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RF PERFORMANCE AND MODELLING OF OPTICALLY CONTROLLED MOSFET

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ABSTRACT

Normally off devices like Metal Oxide Semiconductor Transistors (MOSFET) are sensitive to light and can be controlled optically. These devices have high package density, low power consumption and dynamic operating range. In this paper modelling and simulation of MOSFET devices is carried out in 1GHz to 10GHz frequency band. Devices are controlled optically by varying optical power of incident radiations from 0.25 mW to 25mW at constant gate voltage and drain voltage. Wavelength of incident radiation is 800nm and device length is 0.35µm. Radiations are made to incident perpendicular to the device surface. RF performance is observed by means of Drain current, transconductance, Y parameters and S parameters. Illumination of device gives rise to electron hole pairs thereby increasing inversion level in the channel. Drain current and transconductance of MOSFET increases due this optical absorption.

S parameter is the proper tool to characterize the two-port network description of RF devices. MOSFET can be viewed as two port network with two controlling ports, Gate and Drain with common grounded Source terminal. Optical control provides third controlling port to this two-port network. Result shows that all performance parameters can be controlled optically. Device can be used as OEIC due integrity of optical and RF characteristics.

KEYWORDS: MOSFET, Y Parameters, S Parameters, RF, Optical

INTRODUCTION

Today's communication era demands for high performance, low cost RF solution. There are number of active and passive devices operating at RF. Passive devices are used for detecting, mixing, modulating, or controlling RF signals whereas active devices are used to generate power or to amplify RF signals. Transistors are most widely used active RF solid-state devices. Two main categories of transistors for RF applications are bipolar junction transistors (BJTs) and field-effect transistors (FETs).

For high-frequency applications the goal is to scale down the size of the device. CMOS devices are becoming an attractive alternative to GaAs and Bipolar devices for RF application due to its downscaling, high package density, low cost and low power requirement. With this there is the possibility of integration of complete communications systems on single chip (SOC). Sensitivity towards light is one of the attractive features of MOSFET devices. MOSFET under illumination vary the depletion layer under the gate and thus reduces or increases the conductance path.

At RF noise is prime issue. Optical devices are immune to noise. Optoelectronics and CMOS integration can provide high performance and noise attenuation simultaneously. Device performance can be observed by ac and dc analysis. RF performance can be well understood with S parameters. AC analysis with optical control is carried out at RF. Optical control of DC characteristics is reported. Section II explores modelling of optical interaction in MOSFET. Section III gives DC modelling and section IV provides two port network of MOSFET as well as parameters at RF i.e. Y and S parameters. Results are discussed in section V.

OPTICAL INTERACTION IN MOSFET

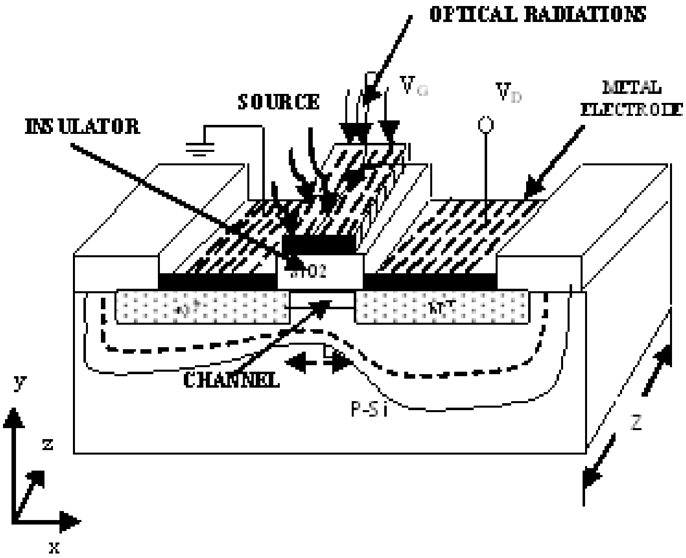

Figure 1: Structure of MOSFET under Illumination

Figure 1 shows the device under consideration [2,3] and optical radiation incident on it. Optical interaction takes place in the inversion layer [4,5]. Device illumination generates photovoltage (Vop) due to photovoltaic effect which causes change in the effective potential at gate thereby increasing the gate bias from Vg to (Vg+Vop)[6]. The generated photovoltage is given by

$$V_{op} = \varphi_b \ ln\left[\frac{q v_y \frac{\pi}{4} \mathrm{P}(0)}{J_{s1}}\right] \tag{1}$$

where, J_{s1} is the reverse saturation current density;

v_y is the carrier velocity along vertical direction

P(0) is the number of holes crossing the junction at y = 0 and is given by

$$\mathrm{P}(0) = \frac{\pi}{4} \mathrm{Z}\left(p_1 \mathrm{Y}_{ds}{}^2 + p_2 \mathrm{Y}_{dD}{}^2\right) \tag{2}$$

Here, p_1 *and* p_2 are the constants dependent on the carrier lifetime under ac conditions [10]. Y_{ds} and Y_{dD} are depletion width at source and drain side.

The calculation of the photovoltage is important because they modify the depletion width y_{dg}, and hence the surface potential which is given by

$$Y_{Dg} = \sqrt{\frac{2\epsilon}{qN_a}\left(\emptyset_B - \delta + v(x) - v_{gs}\right)} \tag{3}$$

Under illumination Y_{Dg} is modified to $Y_{Dg}{}'$ given by,

$$Y_{Dg}{}' = \sqrt{\frac{2\epsilon}{qN_a}\left(\emptyset_B - \delta + v(x) - v_{gs} - v_{op}\right)} \tag{4}$$

Where $v(x)$ is the channel voltage, Φ_B is the bulk potential, δ is the position of Fermi level at the neutral region below the conduction band and N_a is the substrate concentration.

MOSFET AS TWO PORT NETWORK

S-parameters are the reflection and transmission coefficients between the *incident* and *reflected* waves (i.e. the voltage ratios of the waves) fully describing the behaviour of a device under linear conditions at radio frequencies. S-parameters are complex (i.e. comprising both magnitude and angle) because both the magnitude and phase of the signal are changed by the network[7-9].

Any active device (in this case MOSFET) can be represented as a two port as shown in figure 2.

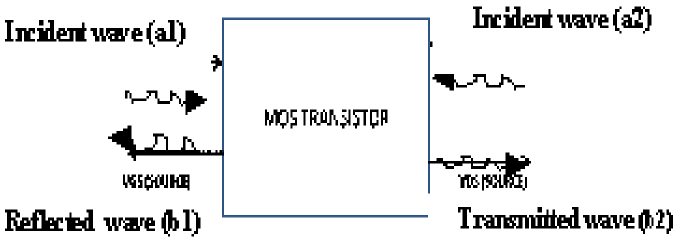

Figure 2: Two Port Network Representation of MOSFET

The scattering parameters are a mathematical construct that quantifies how RF energy propagates through a multi-port network. The S-matrix accurately describes the properties of incredibly complicated networks as simple "black boxes". Thus Scattering Parameters (S-Parameters) plays a major role in network analysis. This importance is due to the fact that practical system characterizations can no longer be accomplished through simple open- or short-circuit measurements, as is customarily in low-frequency applications. In the case of a short circuit with a wire; the wire itself possesses an inductance that can be of substantial magnitude at high frequency. Also open circuit leads to capacitive loading at the terminal. With S- parameters, one has proper tool to characterize the two-port network description of practically all RF devices without harm to DUT.

S-parameters can be determined by using Y to S parameter conversions. Y parameters are realized as in [1] and are given by-

$$Y11 = w^2\left(R_g C_{gg}{}^2\right) + jwC_{gg} \tag{5}$$

$$Y12 = -w^2 R_g C_{gg} C_{gd} - jwC_{gd} \tag{6}$$

$$Y21 = g_m - w^2 R_g C_{gg} C_{gd} - jwC_{gd} + g_{mg} R_g C_{gs} \tag{7}$$

$$Y22 = C_{gd} + w^2 R_g C_{gs} C_{bd} - jw(C_{gd} + C_{bd}) + g_{md} R_g C_{gs} \tag{8}$$

where, $C_{gg} = C_{gs} + C_{gd} + C_{gb}$

g_{mg}, g_{md} are the gate and drain transconductance C_{gs} is the gate to source capacitance

C_{gd} is the gate to drain capacitance and is given by,

$$C_{gs} = \frac{\partial Q_G}{\partial V_s} | V_G, V_D, V_B \tag{9}$$

$$C_{gd} = \frac{\partial Q_G}{\partial V_D} | V_G, V_S, V_B \tag{10}$$

Y TO S parameter conversion is achieved as follows [11,12]

$$S_{11} = \frac{[(Y_0 - Y_{11}) + (Y_0 + Y_{22}) + (Y_{12}.Y_{21})]}{\Delta Y} \quad (11)$$

$$S_{12} = -\frac{2.Y_{12}}{\Delta Y} \quad (12)$$

$$S_{21} = -\frac{2.Y_{21}}{\Delta Y} \quad (13)$$

$$S_{22} = \frac{[(Y_0 + Y_{11}).(Y_0 - Y_{22}) + (Y_{12}.Y_{21})]}{\Delta Y} \quad (14)$$

where $\Delta Y = (Y_0 + Y_{11}).(Y_0 + Y_{22}) - (Y_{12}.Y_{21}))$ [6]

RESULTS AND DISCUSSIONS

Performance of OGMOSFET is investigated theoretically at RF. DC analysis is carried out at 1V gate voltage and 1V drain voltage. S parameters of optically gated MOSFET have been calculated numerically. 0.25 µm process is used for simulation. Short channel effects are considered while modelling the device. Channel length is taken as 0.35µm and absorption coefficient of metal gate is 10^4/m. Optical power of incident wave with wavelength of 800nm is 0.25mW.

Illumination of gate results in generation of excess electron hole pairs due to absorption of incident radiations which increases the net biasing voltage. Figure 3 shows that drain current increases with increase in optical power which leads to increase in transconductance of the device as reported in [10]. Figure 4 shows that by varying optical power from 0.25mW to 25 mW transconductance increases gradually and hence devices can be said as transconductance amplifier.

Figure 5 to 8 shows effect of illumination on y parameters of two port network computed with equations **6-10**. Real and imaginary part of Y parameters are plotted against RF frequency of 1 to 10 GHz. It is seen that there is countable effect on Y21 which gives transconductance amplification of the device.

Small increment in Y22 under illumination shows lowering of output impedance. Remaining parameters are not much sensitive to light.

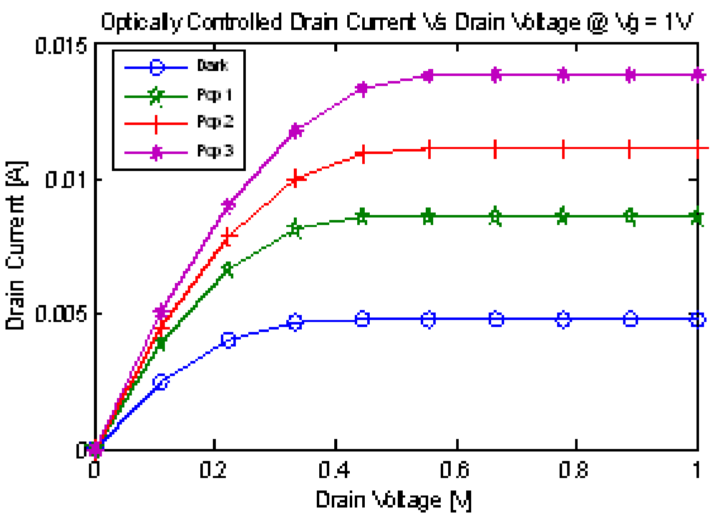

Figure 3: Drain Voltage versus Drain Current for Varying Optical Power

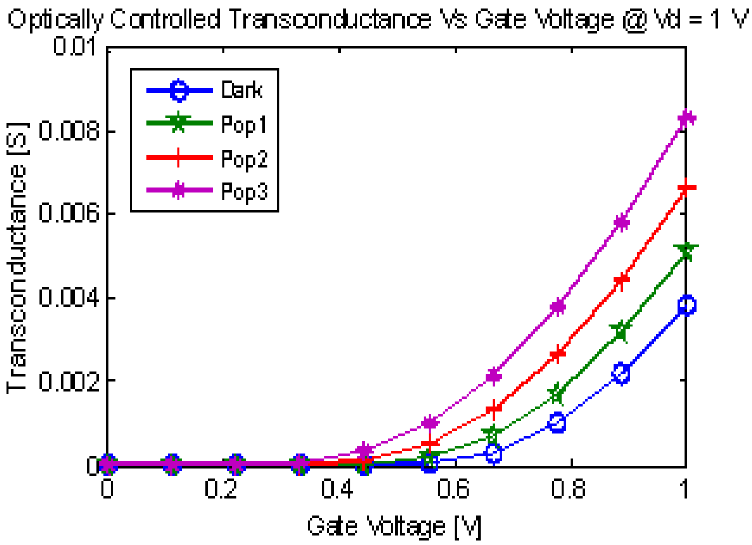

Figure 4: Gate Voltage versus Optically Controlled Transconductance

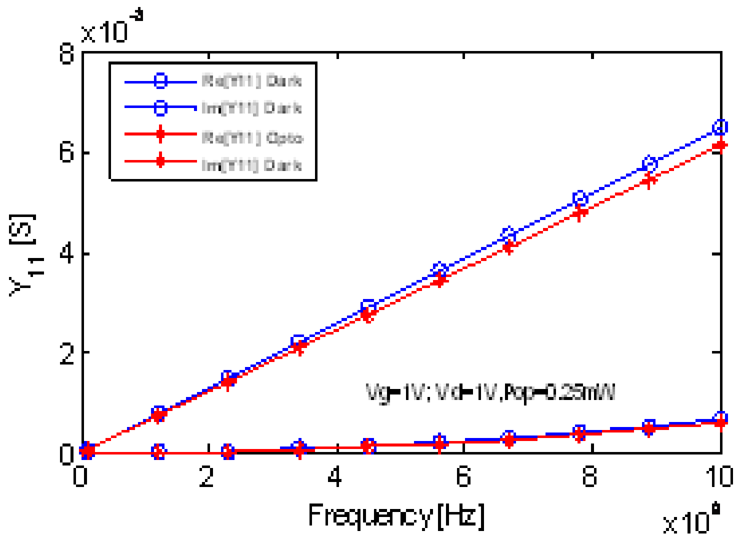

Figure 5: Optical Effect on Real and Imaginary Part of Y11

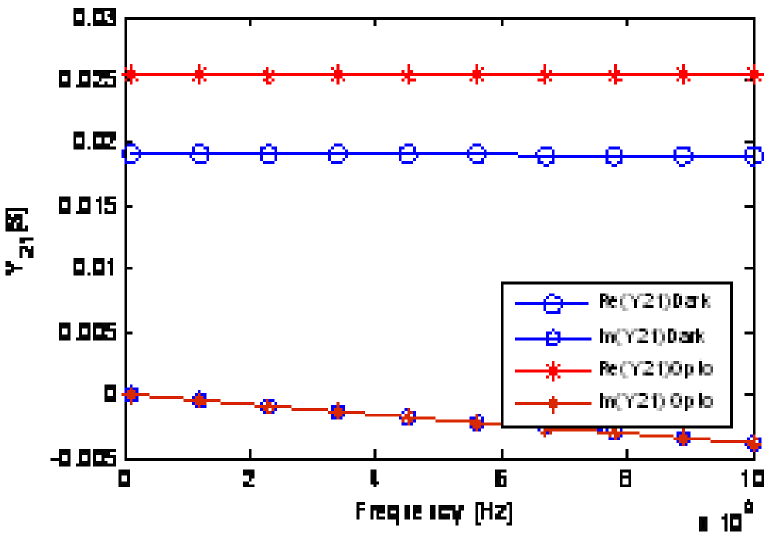

Figure 6: Optical Effect on Real and Imaginary Part of Y21

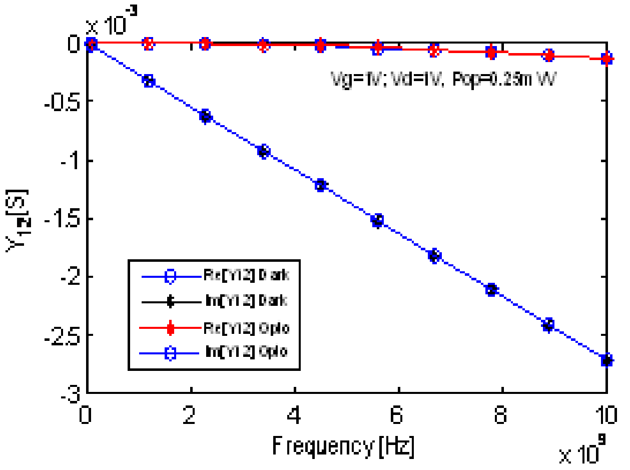

Figure 7: Optical Effect on Real and Imaginary Part of Y12

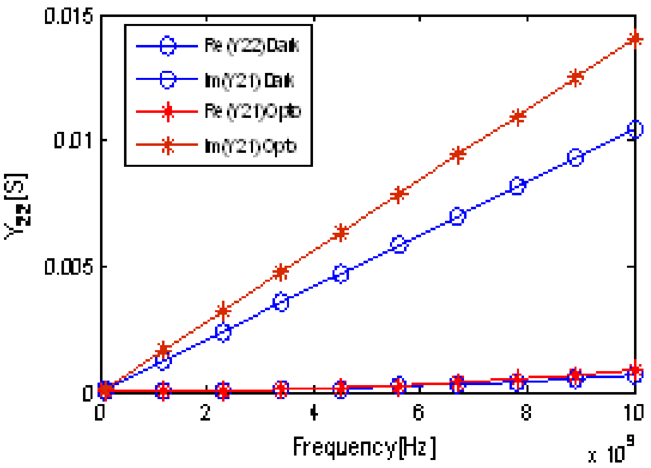

Figure 8: Optical Effect on Real and Imaginary Part of Y22

S parameters are computed by Y to S conversion given through equations **11-13.** S11 and S22 are plotted on smith chart. S12 and S21 are plotted with polar pots as shown in figure 9 and 10. Illumination effect does not affect S11 and S12 much. **Figure 9** shows that S21 can be controlled optically. Sensitivity of S22 to the light is illustrated with **figure 12.** It shows that S22 is very less sensitive to light.

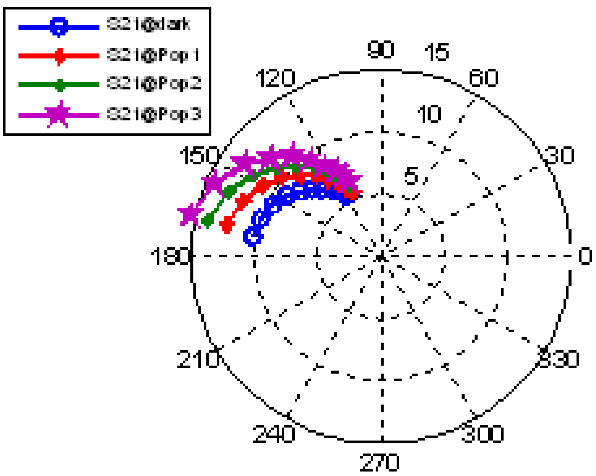

Figure 9: Optical Effect on S21

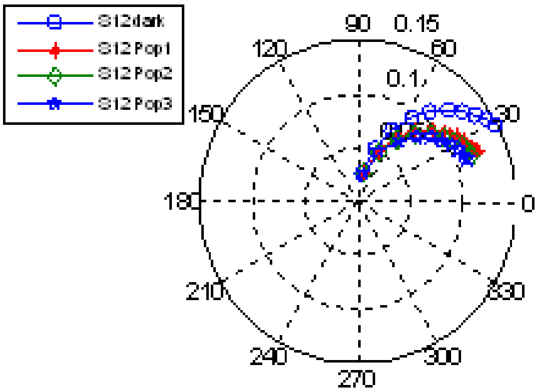

Figure 10: Optical Effect on S12

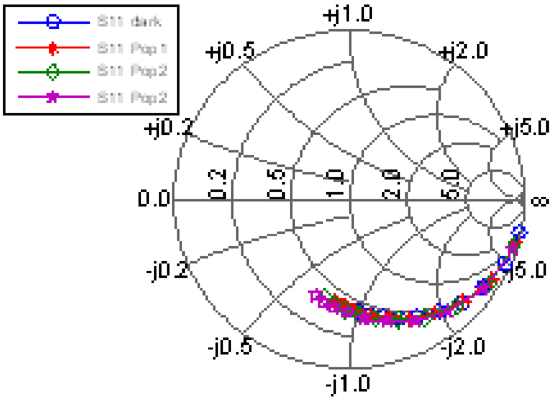

Figure 11: Optical Effect on S11

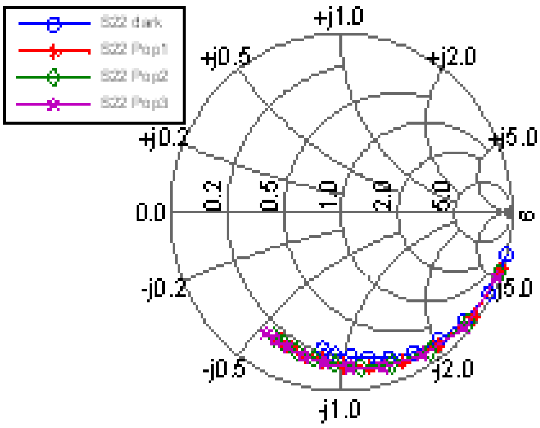

Figure12: Optical Effect on S22

CONCLUSIONS

DC analysis is carried out at Vg = 1V and Vd = 1V. Optical power is varied from 0.25W to 2.5 W. Drain current and transconductance of the MOSFET can be controlled optically. Device behaviour can be well understood with S parameters at RF. S parameters are computed from Y parameters at 1GHz to 10 GHz band. Y21 of Y parameter increases with increase in optical power and the device can work as transconductance amplifier. S21 is Y21 dependent parameter thereby can be controlled optically. Sensitivity of light to all other S parameters is less significant. With this behaviour, device can be used for optoelectronics application at RF.

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