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Improved performance of bipolar charge plasma transistor by reducing the horizontal electric field

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A B S T R A C T

In this paper, we have proposed a modified lateral bipolar charge plasma transistor (BCPT). The appropriate work function engineering is used to induce the electron-hole concentrations under different regions. The reduced work function difference and absence of oxide layer (t_{ox}) in the proposed lateral BCPT reduce the horizontal electric field (E_X) at the emitter. Also, reduced work function difference at base metal contact decreases the electric field at base-emitter and base-collector junctions. 2-D TCAD simulations of the proposed device reveal that there are evenly spaced output characteristic curves, improved cut-off frequency and breakdown voltage. The reduction in horizontal electric field about one-fourth compared to the conventional lateral BCPT results in realistic current gain (β) and reduced on-set voltage makes proposed device suitable for low power applications. The proposed device exhibits improved cut-off frequency (f_T = 7.5 GHz) compared to the lateral BCPT (3.7 GHz) and improved current gain (37.67) and same cut-off frequency (= 7.5 GHz) compared to the conventional BJT ($\beta = 26.5$ & $f_T = 7.5$ GHz).

1. Introduction

Bipolar junction transistors (BJTs) on silicon-on-insulator (SOI) substrate are strong candidates for digital integrated circuits (ICs), analog amplifiers, and mixed-mode circuits due to their well-controllable electrical characteristics, such as, high cut-off frequency, breakdown voltages, and current gain [1–5]. Apart from these benefits, the realization of BJTs with simplified fabrication process and low thermal budget have recently been proposed through charge-plasma (CP) concept, named as bipolar charge-plasma transistors (BCPTs) [1,4–7]. Among these, conventional lateral and vertical BCPTs have shown very high (unrealistic) current gain ≈ 4532–12,800 [1,8–10]. The very high current gain in these devices is due to an enhance horizontal electric field near the emitter contact and silicon interface that opposes the flow of minority carriers diffuse from the base to the emitter, as a result, the base current significantly reduces and current gain increases dramatically. However, the cause of degraded cut-off frequency of the conventional lateral BCPT is not clearly understood and could be due to large intrinsic gaps between emitter-base and collector-base regions [1], hence, limits the prospects for high-speed mixed-mode circuit applications.

Further, higher electric field at emitter varies the current gain, for different base currents, as a result, output characteristic curves are not evenly spaced [1,9,11]. Apart from this drawback, other adverse effects in the conventional lateral BCPT are

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lower breakdown voltage and increased onset voltage as compared to its counterparts (BJT). Even peak current gain is achieved at very high base-emitter voltage (0.95 V) which is not suitable for low power applications. Thus, to comprehend and address the issues of unrealistic current gain, cut-off frequency degradation, current gain variation, low breakdown voltage and the increased onset voltage in CP based devices, we have proposed a new lateral bipolar charge plasma transistor (BCPT) with reduced horizontal electric field. It was observed that the higher horizontal electric field near the emitter contact and silicon interface in the conventional lateral BCPT [1] is a major source of aforementioned issues. Therefore, in the proposed device, we have minimized the horizontal electric field in two ways (a) by removing the oxide layer below the metal electrodes, and (b) reducing ($\phi_{m,E}$ - ϕ_{si}). These modifications in the conventional BCPT yield (a) realistic current gain, (b) high cut-off frequency, (c) evenly spaced output characteristic curves, (d) improved breakdown voltage, and (e) reduced onset voltage. The electrical characteristics of the proposed and conventional devices are simulated and compared using SILVACO ATLAS (2-D Device simulator) [14]. We found that the proposed device possess better electrical characteristics than its counterpart conventional lateral BCPT.

Throughout our simulations: concentration dependent mobility model, field dependent mobility model, band gap narrowing model [12], concentration-dependent life-time model, Selberherr impact ionization model (BV_{CEO}) [13], and auger recombination model [14] are used with default silicon parameters. Moreover, we have facilitated the Klaassens model for Shockley-Read-Hall (SRH) recombination with intrinsic carrier lifetimes $n_{ie} = n_{ih} = 0.2$ μs [15]. Process resistances of base, emitter, and collector contacts are assumed as 400 Ω, 450 Ω, and 450 Ω, respectively, But, for concentrations ($> 10^{17}$ cm^{-3}), tunneling process can play an important role for rapid reduction of contact resistances. In this case, we can assume negligible contact resistances and can ignored for rest of the simulations [11,16].

2. Device structure and simulation parameters

A cross-sectional view of the proposed lateral BCPT and the conventional lateral BCPT are shown in Fig. 1 (a) and Fig. 1(b), respectively. The parameters used in our simulation for the conventional lateral BCPT are emitter length ($L_E = 200$ nm), base length ($L_B = 100$ nm), and collector length ($L_C = 400$ nm). The intrinsic gap between the metal contacts (L_s) is 100 nm. Oxide thickness (t_{ox}), silicon thickness (t_{Si}) and the buried-oxide thickness (t_{BOX}) are 5 nm, 15 nm, and 375 nm, respectively. The ultrathin silicon film doping (N_A) is 1×10^{13} cm^{-3} [1]. The simulation parameters for the proposed device are same as mentioned above except oxide thickness ($t_{ox} = 0$ nm) underneath of emitter/collector metal contacts, and an appropriate work function of metal contacts (electrodes) are used to reduce horizontal electric field as compared to the conventional lateral BCPT.

In conventional BJTs, doping requirements include: (1) ion implantation and (2) annealing (damage removal) and dopant activation (placing the dopant atoms on lattice sites). However, in BCPTs work function difference of metal contact and silicon (ϕ_m - ϕ_{Si}) causes accumulation of electrons and holes at the emitter/collector and base regions, thereby, eliminates the doping requirements essential for BJTs, this mechanism is known as the charge plasma (or electrostatically) doped devices [6]. For inducing the appropriate carrier concentration in different regions, the metal (electrode) work function for emitter/collector contacts ($\phi_{m,E}/\phi_{m,C}$) should be less than the work function of silicon ($\phi_{Si} = 4.73$ eV) to accumulate electrons [1,6,14]. However, the work function of metal in base contact ($\phi_{m,B}$) should be greater than the work function of silicon (ϕ_{Si}) for the accumulation of holes. In general, the work function difference between metal and silicon (ϕ_m - ϕ_{Si}) must be greater than $\sim \pm 0.5$ eV for the accumulation of electrons or holes [17]. The silicon thickness of 15 nm is chosen, which is less than Debye length. The work

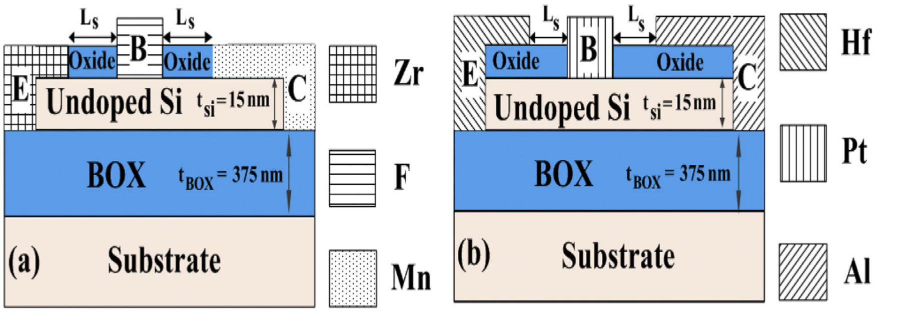

Fig. 1. The schematic diagrams of (a) proposed lateral BCPT and (b) conventional lateral BCPT [1].

Table 1
List of metal workfunction and workfunction difference with silicon.

Devices/work-functions	$\phi_{m,E}$ (eV)	$\phi_{m,B}$ (eV)	$\phi_{m,C}$ (eV)	$\phi_{m,E} - \phi_{si}$ (eV)
Conventional lateral BCPT	3.9	5.65	4.28	−0.83
Proposed lateral BCPT	4.05	5.4	4.1	−0.68