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Research Paper

STUDY OF PARAMETERS OF DIAMOND BASED DDR IMPATT DIODE

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In this paper we have studied the basic parameters of the DDR structure of diamond based IMPATT diode at Ka band. The temperature dependence of carrier mobility and carrier velocity, the variation of generation rate and quality rate with the change in ionization constant are observed. This paper helps to choose the optimal temperature range, as well as quality rate of oscillation.

Keywords: IMPATT diode, Carrier mobility, Carrier velocity, Temperature, Quality rate of oscillation, Generation rate

INTRODUCTION

Generally, wide-band gap semi-conductor materials like Si, GaAs, SiC etc., are chosen as base materials for fabrication of the microwave devices. Similarly for fabricating IMPATT diode 4H-SiC is proven Powell, 1987) to be a better material till now. But the main problem with this material is low breakdown voltages. Diamond can be a better alternative here in this scenario (Mock and Trew, 1989; Hewett and Zeidler, 1992; and Takeuchi *et al*., 2004). Diamond is accepted to have high break down voltages (100-250V) (Robert *et al.*, 1991).

SIMULATION METHOD

The basic parameters of the IMPATT diode which we have considered here are the carrier mobility, carrier velocity, generation rate, quality rate and ionization rate constants. In this simulation we have found out the carrier mobility trend with the temperature changes.The relation between electron mobility and temperature is given by the equations (1) and (2) (Sung Woongje, xxxx).

$$\mu_n = \frac{\mu_{max}(T/300)^{-\alpha}}{1+\left[\frac{N_D+N_A}{N_{ref}}\right]\gamma} cm^2/V.s \qquad ...(1)$$

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μ_n is electron mobility, μ_{max} is mobility of electron at 300K = 2200 $cm^2/V.s$, N_{ref} = 1.94 x 10^{17} cm^{-3}, α = 2.8, γ = 0.61, N_A and N_D are carrier concentrations on both sides, T-absolute temperature.

$$\mu_n = \frac{\mu_{max}(T/300)^{-\alpha}}{1+\left[\frac{N_D+N_A}{N_{ref}}\right]\gamma} cm^2/V.s \quad ...(2)$$

μ_p is whole mobility, μ_{max} is mobility of hole at 300 K = 1800 $cm^2/V.s$, N_{ref} = 1.76 x 10^{19} cm^{-3}, α = 2.8, γ = 0.34.

As the temperature increases atomic vibrations increase resulting in increase of number of collisions between charge carriers and atoms.In this process the velocity of charge carriers decreases. But at higher electric fields the carrier velocity gets saturated. The relation between carrier velocity and temperature is given by the equations (3) and (4) (Aritra Acharyya *et al.*, 2014).

$V_n=V_{ns}[1-\exp(-\mu_n E/V_{ns})]$ for electrons ...(3)

$V_p=V_{ps}[1-\exp(-\mu_p E/V_{ps})]$ for holes ...(4)

V_n, V_p(cm/s)-Velocity of electron and hole respectively, V_{ns} and V_{ps}(cm/s) - Saturation velocity of electron and hole respectively, μ_n, μ_p($cm^2/V.s$)- mobility of electron and hole respectively, E-Electric field(V/cm).

The carrier generation rate and quality rate of oscillation are related to each other in inverse fashion. The relation between the generation rate and quality rate of oscillation is given by (5) and (6) (Joydeep Sengupta *et al.*, 2014)

q = 1/(2g) ...(5)

where q-quality rate of oscillation(sec)

g-generation rate(atoms/s) and

$g = \alpha_n v_{ns} + \alpha_p v_{ps}$ ...(6)

α_n-ionization rate constant of electrons,

α_p-ionization rate constant of holes

DESIGN CONSIDERATIONS

In the simulation of dependency of basic parameters, of diamond the material parameters of the diamond are taken as per the standard shown in the Table 1 listed below. Here ionization constants α_n and α_p are assumed to be of same values (Lawrence S Pan and Don R Kania, xxxx; and Baturin *et al.*, 2010).

RESULTS AND DISCUSSION

The simulation program is used to obtain the mobility and velocity of electrons and holes at different temperatures as shown in Tables 2 and 3 and Figue 1. Also the carrier generation rate and quality rate of oscillation are dependent factors on the ionization constant values Table 4 and Figure 2(c) and (d).

Table 1: Material Parameters Standard Values

V_{ps}	V_{ns}	ϵ_r	μ_p	μ_n	J_0
1.829x10^7cm/s	1.981x10^7 cm/s	5.7	1800 $cm^2/V.s$	2200 $cm^2/V.s$	5x10^4A/cm^2

Table 2: Calculation of Electron and Hole Mobility at Different Temperatures

Absolute Temperature (T)	Electron Mobility, μ_n		Hole Mobility, μ_p	
	Dopping Concentration			
	Higher	Lower	Higher	Lower
300	2200	2200	1800	1800
350	487.66	1428.6	891.32	1167.5
400	335.54	982.99	613.28	803.30
450	241.27	706.84	440.99	577.63
500	179.63	526.26	328.33	430.06
550	137.56	402.99	251.42	329.33
600	107.81	315.85	197.06	258.12

Table 3: Calculation of Electron and Hole Mobility at Different Temperatures

Absolute Temperature	Electron Velocity, V_n	Hole Velocity, V_p
300	19798373.74	18289992.66
350	19652163.70	18288718.79
400	19097342.46	18264670.40
450	17996403.84	18129053.23
500	16469496.33	17750712.87
550	14741425.64	17058942.31
600	13004029.45	16083627.70

Table 4: Calculation of Carrier Generation Rate and Quality Rate of Oscillation at Different Ionization Constant Values

Ionization constants value, α_n, α_p	Carrier Generation rate, g	Quality rate of oscillation, q
19.35×10^{7}	73.7×10^{12}	6.78×10^{-15}
46.99×10^{7}	17.9×10^{13}	2.79×10^{-15}
74.63×10^{7}	28.4×10^{13}	1.75×10^{-15}
10.22×10^{8}	38.9×10^{13}	1.28×10^{-15}
12.99×10^{8}	49.5×10^{13}	1.01×10^{-15}
15.75×10^{8}	60×10^{13}	8.32×10^{-16}
18.52×10^{8}	70.5×10^{13}	7.08×10^{-16}

Figure 1: Charge Carrier Mobilities and Velocities Vs. Temp

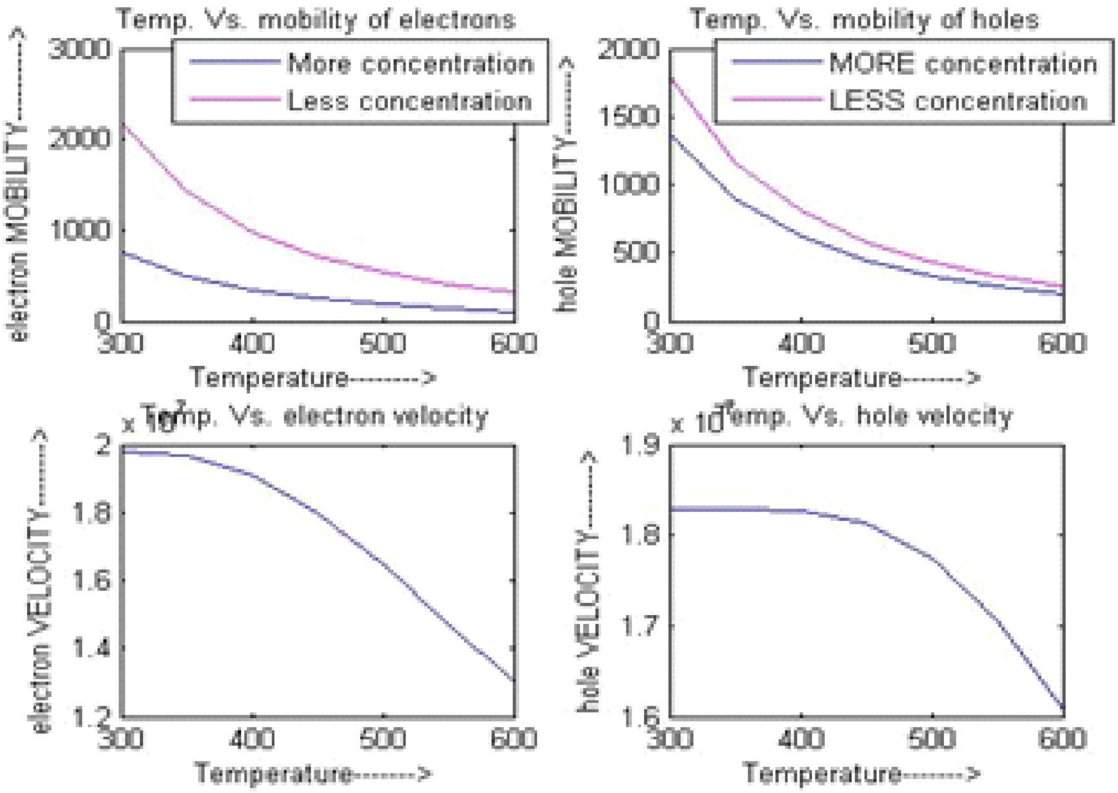
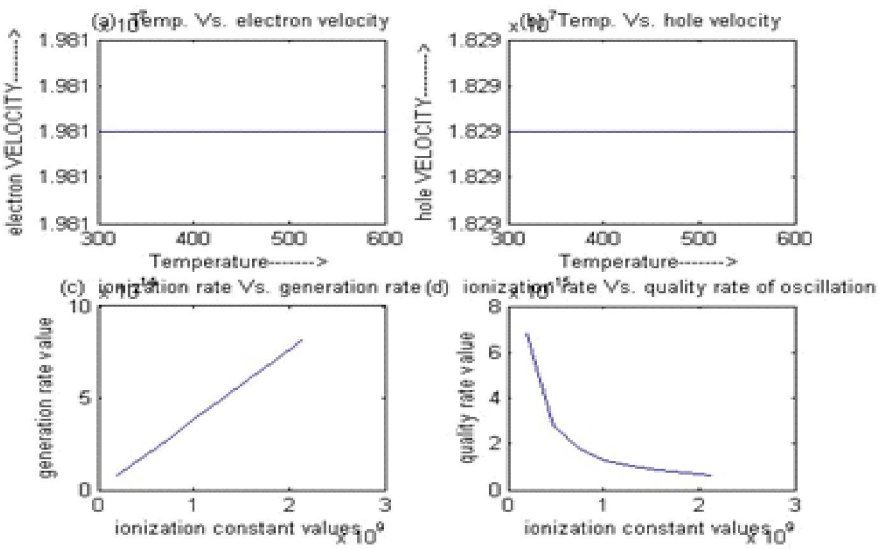


Figure 2(a) & (B): Electron& Hole Velocity Saturated At Higher Electric Field Respectively, Figure 2(c):Carrier Ionization Rate Vs. Generation Rate, Figure 2(d):Carrier Generation Rate Vs. Quality Rate Of Oscillation



CONCLUSION

Diamond is considered to have a wider band gap of 5.5eV (Mock and Trew, 989) compared to other semiconductor materials. Also diamond is proven to have higher breakdown voltages of 100V-200V far larger than the other base materials. And hence diamond is preferred as the base material for fabrication of IMPATT diode. The above results provide the relation between different basic parameters of diamond based DDR IMPATT diode. In case of higher electric field, the carrier velocity becomes saturated and attains the respective saturation velocities of the charge carriers as in Figure 1. In case of the mobility-temperature relation, two different doping concentrations are considered. At higher doping concentrations, we can observe lower mobility as in Figure 1. So the temperature should be maintained optimum not to let mobility to further get lowered. More the number of ionizations take place, more will be the generation rate of carriers. But as the ionization rate increases the quality rate of oscillation decreases and follows an exponential trend with increasing ionization rate. This paper will be helpful in enhancing the performance of the IMPATT by optimizing the temperature, doping concentration, ionization rate and by maintaining proper trade-off.

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