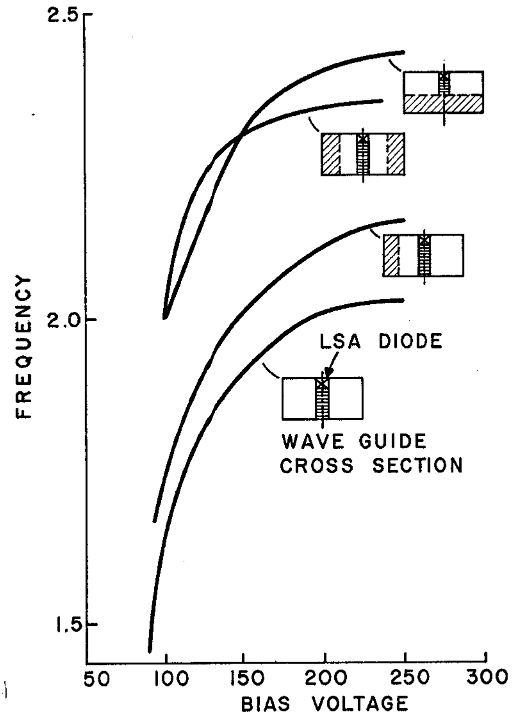


Fig. 2 Frequency versus applied voltage curves for the low frequency fundamental LSA oscillation below cut off of the X-band waveguide. The changes in width and height of the waveguide corresponds to changes in characteristic impedance and length respectively of the transmission line shown in Fig. 1.

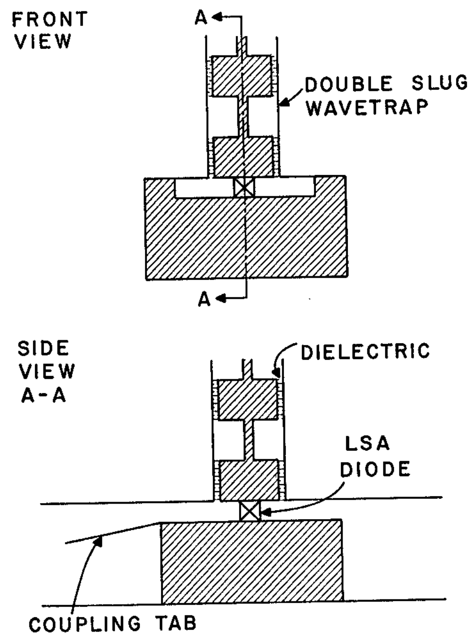


Fig. 3 Thick iris circuit with coupling tab used for operation of epitaxial GaAs diodes in X and $K_A$-band.