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Current voltage characteristics of Nano structured quantum dot transistor with front side Illumination

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ABSTRACT

A study on the DC performance of Nano Quantum Dot Transistor under illumination is presented. A device structure consist of Quantum Dots(QD) in the GaAs layer is considered for illumination. The photoconductive effect in the GaAs and QD layer which increases the 2DEG Channel electron concentration is considered. The I-V Characteristics of Quantum Dot Transistor, under dark and illumination condition have been calculated, plotted and discussed.

Introduction

An increase in interest has been created in the study of optical effect in high speed device due to their potentiality in fiber optical communication and optical integration. Although some investigators have carried out both experimental and analytical studies [1]-[10] on the effect of illumination in GaAs MESFET, AlGaAs MODFET and QDT which shows that there is significant effect of incident light on the electrical parameters of the device, but there is a lack of theoretical and experimental work describing the effect of illumination on Quantum Dot Transistors.

Recently, detectors have been demonstrated, that utilize the photoconductive gain associated with storing photo-generated charge carriers in the vicinity of a two-dimensional electron gas (2DEG) in specially designed field effect transistors (FETs). Approaches to the charge storage in these detectors have included electronic confinement using metallic gates, naturally occurring defect centers in AlGaAs, and self-assembled quantum dots.

A detailed analysis considering all effects resulting from optical illumination of Quantum Dot Transistors is a very complex task. However by making some assumptions, a simplified analysis considering the relevant photo effects can be modeled. In this paper a simplified analysis to account for the photoconductive gain effect is described and from this the change in the DC performance with illumination is estimated. The current Voltage Characteristics of the device Quantum Dot Transistor, with illumination (Photo current) and without illuminations (dark current) are calculated,plotted and discussed

Theory

The structure of Quantum Dot Transistor used for illumination is shown in Fig(1), where source and drain electrodes are ohmic contacts and the gate electrode is a schottky-barrier junction. The major photo effects arising in the illumination of Quantum Dot Transistor are band to band absorption in the GaAs and AlGaAs layer generating hole electron pairs in these regions.

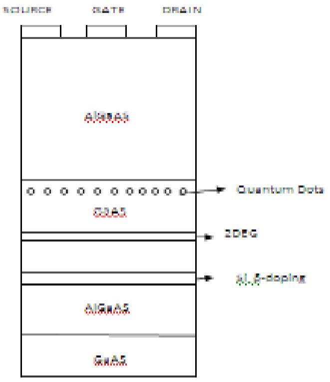

Figure 1 Schematic Diagram of Quantum Dot Transistor

An incident photon with the appropriate energy creates an electron-hole pair in the GaAs absorbing layer. With a reverse bias applied to the gate, the electric field directs the electron to the 2DEG shown in figure and the hole to the Quantum Dots (QDs), where it is trapped.

When photons are absorbed only in the GaAs layer an increase in the electrons concentration of the 2 DEG Channel occurs due to Photoconductive effect.The relevant dimensions and material considered in Quantum Dot Transistor are presented in table 1.The photoconductive effect is dominant when the incident photon energy is equal to or greater than the GaAs band gap but smaller than the AlGaAs band gap($E_{g1}<E_{ph}<E_{g2}$). Then the AlGaAs is transparent to the illumination and the dominant photo effect is the generation of photo electrons in the GaAs layer alone.

In this device, high internal quantum efficiency (IQE) is achieved by using an electric field to direct the holes generated in the absorbing region of the detector to the QDs where ~70% are trapped. This positively charged hole screens the bias field, effectively changing the gate bias by a positive amount, and increases the channel current, I_{ds} .This change in ,

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I_{ds} caused by the addition of N_{QD} positive charges to the QD plane is

$$\Delta I_{ds} = g_m \frac{eW}{e^{'}A} N_{QD} \qquad (1)$$

where g_m is the FET conductance, e is the charge , W is the distance between the gate and the QD layer , $e^{'}$ is the permittivity of AlGaAs and A is the active area of the device. This photoconductive gain makes the device very sensitive to illumination with light of appropriate energy. The quantum efficiency is assumed as unity. The photo electron density generated in the GaAs layer is assumed as

$$\Delta n = \frac{\tau_n P_{opt}}{d_1 E_{ph}} \left(1 - e^{-\alpha_1 d_1}\right) \qquad (2)$$

where P_{opt} is the incident optical power density, E_{ph} is the incident photon energy, α_1 the GaAs optical absorption coefficient and d_1 is the thickness of the GaAs layer. τ_n is the electron life time. Assuming the saturation drift velocity of the photo electron as v_s ,the drain to source photo current is I_{dsp} in the linear region is estimated as ,

$$I_{dsp} = W q n_{sp} v_s \left(1 - e^{-\left(V_D \mu - \frac{v_D^2}{v_s} L\right)}\right) \qquad (3)$$

And the drain to source photocurrent in the saturation current can be estimated as

$$I_{dsp} = W q n_{sp} v_s \qquad (4)$$

And the overall drain to source current due to illumination is

$$I_{dspT} = I_{ds} + I_{dsp} + \Delta I_{ds} \qquad (5)$$

where I_{ds} is the drain to source current without illumination. I_{dsp} is the drain to source photocurrent due to generation of electrons in the GaAs layer. ΔI_{ds} is the photocurrent due to Quantum Dots.

Results and Discussion

The dimensions and other basic parameters used for calculation are given in table1.Numerical calculation have been carried out for Quantum Dot Transistor considering the optical effect.

Table 1.Parameters Used For The Calculation

Symbol	Name	Value
W	Gate Width	17μm
L	Gate Length	0.68μm
Vs	Saturation velocity	2×10^{7}cm/s
h	Plancks Constant	6.6×10^{-34}
q	Electron charge	1.6×10^{-19}
ϵ_1	Permittivity of GaAs	$13.2\ \epsilon_0$
ϵ_2	Permittivity of AlGaAs	$12.1\epsilon_0$
ϵ_0	Permittivity of Vaccum	8.854×10^{-12} F/m
μ	Low field mobility	$6800 cm^2/vs$

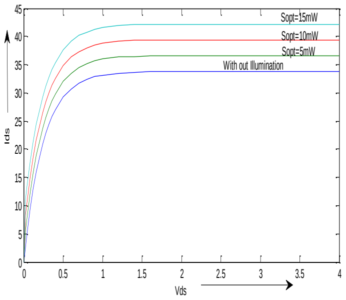


Figure 2. V-I Characteristics of Quantum Dot Transistor with out and with illumination

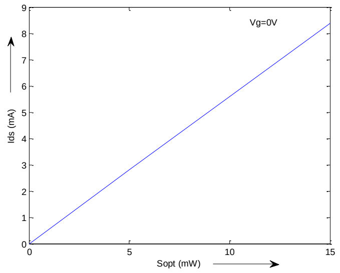
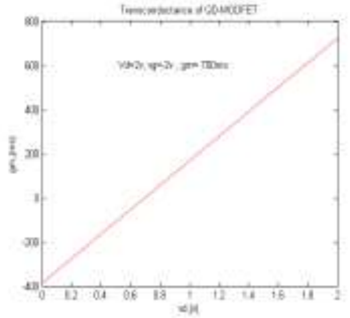


Figure 3.Optical Response of Quantum Dot Transistor



Figure(4)Transconductance of QD- Transistor

The I-V characteristics of Quantum dot transistor under illumination and dark condition are shown in the Fig 2. A tremendous increase in photo current is realized due to illumination. The optical response of the Quantum dot transistor under various optical power is shown in Fig3. Fig4 shows the responsivity of the quantum dot transistor.

Conclusion

The characteristics of Nano structured Quantum Dot Transistor under front side illumination has been obtained and presented here. The offset voltage has been calculated with the effect of illumination. The I-V Characteristics of Quantum Dot Transistor under dark and under illumination condition have been calculated, plotted and discussed .The optical response and transconductance characteristics of the Quantum Dot Transistor is also calculated, plotted and discussed. The I-V Characteristics have been compared with the experimental data, showing good agreement.

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