NUMERICAL ANALYSIS OF AN InSb INFRARED RADIATION PHOTODETECTOR

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ABSTRACT

An InSb p-n photodetector was simulated in order to characterize and optimize its performance over the wavelenght range of 3μm to 5μm. Some device parameters such as surface doping, junction depth and passivation (surface recombination velocity) were varied so that the behaviour of the responsivity, quantum efficiency and noise could be studied. The device operates at zero bias condition and at 77K. The results show that better performance both for responsivity and noise are obtained when the junction is shallow and the surface is highly doped and well passivated (low surface recombination velocity).

1. INTRODUCTION

InSb is an efficent material to use for infrared photodetectors especially due to its narrow band-gap (about 0.18 eV) characteristic [1]. These detectors are often operated at 77K to enhance its responsivity and noise performance, while at this temperature, the energy gap changes to approximately 0.23 eV and the threshold wavelength to 5.5 μm. Between 3 μm and 5 μm, the absorption coefficient of InSb varies from approximately 2.10^4 cm^{-1} to approximately 8.10^3 cm^{-1}, and its influence was taken into account in all simulations. In order to study these devices and to suggest improvements in its performance, some simulations were made varying parameters such as doping concentrations, junction depth and passivation levels.

The characteristics chosen to evaluate the device's performance were the responsivity (photocurrent generated per Watt of incident light for a given wavelenght over the surface) and the detector noise.

2. METHODOLOGY

The main structure configuration is a p$^+$n junction with a 1.10^{15} atoms/cm^3 doped substrate (n side) and a 2000 Å p$^+$ layer with a 1.10^{19} atoms/cm^3 doping concentration. The absorption window area is 100 μm^2. It is desired to detect low intensity signals (about 1 μW/cm^2), so the device is chosen to operate at zero bias condition to reduce noise. All the noise data were collected at the frequency of 1 KHz and all the simulations were made using the device simulation program ATLAS [2].

The value of the p$^+$ doping is then varied and a 4 μm wavelength beam is applied over the absorption window. The light irradiance is then varied from 1 to 2 μW/cm^2 and the generated photocurrent was measured. The derivative of the Photocurrent vs Light Irradiance curve gives the value of the device's responsivity. No reflections on the surface were considered during the simulations, altough they could be considered and minimized by using an antireflection coating.

The same procedure can be applied to measure the responsivity when the junction depth and the surface recombination velocity (s) are varied.

Noise simulations were also performed to verify the total noise behaviour when the previously mentioned parameters were changed. Details about the numerical methods of these simulations can be found on [1].

3. DISCUSSION OF RESULTS

Simulations show that an increasing the p$^+$ doping concentration and decreasing the junction depth result on higher values of responsivity and quantum efficiency (see Figure 1). This is a well-known result for pn photodetectors. Higher values of p$^+$ doping, keeping the n substrate unaltered, result in higher values of the junction electric fields, and, consequently, better collection of the photogenerated eletron-hole pairs. Besides, with the increasing of junction depth, more photons are absorbed in the surface (p$^+$ region) and not in the depletion region, reducing the amount of electron-hole pairs collected.

Other interesting results are shown in Figure 2. Increasing the p$^+$ doping concentration, the noise in the device is reduced and by reducing the junction depth the noise is also reduced. This can be explained by the fact that increasing the doping and reducing X$_j$, reduces the value of the device's resistance. This results on lower shot noise and thermal noise, which are all proportinal to the device's resistance and are the most important noise sources on pn diodes.

Analysing the influence of passivation levels (varying s) shown on Figure 3, one can conclude that low values of s provide a slightly higher responsivity. This happens because for zero bias condiction, the reduction of s implies in the increase of n$_p$ (desity of electrons at p side), σ_n (electron conductance), V$_j$ (potential across the junction) and consequently increasing the total current through the device. Nevertheless, an increase of 10^6 times in the value of s result on an increase of only 0.03% of the total noise and a decrease of only 1.9% of the responsivity, showing that passivation should not be the main concern for the device's improvement. However at reverse bias operation, these variations on s values cause more significative changes on the reverse saturation current. In this case the surface passivation is more important. Lower values of s (better passivation) also reduce noise in the device.

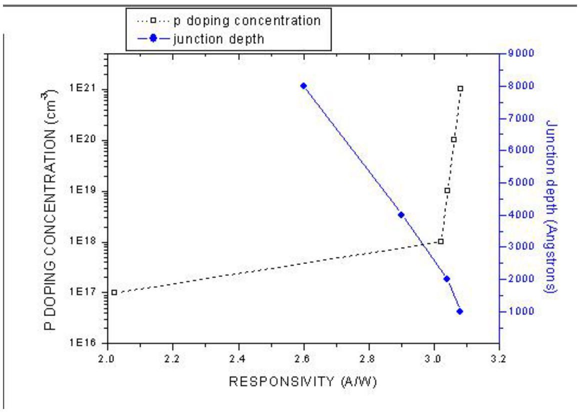


Figure 1: Responsivty as a function of p doping concentration and junction depth. Dotted line represents p doping concentration and is referred to the left axis. Full line represents juntion depth and is referred to the right axis.

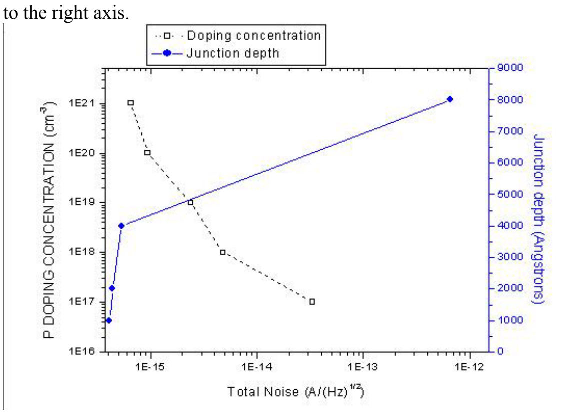
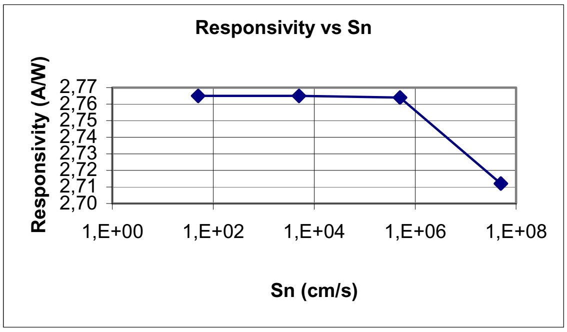
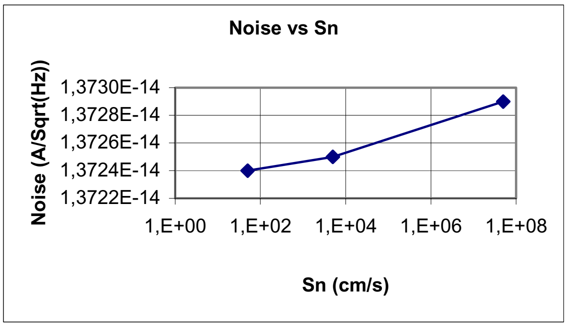


Figure 2: Total noise as a function of p doping concentration and junction depth. Dotted line represents p doping concentration and is referred to the left axis. Full line represents juntion depth and is referred to the right axis.



(a)



(b)

Figure 3: Responsivity as a function of the surface recombination velocity (a) and total noise as a function of the surface recombination velocity (b). The relative diference between the maximum and the minimum values of responsivity and total noise are 1.9% and 0.03%.

4. CONCLUSION

The design of an efficient InSb pn photodetector involves the fabrication of thin and highly doped surface region, which provides high responsivity and low noise values. The device's passivation can also be important although, in the case of zero bias condiction, it does not affect the performance in a significative manner.

5. REFERENCES

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