High Sensitivity Photodetector Using Si/Ge/GaAs Metal Semiconductor Field Effect Transistor (MESFET)

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Abstract. The paper presents the comparative study of MESFET as photodetector for three different channel materials: Si, Ge and GaAs using ATLAS 3D device simulator. Common semi-insulating substrate i.e. sapphire is used for all the three MESFETs. Effect of illumination on the performance of the device has been studied in detail in terms of ratio of dark current to current under illumination, threshold voltage shift and enhanced drain current.

Keywords: ATLAS-3D, MESFET, photodetector, sensitivity

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INTRODUCTION

The Optically controlled MESFET (OPFET) has drawn considerable attention for last two decades for the designing of various optically controlled monolithic microwave integrated circuits (MMIC's) and optoelectronic integrated circuits (OEIC's) [1]. The dc and microwave characteristics of such a device can be controlled precisely by applying optical radiation on it. In optical communication systems, OPFET photodetectors [2] are supposed to be very promising. Recent efforts to develop photodetectors have centered around high data rate applications where the main focus of device structure and design has been to achieve high quantum efficiency and lower dark current. Two dimensional image sensors require small monolithic photodetectors with high sensitivity. Another application of small photodetector is optical on-chip interconnection in which high sensitivity detector is used as a receiver. Photodetectors can be fabricated from a broad range of materials. The material selection is based on a number of factors including optical properties (refractive index, absorption), electrical properties (mobility and conductivity), stability and process compabilities. Depending upon the absorption at the desired wavelength in the UV, visible and near IR regions of spectrum we have simulated MESFET based photodetector for three channel materials: Si, Ge and GaAs. Silicon technology [3],[4] is all pervasive and underpins the IT revolution that is now reshaping society. The technology keeps improving year on year as chip sizes are being continually reduced and transistor speed increases. In order to achieve higher detection efficiency, absoption at wider range of frequencies new channel materials are being used. Ge [5]-[7] has particularly become of great interest as a channel material for IR detection. GaAs has many advantages over Silicon such as higher electron mobility, shorter transit time, higher rresistivity, lower thermal conductance and is commonly used for optically controlled MESFET devices [8]-[9]. In this paper, we have studied the performance of MESFET based photodetector for three different channel materials: Si, Ge and GaAs using ATLAS 3D device simulator [10]. Common semi-insulating substrate i.e. sapphire is used for all the three MESFETs. The three photodetectors have been optimized to have same threshold voltage (i.e. V_{th}= -0.18 V) under dark so as to compare their performance in terms of ratio of drain current under illumination to the drain current under dark conditions i.e. I_{illum}/I_{dark} at different biasing conditions. The impact of variation of intensity of incident radiation and its wavelength has also been studied in detail through extensive simulations.

DEVICE STRUCTURE

The schematic structure of a MESFET under illumination is shown in Fig. 1.

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Here gate metal is assumed to be transparent.

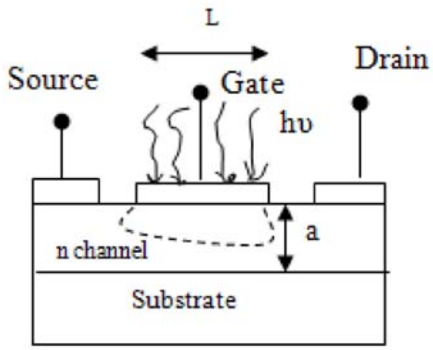

FIGURE. 1 Schematic structure of a MESFET. Channel length (L)=1μm, channel width (Z)=10μm, Active layer thickness (a)=0.3μm, Active layer doping (N_d)=1x10^{22} m^{-3}, Substrate doping (N_a)=10^{21} m^{-3}, Metal work function, Φ_m=5.0 eV.

RESULT AND DISCUSSION

Fig.2 shows the available photocurrent (I_{ph}) as a function of incident radiation power. As can be seen I_{ph} increases with the power due to the enhanced generation of electron hole pair (EHP) in the depletion region beneath the schottky gate. Fig.3 shows I_{ph} as a function of wavelength of incident radiation for Si, Ge and GaAs. As can be seen from the figure the cut-off wavelength after which there is no absorption for Si, Ge and GaAs is : 1.1um, 1.79um and 0.84um resp. Fig.4 ,5 and 6 illustrate the ratio of drain current under illumination to the drain current under dark conditions i.e. I_{illum}/I_{dark} as a function of V_{gs}-V_{th} for Si, Ge and GaAs. The device has been optimized to have same threshold voltage (V_{th}=-0.18V) under dark condition for all the three materials. V_{th} under illumination is reduced to -0.22V, -0.187V and -0.192V for Si, Ge and GaAs respectively for incident radiation power (P_{op})=4μW and at wavelength of radiation (λ)=0.35μm. At V_{gs}=-2V, V_{ds}=0.05V, λ = 0.55μm (visible region) and P_{op}= 4 μW, the ratio I_{illum}/I_{dark} for Si, Ge and GaAs is 4.3x10^6, 2.12x10^3 and 1.8x10^{10} respectively. Under same conditions but at a wavelength of 0.15μm (UV region) I_{illum}/I_{dark} for Si, Ge and GaAs is 1.58x10^6, 9.38x10^2 and 4.17x10^9 respectively. At wavelength of 1.15μm (near IR region) I_{illum}/I_{dark} for Si, Ge and GaAs is 6.31x10^2, 1.08x10^2 and 1 respectively. Thus GaAs has the highest I_{illum}/I_{dark} ratio and hence higher sensitivity in UV and visible regions but it cannot be used in near infrared region as there is no absorption in near IR region for GaAs. As can be seen from the figure I_{illum}/I_{dark} ratio is higher for larger negative V_{gs} values as larger negative V_{gs} implies larger depletion width and hence more absorption. Also I_{illum}/I_{dark} is higher (lower) at wavelength=0.55μm (1.15 μm) than 0.15 μm.

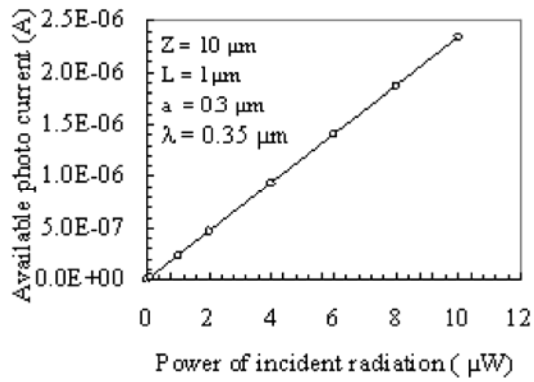

FIGURE. 2 Available photocurrent Vs intensity of incident radiation. L=1μm, Z=10μm, a=0.3μm, P_{op}= 4 μW.

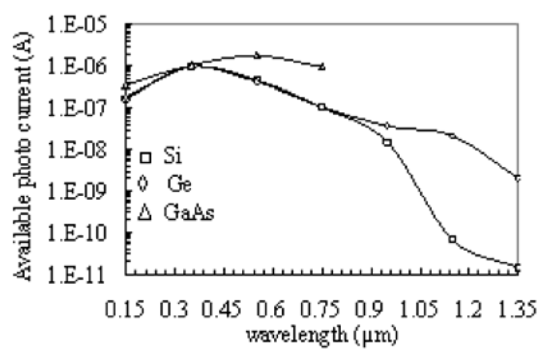

FIGURE. 3 Available photocurrent as a function of wavelength of incident radiation. L=1μm, Z=10μm, a=0.3μm, P_{op}= 4 μW.

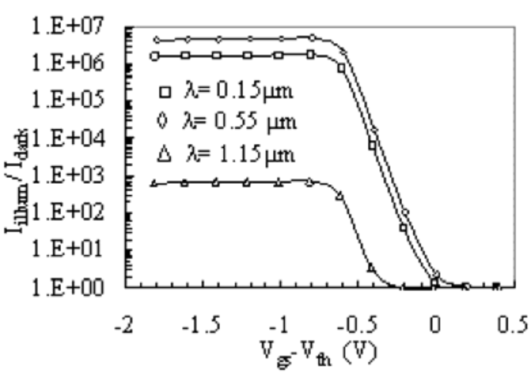

FIGURE. 4 I_{illum}/I_{dark} ratio as a function of V_{gs}-V_{th} for Si. L=1μm, Z=10μm, a=0.3μm, N_d=1x$10^{22}$$m^{-3}$, N_a=10^{21} m^{-3}, P_{op}= 4 μW.

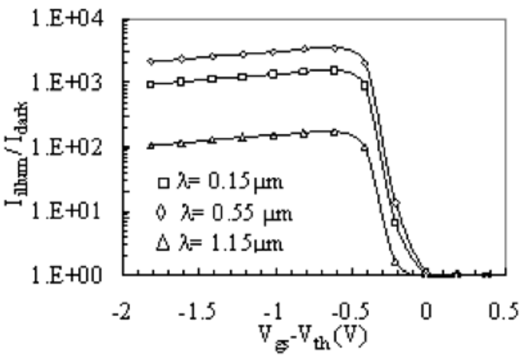

FIGURE. 5 I_{illum}/I_{dark} ratio as a function of V_{gs}-V_{th} for Ge. L=1μm, Z=10μm, a=0.3μm, N_d=1.62x10^{22}m^{-3}, N_a=10^{21} m^{-3}, P_{op}= 4 μW.

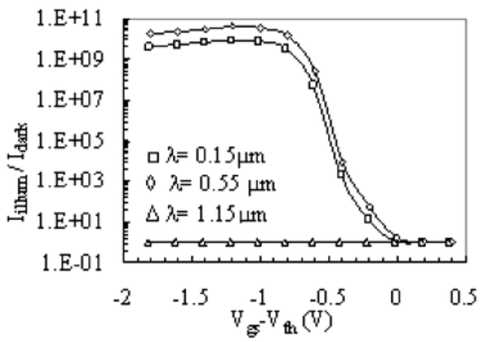

FIGURE.6 I_{illum}/I_{dark} ratio as a function of V_{gs}-V_{th} for GaAs. L=1μm, Z=10μm, a=0.3μm, N_d=1.48x10^{22}m^{-3}, N_a=10^{21} m^{-3}, P_{op}= 4 μW

Table. 1 compares the effect of increasing intensity on the I_{illum}/I_{dark} ratio for all three materials. As can be seen I_{illum}/I_{dark} ratio is improved at higher intensities.

TABLE.1 Effect of intensity on I_{illum}/I_{dark}

Radiation Power (P_{op}) μW	I_{illum}/I_{dark} Si	I_{illum}/I_{dark} Ge	I_{illum}/I_{dark} GaAs
4	9x10^6	4.87x10^3	1.23x10^{10}
8	1.82x10^7	9.73x10^3	2.46x10^{10}
10	2.27x10^7	1.22x10^4	3.08x10^{10}

CONCLUSION

MESFET based photodetector is simulated using three materials. Out of three materials used GaAs has the highest Ion/Ioff ratio and hence higher detection efficiency but its use is limited to UV and Visible region only. For near IR region upto 1.15um Si is better than Ge in terms of Ion/Ioff ratio but for IR region beyond 1.15um Ge is the best choice.

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