Optimum Design of the Interdigitated CB Structure

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Abstract- **Some measures are provided for the optimum design of specific on-resistance R_{on} and breakdown-voltage V_B of interdigitated CB (Composite Buffer) MOSFET, including introducing opposite type impurity into the P region near the N^+ contact, separating P region from N region with an oxide film, and a groove in the N region near the P^+ contact. The new relationship between the R_{on} and V_B, which proved by numerical device simulation, are more exact and minute than the qualitative results before.**

Index Terms— **interdigitated, Composite Buffer(CB) structure, specific on-resistance, breakdown voltage.**

I. INTRODUCTION

Traditional power MOSFET is limited by:

$$R_{on} = 8.2 \cdot 10^{-9} \cdot V_B^{2.5} \ \Omega \cdot \mathrm{cm}^2 \qquad (1)$$

where R_{on} represents specific on-resistance and V_B is breakdown-voltage. Eqn. (1) is called "silicon limit", which prevents it from being used in the field of high voltage and high current density. The COOLMOST realized in 1998 breaks the above limit, and takes as a milestone of power device [1]. The reason for low specific on-resistance of COOLMOS under high breakdown-voltage lies in the voltage-sustaining layer (Composite Buffer, simply as CB) used in it [2-6]. CB structure consists of some neighbored P and N regions shown in Fig. 1. Small on-resistance is achieved by transporting electrons through highly doped N regions while on, and high breakdown-voltage is achieved by the charge compensation effect of P and N regions while off.

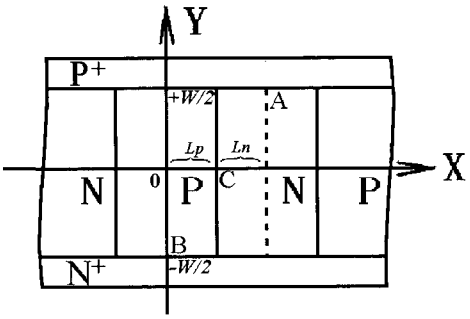

Fig. 1. Structure of CB.

As the CB structure has many patterns, the interdigitated CB is the simplest one. In this article some measures will be provided for the optimum design of it.

II. OPTIMUM DESIGN

The sketch map of interdigitated CB structure is shown in Fig. 1. The region from $x = 0$ to $(L_p + L_n)$, $y = -W/2$ to $+W/2$ is considered as a cell which includes a half of P and N regions. Let L_n/L_p denoted by a, doping concentration in N region denoted by N_D, and N_A in P region. According to charge compensation we get :

$$N_A = N_D a \qquad (2)$$

The expression of specific on-resistance of CB structure can be achieved referring to [3,5]:

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$$R_{on}=\frac{A^{17/36}}{2.58\cdot 10^{4}q^{1/12}\varepsilon_S^{11/12}}\cdot \frac{V_B^{43/18}(1+a)^{23/12}(L_p/W)^{11/12}c_A^{11/12}[1+F(\alpha_P)\frac{s_P}{L_p}\frac{L_p}{W}]^{17/36}}{a\alpha_A^{11/12}} \tag{3}$$

where A, q, ε_S, V_B, W, c_A, α_P, $F(\alpha_P)$, s_P have the same definitions as those in [3,5], and $L_P(1 + a)$ corresponds to b. In this paper the values of α_P will vary instead of the constant value of 1.

The ratio of lateral and vertical dimensions of P or N region in CB is limited by process technology, which can't get small infinitely. Supposing the technologically achievable one is b/W, then $L_p/W = (b/W)/2$ when $a \geq 1$ or $L_p/W = (b/W)/2a$ when $a < 1$. Obviously b/W shouldn't be too large or the charge compensation will not work well. The reasonable range may be 0 to 0.5. The value of L_n/L_p (that is, a) should be larger than zero. α_A should be in the range of 0 to 1 because α_A represents the ratio of electrical field caused by impurity and terminal voltage at point A. If $\alpha_A > 1$ the bottom of N region will not be depleted fully which can't be the optimum situation. The optimum results can be derived by varying the values of α_A and a for a given breakdown-voltage V_B and the technologically achievable aspect ratio b/W. Each b/W corresponds to an optimum a and α_A, shown in Fig. 2 (dashed line), from which specific on-resistance can be obtained by (3).

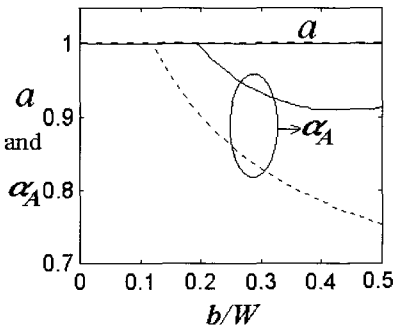

Fig. 2 Optimum α_A and a (solid curve – with three measures; dashed curve – without measures.)

According to our analysis, the breakdown of a typical CB structure will happen at point A or B before C, shown in Fig. 1, which determines the relationship of V_B and R_{on}. If the breakdown at point A and B can be avoided, then the specific on-resistance will be decreased for a given breakdown voltage. In fact, the breakdown at point B can be avoided by introducing opposite type impurity into the bottom of N region, and the breakdown at point A can be avoided by a groove nearby. With these measures only breakdown at point C should be considered, and a smaller specific on-resistance can be achieved.

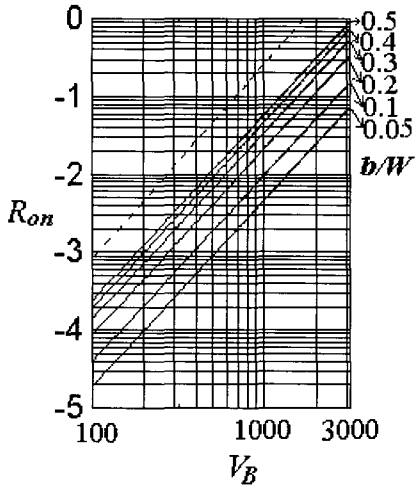

Fig. 3 Optimum R_{on} and V_B.

Furthermore, the breakdown at point C can also be improved by separating the P region from the N region with a thin oxide film. Since the breakdown voltage should be determined by the condition of the ionization integral along a field line equal to one, only the larger one of two integrals along the field line through point C either in P region or N region needs to be considered. So the minimum specific on-resistance can be achieved, which is only 64% to 80% of that without measures (refer to Table 1). The most optimum values of a and α_A can be obtained according to E (3), shown in Fig. 2 (solid line), and the most optimum specific on-resistance can be expressed approximately as follows (error less than 1%):

$$R_{on}=V_B^{1.32}b^{0.917}\cdot 10^{-7}\begin{cases}1.9+2.1(b/W)^{0.8} & 0\leq b/W\leq 0.3\\ 1.47+1.585(b/W)^{0.2} & 0.3\leq b/W\leq 0.5\end{cases} \tag{4}$$

The specific on-resistance R_{on} versus breakdown-voltage V_B for some given values of b/W can be achieved

TABLE. 1 Simulation parameters and results

Parameters and Results		Corresponding to different values of *b/W*					Origin of data
b/W		0.1	0.2	0.3	0.4	0.5	Given
α_A		1.0000	0.9955	0.9334	0.9109	0.9136	Fig. 2
a		1	1	1	1	1	Fig. 2
$E_0(10^5 V/cm)$		1.9638	1.8643	1.8385	1.8186	1.8043	Eqn.7 [3]
W (μm)		30.553	32.184	32.636	32.993	33.254	V_B/E_0
L_p (μm)		1.5276	3.2184	4.8954	6.5985	8.3136	$W \times b/W/2$
$N_D(10^{15}cm^{-3})$		11.21	5.0287	3.057	2.1911	1.7361	Eqn.3a[3]
$N_A(10^{15}cm^{-3})$		11.21	5.0287	3.057	2.1911	1.7361	Eqn. 2
Doping in p region (μm)		3.553	4.184	5.636	4.993	5.254	Width of n region
Groove in n region (μm)		0.1	0.1	0.1	0.1	0.1	*d1*
Groove in n region (μm)		0.7552	2.4378	3.4928	5.078	5.5148	*d2*
Groove in n region (μm)		1.6	1.5	1.8	1.6	1.7	*d3*
Groove in n region (μm)		1.4	1.5	1.2	1.4	1.3	*d4*
V_B (V)		600	600	600	600	600	Given
$R_{on}(\Omega \cdot cm^2)$		0.00287	0.0063	0.0101	0.01385	0.01728	Eqn. 3
Simulation results of VUMOS	V_B (V)	553	549	550	555	551	
	$R_{on}(\Omega \cdot cm^2)$	0.00348	0.0071	0.0114	0.0153	0.0193	
	Corrected $R_{on}(\Omega \cdot cm^2)$	0.0029	0.00635	0.0102	0.0138	0.0173	
$R_{on}(\Omega \cdot cm^2)$ (no measures)		0.00361	0.00848	0.0141	0.0204	0.027	Eqn. 3

from (4), shown in Fig. 3(solid line), where dash line represents the "silicon limit" referring to (1).

III. Simulation Results

Some of the optimum results are chosen to simulate with device simulation tool MEDICI [7]. The structure for simulation is shown in Fig. 4(a). And the groove near the point A is shown in Fig. 4(b), which is like a quarter of an ellipse and can be described by the parameters of *d1*, *d2*, *d3* and *d4*. The thickness of oxide film between the P and N regions is 0.1um. The structure for simulation is generated by triangular grid.

According to table 1 the simulation results of V_B are about 10% less than the theoretical ones because the theoretical values are corresponding to a completed CB structure while the simulation values are not. The values of R_{on} are 10% larger because the depleted region caused by the build-in potential between the P and N regions, also the channel resistance of the active region, have not been taken into consideration. The values corrected by considering the above two facts are almost the same as the theoretical ones. So we may draw the conclusion that the simulation results are in coincidence with the theoretical values and the theory is precise enough.

A device with V_B equal to 600V and R_{on} equal to $35m\Omega \cdot cm^2$ is published in Ref. [2]. In our paper R_{on} is only 50% of it even in the worst case (*b/W* equal to 0.5).

IV. Discussion

Some measures for the optimum design of interdigitated CB MOSFET are brought forward which are proven by simulation. The minimum R_{on} for certain

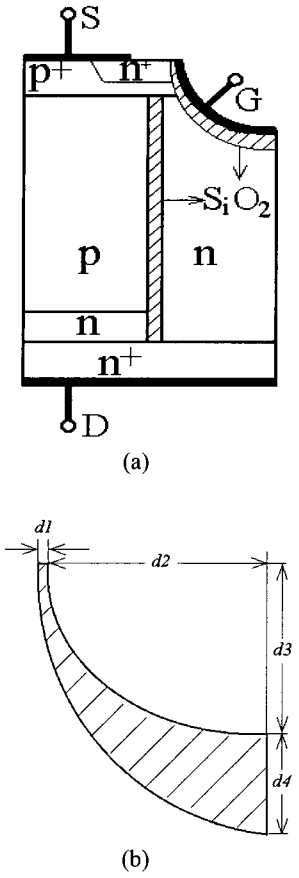

Fig. 4 (a) Structure for simulation (b) Dimensions of the groove.

V_B is achieved corresponding to various values of b/W. Another possible method to reduce the peak field at the point A is to introduce some impurities of opposite type of conductivity (i.e, p-type) to the place around the point A. However, such a method will increase the specific on-resistance.

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