Effect of Mole Composition on the Responsivity of $In_xGa_{1-x}N$ p-i-n Photodiode

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1. Introduction

Photonics technology offers unique solutions whereas today's conventional technologies are approaching their limits in terms of speed, capacity and accuracy. It has important applications in several areas such as displays, optical data communications, solid-state lighting (SSL), imaging, sensing etc. Photodetector is one of the key elements to determine the performance of a photonic system. Further, in recent times, III-nitride semiconductors have attracted a great deal of interest among researchers because of their interesting properties. In particular by changing the mole composition (x) of an $In_xGa_{1-x}N$ photodetector, the detector can be designed over a wide range between UV-IR regions. Such devices are thus very promising in the fields of biomedicine, flame sensing applications, photolithography, environment monitoring, etc. Some earlier works on the responsivity of InGaN based p-i-n photodiodes have already been reported in literature [1-3]. It is seen that the wavelength of operation has a role to determine the sensitivity of the photodiode, because the density of photon flux also changes with wavelength. An earlier work suggests the variation of responsivity may be modified by changing the thickness within a small range [4]. However, mole composition plays an important role in the determining the responsivity. No such detailed study on $In_xGa_{1-x}N$ photodiode with mole composition has been explored earlier, as per knowledge of the authors. In this paper, we study the spectral response and, hence, the responsivity of an $In_xGa_{1-x}N$ p-i-n photodiode for variable composition of x. This study is used to suggest optimum wavelengths for peak responsivity for different mole compositions.

2. Theoretical Background

An $In_xGa_{1-x}N$ p-i-n photodiode structure is used for the analysis in this work. The doping concentration is chosen as 10^{20} cm^{-3} for both donor and acceptor impurities. The i-layer is actually undoped, though a very small donor concentration of 10^{18} cm^{-3} has been assumed considering the possibility of unintentional doping. As the mole composition changes, some properties of $In_xGa_{1-x}N$ can be obtained using interpolation technique (Vegard's law). However, in some cases, bowing parameter is used for more accurate estimate of the property. For example, the band gap has been estimated using the formula:

$$E_g^{InGaN} = xE_g^{InN} + (1-x)E_g^{GaN} - 1.43x(1-x) \quad (1)$$

where $E_g^{InN} = 0.7eV and\ E_g^{GaN} = 3.42eV$, and bowing parameter is 1.43eV.

The refractive index was calculated based on the relation [5]:

$$n(E) = \sqrt{A(x)\frac{E}{E_g}^{-2}\left\{2 - \sqrt{1+\frac{E}{E_g}} - \sqrt{1-\frac{E}{E_g}}\right\} + B(x)} \quad (2)$$

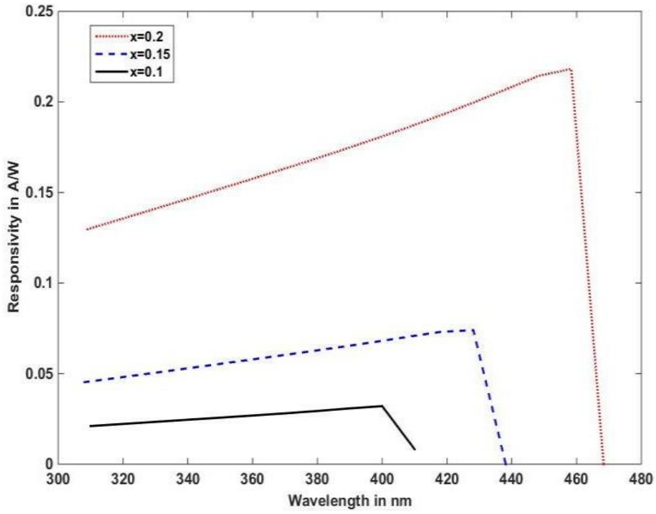
where $E = \frac{hc}{\lambda}$ the photon energy and A(x) and B(x) are material dependent parameters given by the expressions:

$$A(x) = 9.827(1+x) - 53.57x \quad (3)$$

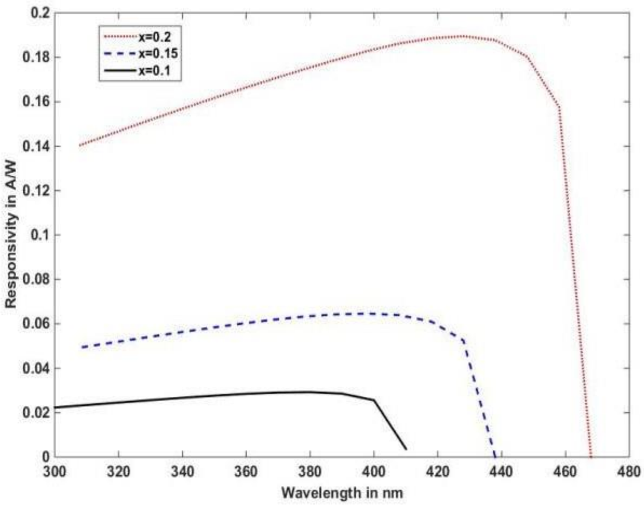
$$B(x) = 2.736(1+x) - 9.19x \quad (4)$$

2 Device Performance

In the computation, the primary object is to study the effect of variation of mole composition on responsivity. So, the device width is kept fixed at 8μm. The diode is assumed to be reverse biased with 2V, and the power of the incident light is kept fixed at 10μW. Few results based on the simulation study carried out using COMSOL Multiphysics 6.0 are presented below. Responsivity at different wavelengths for three chosen mole compositions is shown in Fig.1. The study has been restricted to maximum value of *x* at 0.2 as practical maximum used in different literatures. The plot shows that there is a wavelength at which the responsivity reaches the maximum, the peak value being a function of *x*. The peak increases with increase in x and the optimum wavelength for which peak occurs shifts to higher wavelengths. In Fig. 1(a), the plot is shown for thickness (*t*) of 0.6μm, while in Fig. 1(b) it is shown for *t* of 0.2μm. Comparing the two plots, it may be seen that the peak responsivity increases with increase in thickness. The peak responsivity and optimum wavelength have been shown in Fig.2. In Fig.2(a), it is shown for t= 0.6μm, and in Fig. 2(b) it is shown for *t* = 0.2μm. The plots indicate nearly linear variation of optimum wavelength, and non-linear increase of peak responsivity with increase in x.

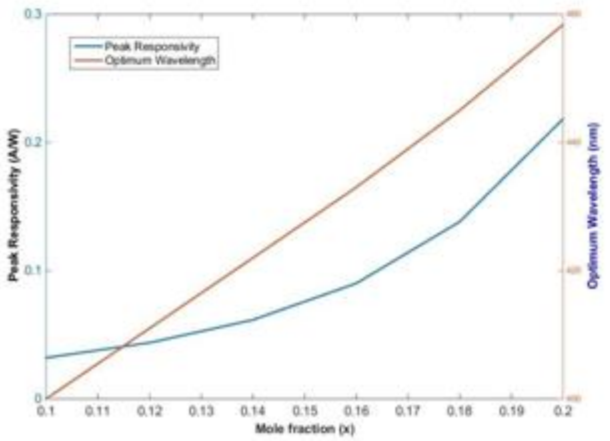


(a)

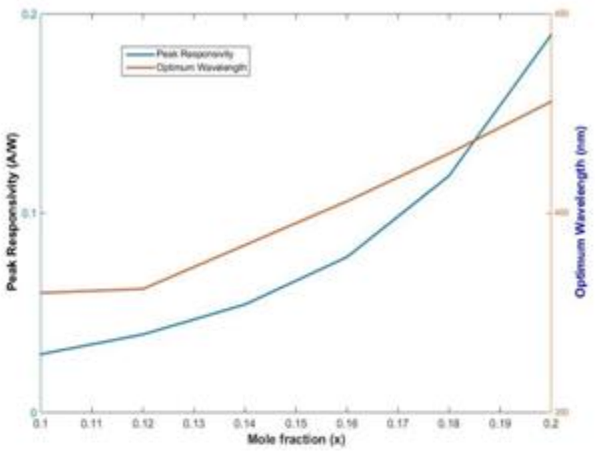


(b)

Fig.1. Responsivity versus Wavelength for three different mole composition (x). (a) Thickness t=0.6µm, (b) t=.2µm. Width w=8µm in both cases



(a)



(b)

Fig.2. Peak Responsivity and Optimum Wavelength versus mole composition (x). (a) Thickness t=0.6µm,.(b) t=.2 µm. Width w=8µm in both case

3. Conclusion

The responsivity of $In_xGa_{1-x}N$ P-i-n photodiode for different mole compositions (x) has been obtained using COMSOL Multiphysics 6.0 simulation software. Responsivity as high as 0.22A/W has been obtained for x=0.2 taking thickness of the active layer of the photodiode as 0.6μm. The peak responsivity for different mole compositions and the corresponding optimum wavelengths are obtained from the study. The study suggests optimum wavelengths to be chosen to get the maximum responsivity for a given thickness of the diode.

6. Acknowledgements

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7. References

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