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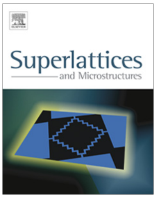

High permittivity material selection for design of optimum Hk VDMOS

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ABSTRACT

In this paper, we have proposed a novel approach for the selection of high permittivity (Hk) material for the optimum design of Hk vertical double diffused MOS (VDMOS). The optimum design parameters under consideration are geometry, doping concentration and breakdown voltage (BV). We have investigated reliability and sensitivity of the Hk VDMOS using BV and figure-of-merit (FOM) analysis, respectively. Further, we have compared results of Hk VDMOS with superjunction (SJ) VDMOS and conventional VDMOS. The observation clarifies that the higher doping concentration can be used in the drift region of Hk n-pillar when comparing with a SJ VDMOS and conventional VDMOS without affecting the BV. Due to this, the area-specific ON-resistance ($R_{on}A$) of the Hk VDMOS is less as compared to the SJ VDMOS and conventional VDMOS with the same BV. Using FOM, we can select the Hk material for maximum doping concentration and maximum BV with lowest $R_{on}A$ for specific design application of Hk VDMOS.

1. Introduction

The conventional silicon-limit (Si-limit) has been optimized by superjunction (SJ) structure concept [1,4,5]. The advantages of Si-limit optimization are improved breakdown voltage (BV) and optimized area specific ON-resistance ($R_{on}A$) in the power device applications. However, charge imbalance (CI),

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charge termination (CT) and process difficulty to form the high aspect ratio of cell pitch-to-epitaxial layer thickness with higher doped n/p pillars still remain key issues [1]. The shallow angle ion implantation through the deep trenches was proposed to overcome these issues [2]. Nevertheless, these improvements are not satisfying the desire requirement of power device fabrication. Even, previously reported models have not shown much optimization of CI and CT [2,3,5]. Recently, for the solution of these issues, a new High-k (Hk) vertical double diffused MOS (VDMOS) has been introduced [6,7,8,12,13]. This Hk VDMOS is using separate Hk permittivity pillar with integrated n-drift layer. The advantage of Hk VDMOS is to avoid impurity inter-diffusion within the pillar, rectify CI and optimize $R_{on}A$ without affecting BV.

In this paper, we have performed reliability and sensitivity analysis of Hk material for the optimum design of Hk VDMOS. The BV and figure-of-merit (FOM) analysis are important for the selection of suitable Hk material. The Hk materials interface may be possible with Si, due to lattice match [9,11]. Hereafter, we have tested the reliability of many Hk materials like lead monoxide (PbO), stannous oxide (SnO), hafnium oxide (HfO_2), barium strontium titanate (PZT) and lead telluride (PbTe). These are some candidates of Hk material which like polymer based composites [10] having the value of electrical permittivity varies from $12 \sim 1300$. Among all these types of Hk materials, PbTe has the highest static electrical permittivity (412 ± 40 at 300 K and 1267 ± 50 at 4.2 K) [15,16]. Further, we have compared the characteristics of Hk VDMOS, SJ VDMOS and conventional VDMOS for various geometry dimensions. In addition, the Hk-pillar has been used with various types of Hk material to control and observe the charge flow in the Hk VDMOS drift region.

This paper is organized as follows:- Hk VDMOS device specification and advantages are discussed in Section 2. The electric field model for Hk VDMOS is discussed in Section 3. The results and discussion are presented in Section 4. Conclusion is presented in Section 5. Parameter and symbols used in this paper are shown in Tables 1 and 2, respectively.

Table 1
Hk/SJ/conventional VDMOS design specification.

Parameter name	Symbol
n-pillar width	a
Hk/n-pillar width	b
Unit cell pitch	$a + b$
Epitaxial layer thickness	t
Source thickness	d
Drain thickness	d
channel length	l_c
Gate thickness	d+l_c

Table 2
Analytical symbol and their description with SI unit.

Symbol	Description	Unit
N_a	Acceptor doping concentration	atom/cm^3
N_d	Donor doping concentration	atom/cm^3
ρ	Charge density	/cm^2
ϵ	Permittivity	F/cm
ϵ_{Si}	Permittivity of silicon	F/m
ϵ_{Hk}	Permittivity of Hk material	F/m
E_x	Lateral electric field	V/cm
E_y	Vertical electric field	V/cm
E_c	Critical electric field	V/cm
BV	Breakdown voltage	Volt
$R_{on}A$	Area specific on resistance	mΩ cm^2
FOM	Figure of merit	MW/cm^2
f_r	Factor ratio	Unit less
$H - K_r$	Hk pillar width ratio	Unit less
κ_r	Hk permittivity versus silicon permittivity ratio	Unit less