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200 GHz Tunnett Diodes

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Introduction

The transit-time negative resistance diode was proposed by Y. Watanabe and J. Nishizawa in 1953[1] before Schockley in 1954. J. Nishizawa and Y. Watanabe proposed the transit-time negative resistance diode using the tunneling effect as a injection mechanism in 1958[2]. With the development of the semiconductor technology, the impact ionization avalanche transit time diode (Impatt) and the tunnel injection transit time diode (Tunnett)[3] have been realized experimentally for extremely high frequency application.

The oscillation frequency of the transit-time negative resistance diode becomes higher in inversely proportion to the thickness of the transit region of these devices. Finally the oscillation frequency of the Impatt become to be limited by the avalanche builed-up process, which has been neglected for a long years. When the thickness of the generating layer becomes narrower, the avalanche phenomenon ceases to occur and then tunnel injection becomes dominant. Hence Tunnett can be thought as the extreme case of the narrowest generating layer thickness which can operate in the highest frequency region. The Tunnett can operate even at the smaller bias voltage and has lower noise than that of the Impatt. Moreover, the f_{max} has been estimated about 1000 GHz[4].

Design

The structure and the principle of the operation of the Tunnett are given in Fig.1. The tunnel injection occurs at $\pi/2$ radian and then the transit angle is $3/2\,\pi$ radian. The drift space Wd is given by $Wd = 3\,v_s/4\,f$, where v_s is the saturation velocity of the carriers and f is the operating frequency. The high electric field in the tunnel injection region and the active layer are neccessitated for efficient operation and for high frequency application, respectively. Some structures and the materials to obtain tunneling effects easily have been proposed such as reverse biased pn junctions, etc[4].

Experiment

At first, gallium arsenide diodes with p^+n and p^+nn^+ structure were fabricated. The epitaxial layer of n and nn^+ GaAs was grown on the (100) p^+ GaAs substrate by a Temperature Difference Method under Controlled Vapor Pressure (T.D.M. C.V.P.)[5]. The carrier concentration (N_D) of the n layer was higher than 5×10^{17} cm^{-3}. The pulse-driven diodes (10μm thickness and $< 1\times10^{-5}$ cm^2) tested in T band with a hat-structure cavity gave the results listed in the Table 1.

The relation between the output voltage of the detector (Vout) and the oscillation frequency (f_{osc}) is shown in Fig.2, as an example. The oscillation were the fundamental mode. The highest oscillation frequency observed is 200 GHz and the maximum electric field (E_{max}) estimated in the junction is about 1650 kV/cm. In general, the temperature coefficient (β) of the I-V characteristic is used to judge the injection mechanism. When β is negative, the injection is thought to be due to the tunnel effect. The value of β changes with the impurity concentration (N_D) in the n layer, and $\beta \simeq 0$ at $N_D = 5 \quad 10^{17}$ cm^{-3} and $\beta < 0$ at $N_D \gtrsim 8 \times 10^{18}$ cm^{-3}. The oscillation performance of the diodes with $\beta < 0$ is superior ~~than~~ to that of the diodes with $\beta \simeq 0$ as shown in Fig.2. Therefore, the Tunnett should be able to operate in much higher frequency region than Impatt.

Conclusion

GaAs Tunnetts with p^+n and p^+nn^+ structure have been fabricated and the maximum fundamental oscillation was obtained at 200 GHz. Much higher frequency oscillation from Tunnett will be obtainable by the introduction of other materials, the improvement of the diode structure and size, and the circuit.

References

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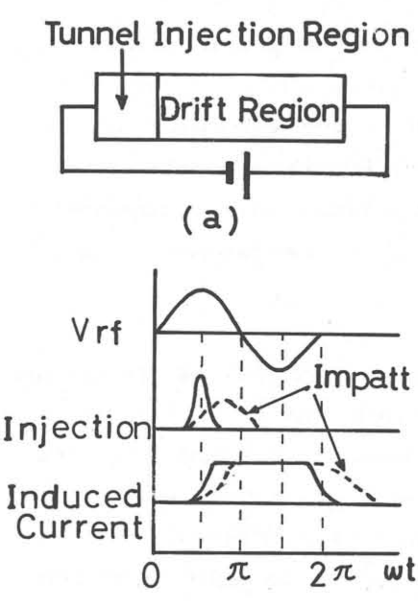

Fig.1 (a) Structure and (b) Principle of operation of Tunnett diodes

Type	N_D(cm^{-3})	β	Threshold Voltage(V)	f_{max}(GHz)	$\mathcal{E}_{max}$(kV/cm)
p^+n	5×10^{17}	$\simeq 0$	-6.5--7.8	130	$\simeq$1150
p^+n	$8-10\times10^{17}$	-	-7 - -10	188	1400~1500
p^+nn^+	1×10^{18}	-	-6.8--7.9	200	1600~1800

Table1 Parameters of the diodes

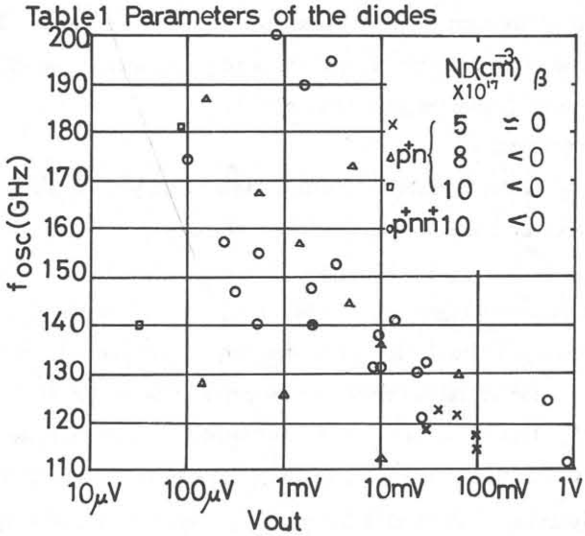

Fig.2 fosc versus Vout