Indian J. Phys. **77A (2)**, 173–175 (2003)

IJPA — AN INTERNATIONAL JOURNAL

A comparative study of ν- and π-type DAR IMPATT diode structures based on InP material

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Abstract A comparative study of small signal and noise behaviour of $n^+p\nu np^+$ (ν-type) and $n^+p\pi np^+$ (π-type) structures of DAR IMPATT diode based on InP material has been made by computer simulation method developed by our group. Both the structures are taken of a fixed width of 800 nm. Multiple peaks for negative conductance and mean square noise voltage are obtained for both type of structures. It is observed that the device negative conductance ($-G_p$) as well as the device negative resistance ($-Z_{R_p}$) for the π-type InP DAR IMPATT diode is much higher than those of the ν-type InP DAR IMPATT diode, both for operation in *W*-band and *D*-band. Similarly, the mean square noise voltage peaks for the π-type InP DAR IMPATT diode are observed to be higher than the corresponding peaks of the ν-type InP DAR IMPATT diode This is obvious because of the fact that the high power generating mechanism also creates a higher noise. However, the π-type InP DAR IMPATT diode can be used for high power performance with a moderate noise by suitably choosing the frequency of operation.

Keywords IMPATT, DAR, noise

PACS Nos. : 85 30.–z, 73 40.–c, 07.50.Hp

1. Introduction

IMPact Avalanche Transit Time (IMPATT) diodes have been used for high power performance at frequencies extending to millimeter wave range. These diodes have many potential applications in military as well as commercial fields. However, the underlying material parameters greatly affect its performance. So research works are carried out on IMPATT diodes based on different materials. InP is one of the Group III-V semiconductors, which has generated revived interest in recent years for fabrication of high frequency devices. Since InP has a wider band gap than Si, the breakdown voltage and hence the output power are expected to be higher for InP IMPATT diodes than those for conventional Si IMPATT diodes. The Double Avalanche Region (DAR) IMPATT diode of the form n^+pinp^+ proposed in [1] has been found to possess some interesting properties where the *i*-region may be replaced by a low doped $n(\nu)$ or $p(\pi)$ region. So we have taken interest for a comparative study on the performance assessment of the $n^+p\nu np^+$ (ν-type) and $n^+p\pi np^+$ (π-type) structures of DAR IMPATT diodes based on InP material using some computer simulation methods developed by us [2,3].

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2. Design consideration

The 1-D schematic diagrams for ν-type and π-type DAR IMPATT diodes are shown in Figures 1 and 2 respectively.

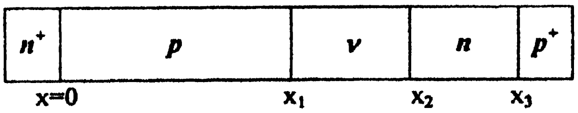

Figure 1. ν-type InP DAR diode.

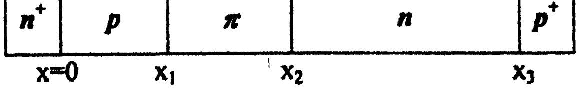

Figure 2. π-type InP DAR diode.

Both the diode structures are taken of fixed width of 800 nm, with 400 nm for the p-side and 400 nm for the n-side. For the ν-type DAR diode, the n-side 400 nm is split into two regions namely the n-region of width 150 nm and ν-region of width 250 nm. Similarly for the π-type DAR diode, the p-side width of 400 nm constitutes two regions of different doping namely the p-region of width 150 nm and the π-region of width 250 nm. The doping concentrations for the n- and p-regions are taken as 1.5×10^{23} m^{-3} and those for the ν- and π-regions are taken as 1.5×10^{21} m^{-3} for an optimal punch through field profile of the diode. The operating current density and the diode area are taken as 5×10^{8} Am^{-2} and 10^{-10} m^2 respectively.

3. Method

For the present study, we have used a set of computer simulation programs developed by our group [2,3]. The method starts with DC analysis for both the diodes. The DC analysis is initiated from the location of field minimum and covers the entire active region solving simultaneously the Poisson's equation, combined carrier continuity equation and space charge equation with appropriate boundary conditions [4]. The results obtained are utilized for small signal analysis. Two second-order differential equations on the diode resistance and diode reactance were solved and the negative conductance ($-G$), susceptance (B) and negative resistance ($-Z_R$) of the diode are determined using the simulation program [2]. Since noise is an important aspect of IMPATT study, we have simulated the mean square noise voltage per bandwidth and noise measure by the help of another computer simulation program [3]. The simulation methods have been made realistic by incorporating experimentally determined material parameters like drift velocities and carrier ionisation rates for InP [5–7]. We have also incorporated realistic doping profiles at the junctions and epitaxy. A more detail on the method can be obtained from [8].

4. Results and discussion

The results obtained from small-signal analysis and noise analysis have been presented in Table 1. The table reveals that the values of the device negative conductance ($-G_p$) and the device negative resistance ($-Z_{Rp}$) at the respective optimum frequencies (f_p) are found to be higher for the π-type InP DAR diode than the corresponding values for the ν-type InP DAR diode. This fact is also reflected in Figure 3 where the negative conductance has been plotted as a function of frequency for the two complementary InP DAR diodes. Further, Figure 3 clearly depicts the existence of multiple conductance bands in a DAR diode. From the small signal properties of Table 1 and Figure 3, it is evident that the π-type InP DAR diode would show superior microwave performance in terms of the power output of the diode.

Table 1. Microwave and noise properties of the ν-type and π-type InP DAR IMPATT diodes.

Diode structure	Band-width in GHz	f_p in GHz	$-G_p \times 10^6$ in S m^{-2}	$-Z_{Rp} \times 10^{-9}$ in Ω m^2	f_{max} in GHz	$(\langle v^2 \rangle/df)_{max}$ in V^2 s
					34	8.0×10^{-15}
ν-Type	80–90	82	4.2	2.1	76	9.1×10^{-15}
	120–196	160	7.6	4.8	110	6.4×10^{-16}
					150	3.4×10^{-17}
					34	8.3×10^{-15}
π-Type	80–88	82	4.7	2.8	78	1.2×10^{-13}
	138–194	156	9.8	6.7	110	7.9×10^{-15}
					152	4.9×10^{-17}

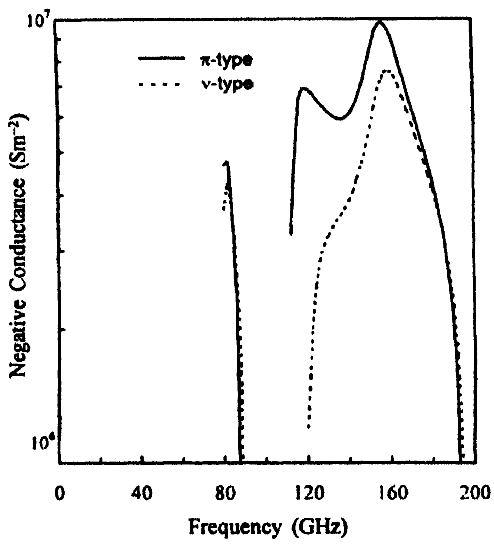

Figure 3. Variation of device negative conductance with frequency for ν-type and π-type InP DAR IMPATT diodes.

The values of peak mean square noise voltage per bandwidth at the respective f_{max} (corresponding to peak of the noise voltage) are also shown in Table 1 for both ν-type and π-type InP DAR diodes. The mean square noise voltage as a function of frequency has been plotted in Figure 4. From Table 1 and Figure 4, it is observed that there exists four mean square noise voltage peaks in the frequency range of 20–200 GHz. Now comparing the peaks of the ν-type and π-type diodes it can be seen that each peak of the π-type InP DAR diode is higher than the corresponding peak of the ν-type InP DAR diode. This indicates that the π-type InP DAR diode would be more noisy compared to the ν-type InP DAR diode. This fact is natural because the very power generating mechanism in a DAR diode is a noisy one.

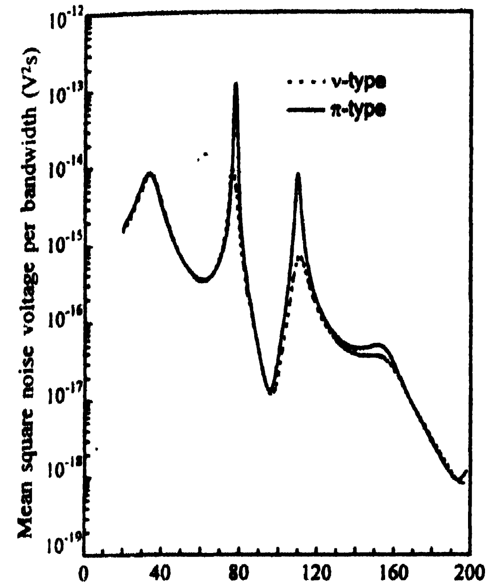

Figure 4. Variation of mean square noise voltage as a function of frequency for ν-type and π-type InP DAR IMPATT diodes.

The noise measure (NM), which is a more important parameter to assess the noise to power ratio, is plotted in Figure 5. It can be observed from this figure that the noise measure for the π-type DAR diode has lower values at all the frequencies in the II band between 110 and 190 GHz. The lowest minimum is observed to be 16.7 dB for the π-type InP DAR diode as against the corresponding value of 17.9 dB for the ν-type InP DAR diode at a frequency of 188 GHz. Thus, although the mean square noise voltage for the π-type InP DAR diode has a higher value, it has a better power to noise relation compared to the ν-type InP DAR diode.

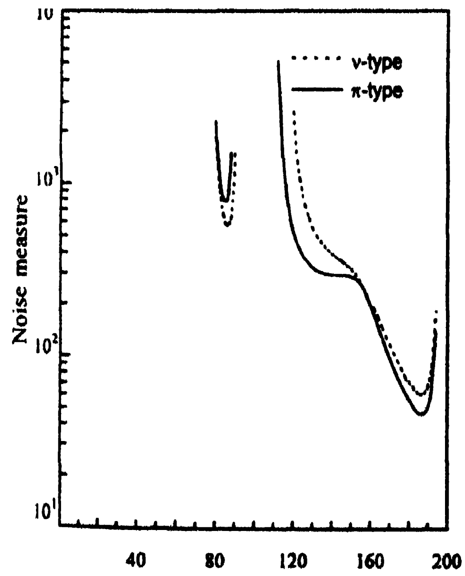

Figure 5. Plot of noise measure as a function of frequency for ν-type and π-type InP DAR IMPATT diodes.

5. Conclusion

The potentials of InP are explored for application as a DAR IMPATT diode. The performances of the two complementary InP DAR IMPATT diodes namely the ν-type and the π-type are assessed. It is observed that the π-type InP DAR diode exhibits better small signal properties leading to higher power performance than the ν-type InP DAR diode. On the other hand, the ν-type InP DAR diode has better noise properties than that of π-type InP DAR diode in terms of mean square noise voltage per bandwidth. However, the π-type InP DAR diode shows better power to noise relation at higher frequencies. Thus, it can be preferred to the ν-type InP DAR diode for better power and lower noise by suitably choosing the frequency of operation.

Acknowledgment

The authors wish to acknowledge the Department of Science and Technology, Government of India for financial support of this work through a major research project (SP/S2/M-12/98).

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