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# TCAD ANALYSIS OF LUMINOUS POWER IN TRANSPARENT GATE RECESSED CHANNEL (TGRC) MOSFET

**Anuj Kumar Sinha*1 & Aditya2**
* 1&2ECE, School of Engineering & Technology Soldha, India

## ABSTRACT

In this paper, we report the effect of luminous behavior of transparent gate Recessed Channel MOSFET (RC-MOSFET). The proposed device has an elliptical lenslet above the RC MOSFET to focus the ray trace in to the transparent indium tin oxide (ITO) gate. The effect of illumination with improved photo generation rate, optical intensity, switching ratio and light absorption is studied. It involves a recessed channel and incorporates Indium Tin Oxide as a transparent gate. TCAD analysis shows that the performance of RC-MOSFET surpasses Conventional Recessed Channel (CRC)-MOSFET regarding high $I_{ON}/I_{OFF}$ ratio and low power switching application. The work proves the effectiveness of transparent gate RCMOSFET for higher efficiency, speed, reduction in power dissipation, low noise and better temperature stability. Luminous-3D RC-MOSFET is fully integrated with ATLAS and the Device 3D.

***Keywords:*** *ITO, RC- MOSFET & Transparent Gate*

## I. INTRODUCTION

In this paper Indium oxide luminous analysis is performed for Recessed channel MOSFET and conventional MOSFET for DC and AC under small signal condition for incident frequency range of 500nm to 1000nm. Use of transparent ZnO as a gate material has the advantage of minimal reflection at the gate surface so that most of the raytrace by elliptical lens incident on the gate reach the channel region. The transparent ZnO RC MOSFET shows the possibility to operate at relatively low temperature of 100 $^0$C, due to the characteristics of downsizing and cost reduction in fabrication of integrated circuits [4]. Tindoped ITO semimetal gate electrodes of the RC

MOSFET is a solid solution of indium oxide ($In_2O_3$) and Tin oxide ($SnO_2$) material of 91:9 weight percent with purity of 98.99%[7]. The advantage of ZnO is that it possesses high electrical conductivity and high optical in semiconductor manufacturing techniques and more and more demand for high speed and more complicated Integrated Circuits (ICs) have driven the associated Metal Oxide Semiconductor Field Effect Transistor (MOSFET) sizes close to their physical limits. On the other hand, it is difficult to scaledown the supply voltage used to perform these ICs consistently due to compatibility problem with earlier generation circiuts, power, noise margin and delay requirements, and not scaling of thresold voltage and subthresold slope [1]. While the successive increase in internal electric fields in aggressively scaled MOSFETs comes with the additional ameliorate of increased carrier velocities, and hence increased switching speed, it also presents higher reliability complications for the long period of operation of these devices[12].

From the last several decades, the hot carrier reliability performance in a MOS device has been studied since MOS device is scaled and suffered from hot carrier effect which also pervert analog circuit desideratum. When we scaled the device, the ameliorates of higher electric fields impregnate while associated reliability problems get worse [15]. When electric field will be large in MOSFETs, then carrier will have high energy and these carriers are hot carriers. To abate these hot-carrier effects in CRC-MOSFET, instead of metallic gate we are using Oxide (ITO). In luminous analysis, lenslets are not meshed for drift diffusion type analysis and is only used for raytracing. In elliptical lens, we specify the semi major axis, center and index. The light rays when pass through the lens converge on a single point. The single point to which the light rays are converging is called the focal point. The lens is used to specify lenslet characteristics used for light propagation analysis [18].

ITO is one of the most widely used transparent conducting oxides. By using ITO, we improve $I_{ON}$ which causes the decrease in device power consumption. The $In_2O_3$ phase itself contributes free electron for electrical conductivity [17]. When Tin (Sn) is diffused, then some of the oxygen vacancies may be created by $SnO_2$ which creates free electrons to enhance the concentration of carriers and hence increase conductivity and decrease the resistivity with temperature[1]. The need of excellent performance of ICs has led to the scaling of MOSFETs down to 25 nm and below [9].

## II. DEVICE STRUCTURE AND ITS PARAMETERERS

The simulation device structure i.e. ITO RC-MOSFET consists of gate which is made by transparent conducting material ITO/ZnO as shown in Fig1. The total gate length is 25 nm and thickness of oxide is 2.0 nm. In this case, substrate doping is p-type with concentration of $1\times10^{16}cm^{-3}$; source and drain are n-type with uniform doping profiles is $1\times10^{20}cm^{-3}$. Analysis of Recessed channel MOSFET using ITO gate has been performed using ATLAS and DEVEDIT 3D device simulator. Silvaco ATLAS advanced luminous 3D optical device simulator has been used to extract the device characteristics under illumination [3]. Fig 1 shows the simulated device structure of Transparent RC MOSFET under illumination. The ITO RC MOSFET uses a p-type substrate of concentration of 1×1016 cm-3 ,source and drain regions have peak concentration of 1×1019 cm-3. The channel

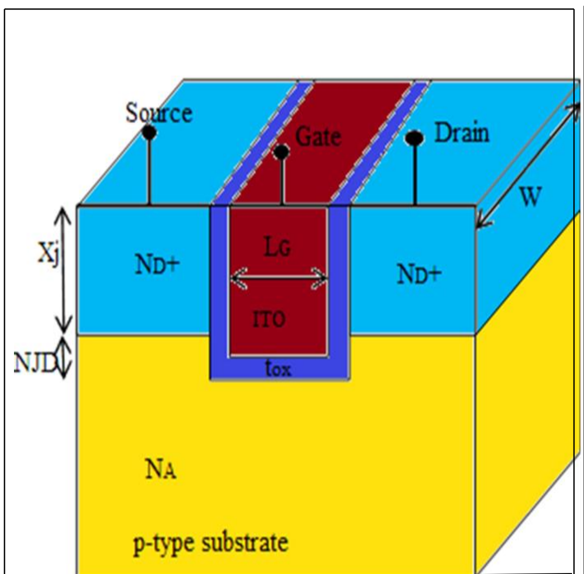


*Fig1(a): Simulated device: - ITO RC- MOSFET*

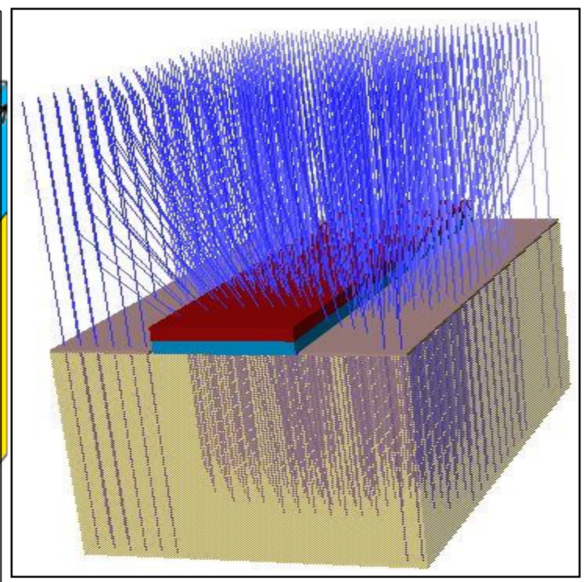

*Fig1(b): Simulated device: - Ray Trace RC- MOSFET*

***Table-I***

| Design Parameters for ITO Conventional MOSFET & RC-MOSFET device designs | |
|---|---|
| Channel Length ($L_G$) | 30nm |
| Device Width (W) | 200nm |
| Groove Depth (d) | 40nm |
| Source/Drain Junction Depth | 30nm |
| Negative Junction Depth (NJD) | 20nm |
| Substrate Doping ($N_A$) | $1\times10^{16}$ $cm^{-3}$ |
| Source/Drain Doping ($N_D^+$) | $1\times10^{19}$ $cm^{-3}$ |

| | |
|---|---|
| Physical Oxide Thickness ($t_{ox}$) | 5.0nm |
| Permittivity of $SiO_2$ | $\varepsilon_{ox}$= 3.9 |
| Wavelength | 600nm to 900nm |
| Gate to Source voltage ($V_{GS}$) | 0.8V |
| Drain to Source voltage($V_{DS}$) | 0.55V |
| Work function(Φ) Conventional MOSFET | 4.7eV |
| Work function(Φ) RC MOSFET | 4.7eV |
| Dimension | 100×80nm |

voltage of the fabricated structure extracted is 0.28V. All simulations were carried out at 300K and bias voltage Vgs=0.8V and Vds=0.5V. We use a light source which range between 600nm to 900nm wavelength. The models used in the simulations of RC MOSFET are Shockley–Read–Hall (SRH), Fermi Statistics (FERMI), AUGER, FLDMOB and lombaerdi mobility model (CVT) for transverse field dependence. The CVT model sets a general purpose mobility model to include concentration, temperature, parallel field and transverse field effects [4]. The SRH model accounts for recombination/generation effects and uses fixed minority carrier lifetimes. Ray trace method has been used in simulator to solve photo generation rate at each grid point[14].

## III. RESULTS AND DISCUSSION

In this paper, we compare transparent gate RC MOSFET and conventional MOSFET. The present analysis is carried out for a channel length, Lg=30nm, wavelength=600nm angle=900,Theta=900,and thickness of oxide, tox= 5.0nm, work function ΦITO=4.7Ev

Fig2. It shows the variation of surface potential along the channel for Conventional RC-MOSFET and Trasnsparent RC-MOSFET at two different drain voltages $V_{ds}$=0.5 V and 0.8 V The Variation of the bending energy gap due to the threshold voltage variation ($\Delta V_{th}$) is mainly governed by the increase of the drain voltage.

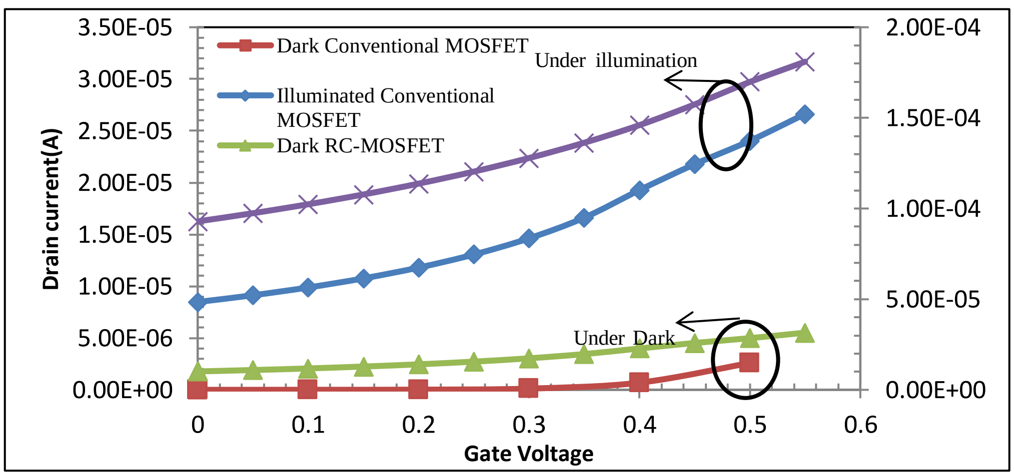


***Fig 2 Drain current Vs. Gate Voltage for $V_{DS}$= 0.5 in under illumination and dark RC-MOSFET & Conventional MOSFET.***

Fig 3 (a) & (b) Shows the Conduction band energy and Valence band energy variation along the channel with Electron Quasi Fermi Level at zero bias V=0 under dark and illuminated RC-MOSFET .

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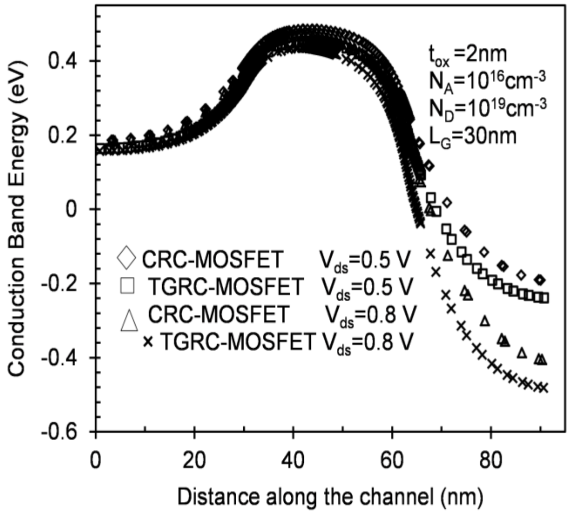


*Fig 3(a) Conduction band energy as a function of position along the Channel for CRC- MOSFET and ITORC-MOSFET at $V_{ds}$=0.5 V and $V_{ds}$=0.8 V.*

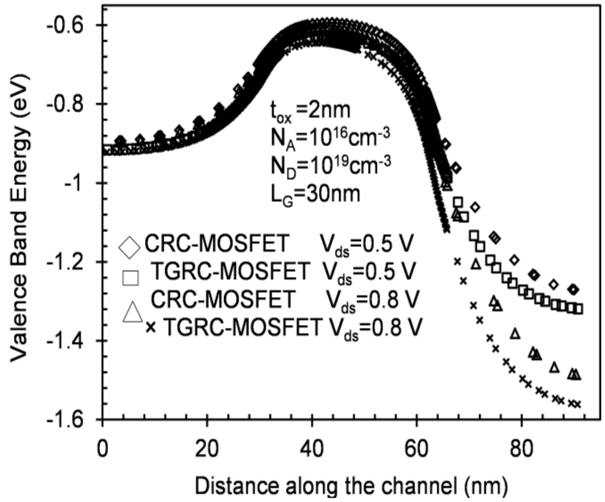


*Fig 3(b) Valance band energy as a function of position along channel for CRC- MOSFET and TGRC-MOSFET at $V_{ds}$=0.5V and $V_{ds}$=0.8 V.*

It shows the variation of conduction band and valence band with electron quasi fermi level along the channel length of RC MOSFET examined under dark and illuminated conditions & it is mainly due to electron quasi Fermi level which lies within the valence band and conduction band at source and drain region. It helps to analyze the motion of the carriers i.e. carriers always flow from the source to drain[16]. In normal operation of an n-channel MOSFET, free electrons move from source to drain but the current direction is from drain to source.

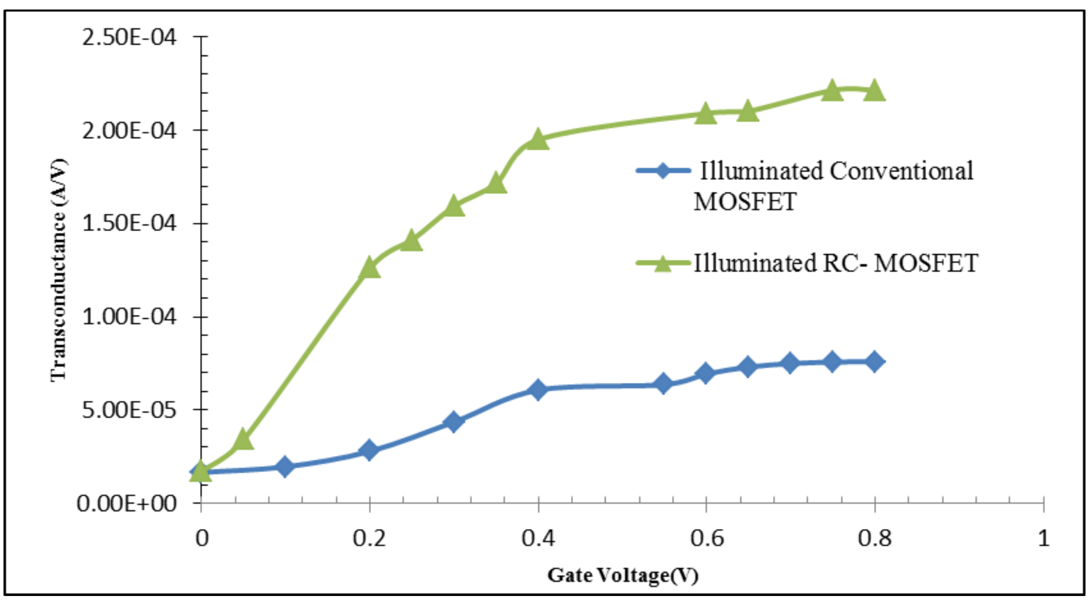


*Fig. 04: Transconductance Vs Gate Voltage for $V_{DS}$= 0.5 in under illumination RC-MOSFET & Conventional MOSFET*

Fig. 04: shows the variation of transconductance with respect to drain voltage under varying gate voltage from 0V to 0.8V. The drain current is very small till the device enters the inversion layer due to this the change in RC MOSFET gate transconductances is seen at higher gate voltage as shown in figure. The transconductance curve reaches a peak and then remains constant in the saturation region.

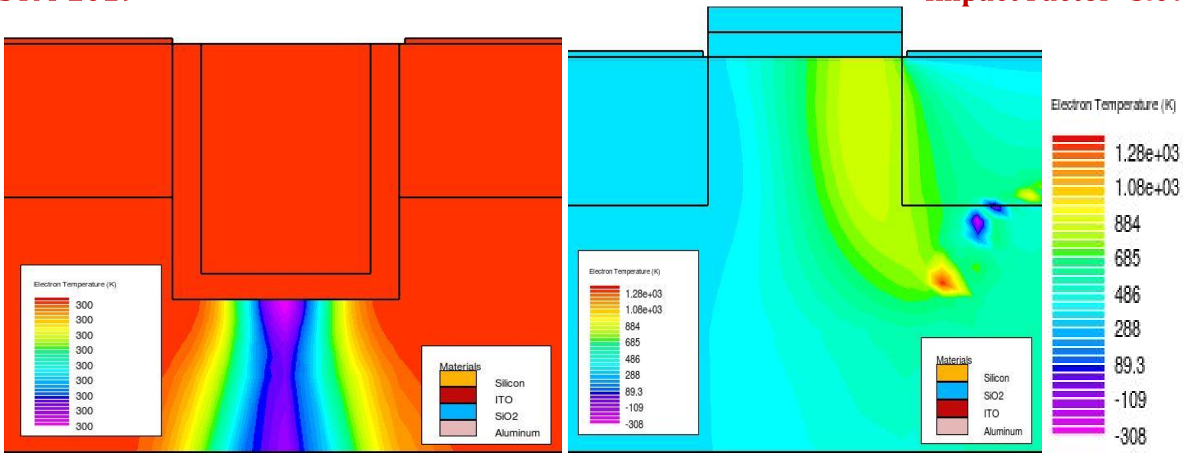


***Fig.5.(a) & (b) Contour plot of Electron temperature of RC-MOSFET & Conventional MOSFET.***

Fig. 5 (a) & (b) shows the variation of electron temperature along the channel length from source to drain under dark and illumination RC MOSFET. As it is clear from the results, an appreciable reduction in electron temperature for illuminated RC MOSFET at the drain side [4]. This is because incident radiation results in large amount of photon-generated electron hole pair in the depletion layer.

## IV. CONCLUSION

The work proposes an accurate 2D and 3D Ray trace model for the recessed channel (RC) MOSFET considering a indium tin oxide (ITO) transparent gate, which is demonstrated through simulations. An extensive analysis is carried out to find the impact of numerous device parameters like optical intensity, photo generation, oxide thickness, switching ratio, etc. on the light propagation, absorption, threshold voltage. Luminous analysis of transparent RC MOSFET has been studied using silvaco TCAD software. In this paper, we emphasize our focus on transparent ITO gate RC MOSFET for improved switching ratio and reduction in power dissipation. The high photogenration rate is attributed to improved transmittance of the transparent ITO gate RC MOSFET compared to conventional MOSFET. The work thus presents a transparent RC MOSFET design as a promising solution for high-performance optical applications in the visible range of wavelength.

## V. ACKNOWLEDGEMENTS

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