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Editorial

Numerical Investigation of a New Junctionless Phototransistor for High-performance and Ulta-low Power Infrared Communication Applications

H. Ferhati[1], F. Djeffal*[2], T. Bentercia[3]
[1,3]LEA, Department of Electronics, University of Batna 2, Batna 05000, Algeria
[2]LEPCM, University of Batna 1, Batna 05000, Algeria
*Corresponding author, email: faycal.djeffal@univ-batna2.dz, faycaldzdz@hotmail.com

Abstract

In this paper, a new junctionless optical controlled field effect transistor (JL-OCFET) is proposed to improve the device performance as well as achieving low power consumption. An overall optical and electrical performances comparison of the proposed junctionless design and the conventional inversion mode structure (IM-OCFET) has been developed numerically, to assess the optical modulation behavior of the OCFET for low power optical interconnections applications. It is found that, the proposed design demonstrates excellent capability in decreasing the phototransistor power consumption for inter-chip optical communication application. Moreover, the proposed device offers superior sensitivity and I_{ON}/I_{OFF} ratio, in addition to lower signal to noise ratio as compared to the conventional IM-OCFET structure. The obtained results indicate the crucial role of the junctionless (JL) design in enhancing the phototransistor performance and reducing the total power dissipation. Such a very sensitive OCFET can be very promising in the future low power optical receiver less compatible to CMOS modern technology for high-quality inter-chips data communication applications.

Keywords: *Junctionless, OCFET, Sensitivity, CMOS, Power consumption.*

In the long-haul telecommunication system, the huge power consumption by the traditional transmission wires is an important limitation which degrades the communication system performance in terms of cost and power dissipation [1-2]. However, optical interconnects are considered as a good solution to remedy the problems faced by electric wires and can refashion the inter-chip data communications systems [2-4]. The quality of optical receivers in optical wireless communication systems (*OWCS*) greatly determines the total power consumption in these systems, where it is crucial to develop receivers' with faster and efficient response. In this context, several published works deal with numerous optical receivers' structures based on Schottky barrier photodiode, *MSM* photodetectors and *FET*-based phototransistor [5-8]. This latter is considered as the most common device due to the opportunity for avoiding the high density of the optical circuits namely Trans-Impedance Amplifier (*TIA*) and the limiting amplifiers used in readout circuit. These amplifiers constitute a serious impediment in high-performance communication compatible with *CMOS* technology. Previously, different scientific endeavors have originated the *OCFET* with *IV* group material or germanium (*Ge*) sensitive gate [7-10]. The operating mechanism of this device dwells on exploiting the photo-generated carriers to modulate the band bending in the transistor, and thus changes the output current. However, the *Ge*-based OCFET operating at an appropriate wavelength of ($\lambda=1.55\mu m$), seems to be preferable for infrared communication due to the low optical band gap and the high carrier mobility offered by the *Ge* semiconductor. Besides, the excellent compatibility of the *Ge* material to be growing on Si platform leads to an ultra-high sensing performance, large bandwidth and efficient compatibility with state-of-art *CMOS* technology [11-12]. Nevertheless, the *Ge*-based *OCFET* has constantly well-known optical and electrical concerns namely the low sensitivity, high fabrication cost and power consumption.

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These persistent problems adversely affect the device optical and electrical performance for chip-level infrared optical communication. Hence, it is of great significance to propose lower cost designs, enhance the electrical behavior of the conventional *Ge*-based *OCFET* and make it consumes less power. For achieving this objective, the *JL* design can be considered as a paramount solution for reaching the desired improvement in fabrication process cost. In this framework, the main advantage offered by this design resides principally on avoiding the formation of the source/drain regions (n^{++}) and hence the establishment of junctions which seems to be an intractable task. Several experimental studies have confirmed the low-cost fabrication of the *JL* structure in comparison with the conventional *IM* design, where uniform *n*-type channel doping is sufficient to conduct the transistor [13-16]. In this paper, we propose a new *JL-OCFET* to enhance the device performance and achieve low power consumption. We perform also an overall optical and electrical performances comparison of the proposed *JL* design and the conventional one.

The proposed junctionless design is built principally on the suppression of the source/drain regions and adopting uniform *n*-type channel doping. In order to obtain an initial band bending, we assume the *Ge* gate in our proposed *JL-OCFET* with *p*-type doping. To this extent, Figure 1 shows the cross-sectional view of the proposed junctionless design, where N_{Ge} and N_{Si} are the *Ge* gate and the *Si* channel doping concentration, respectively, *L* represents the channel length and t_{Ge} refers to the germanium thickness.

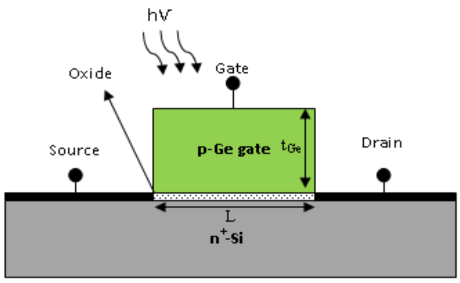
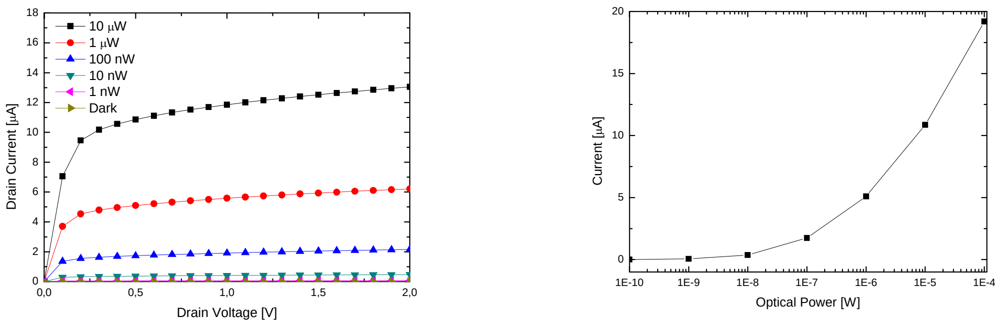


Figure 1. Cross sectional view of the proposed JL-OCFET phototransistor.

For our numerical investigation, we use Atlas 2-D simulator [16], to develop the numerical model of the proposed design that is more accurate and allows evaluating the *JL-OCFET* electrical behavior for the optical communication application. The photo-generated current in the *Ge* gate is calculated using the solution of Poisson's equation and continuity equations. To describe the carrier recombination mechanism, Fermi model and recombination models (Shockley–Read–Hall (*SRH*), Auger and surface recombination) are also included. Furthermore, due to the high level doping in the junctionless design, the carrier mobility is taken dependent on the doping concentration.

The principal aspect of the *OCFET* is the optical modulation behavior of the output current using different incident power with an appropriate wavelength value. Hence, in order to evaluate the proposed design regarding this aspect, we illustrate in Figure 2(*a*) the transfer characteristics of the proposed *JL-OCFET* with different incident power for a fixed gate voltage value ($V_{gs}=-1V$).

It is clearly observed from this figure, the simple and the good operating behavior of the *JL* design, where by increasing the optical power, we can change the band-bending in the channel and hence increase the drain current. This phenomenon is depicted clearly in Figure 2(b), where we observe the logarithmic dependency between the drain current and the incident optical power confirming the excellent operation of the proposed design. We can also notice the low dark current value of ($I_{off}=8\times10^{-13}A$) obtained by adopting the *JL* design, which can be attributed to the doping level of the channel in addition to the fully depletion mode of the device with $V_{gs}=-1V$.



(a) (b)

Figure 2. (*a*) *I–V* characteristics of the proposed *JL OC-FET* for different optical powers, with $N_{Si} = 1{\times}10^{18}\ cm^{-3}$, $N_{Ge} = 1{\times}10^{18}\ cm^{-3}$, $V_{gs} = -1V$ and $L=180nm$. (*b*) Drain current as a function of the optical power with $V_{gs} = -1V$ and $V_{ds} = 0.5V$

In order to elucidate the performance improvement of the proposed *JL* design over the conventional *IM-OCFET*, it is important to compare the electrical performance provided by both devices. For this purpose, Table 1 summarizes the overall electrical and optical performance comparison between both *IM* and *JL OCFET* designs. From this table, it is demonstrated that the device figures of merit (*FoMs*) regarding the power consumption are greatly improved compared to the conventional counterpart. Moreover, the proposed *JL* design exhibits superior sensitivity, which makes it valuable for low cost and low power consumption receiver for high-performance chip-level infrared communication applications.

Table1. Comparison summary between *IM* and *JL OCFET* designs

Symbol	**Conventional IM-OCFET design**	**Proposed JL-OCFET design**
Design variables:		
Wavelength λ *(nm)*	1550	1550
Drain voltage $V_{ds}(V)$	0.5	0.5
Gate voltage $V_{gs}(V)$	0.5	-1
Ge doping concentration *(cm^{-3})*	P type $1{\times}10^{18}$	N type $1{\times}10^{17}$
Si doping concentration *(cm^{-3})*	N type $1{\times}10^{18}$	P type $5{\times}10^{16}$
Channel length *L(nm)*	180	180
Si thickness $t_{Ge}(nm)$	120	120
Incident power *P (µW)*	10	10
Performance parameters:		
OFF current (I_{OFF}) *(nA)*	4	$8{\times}10^{-4}$
ON-OFF Current Ratio (I_{ON}/I_{OFF}) *(dB)*	65	396
Sensitivity *(S)*	1258	$1.25{\times}10^{6}$
Signal to Noise ratio *(SN)*	13	$12{\times}10^{3}$

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