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# OPTIMIZATION OF A POWER MOSFET AND ITS MONOLITHICALLY INTEGRATED SELF-POWERING CIRCUITS

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**Abstract**. The paper presents a physical structure optimization of an integrated semiconductor device design: a power MOSFET and other vertical transistors are integrated within the same die, introducing a novel self supplied power transistor. This integrated optimal design leads to complex optimization problems with close constraints. The main constraint deals with the avalanche phenomenon that is formulated by multiple integral expressions of numerical functions. The paper focuses on two aspects: the integral formulation of the avalanche model and more specifically its gradient computation in the view of applying a gradient-based optimization algorithm, and the comparisons of several optimization methods on this problem.
**Keywords**: Genetic optimization algorithms, gradient-based optimization algorithm, integration constraint, Power MOSFETs, design of monolithically integrated circuits.

## I. INTRODUCTION

During the past several years, power MOSFETs have become established in a wide variety of power control and conversion applications. Optimizing the structure of this component has already been achieved for different applications [1]. The paper deals with the optimization of the power losses of a power MOSFET integrating the self-powering circuit on the same substrate of the main MOSFET with a close integration constraint (avalanche phenomenon). The paper focuses on the integration constraint of a power MOSFET, which will be partially presented in the next section. Then, the gradient-based optimization algorithms as the sequential quadratic programming (SQP) method [4] and several genetic optimization algorithms [5][6] are compared. Specifically, partial derivative computations are introduced and discussed.

## II. AVALANCHE PHENOMENON FOMULATION

The avalanche phenomenon can be analytically defined by a sum of three terms as presented in Eqn.(1), where $J$ is the reverse current density, $M_N$, $M_P$ and $M_g$ are respectively the multiplication coefficients for the electrons, the holes and the thermal current densities (see Eqn (2)). The criterion to constrain for design is the integral expression $F(a)$ defined by Eqn (3).

(1) $$J_{avalanche}(a) = M_N(a).J_N(End(a)) + M_P(a).J_P(Begin(a)) + M_g^{th}(a).J_g^{th}(a)$$

(2) $$M_N(a) = \frac{1}{1-F(a)} \qquad M_P(a) = \frac{z(End(a),a)}{1-F(a)}$$

(3) $$F(a) = \int_{Begin(a)}^{End(a)} e^{-\int_{Begin(a)}^{x} \alpha_N(y,a)-\alpha_P(y,a)dy} .\alpha_N(x,a)dx \quad , \quad \text{with} \quad \alpha_P(x,a) = A_P.e^{\left(-\frac{B_P(x,a)}{|E(x,a)|}\right)} \quad \alpha_N(x,a) = A_N.e^{\left(-\frac{B_N(x,a)}{|E(x,a)|}\right)}$$

$$z(x,a) = e^{-\int_{Begin(a)}^{x} \alpha_N(y,a)-\alpha_P(y,a)dy} \quad g_2(x,a) = z(x,a).\alpha_N(x,a) \quad g_1(x,a) = \alpha_N(x,a) - \alpha_P(x,a)$$ and $a = \{X_{jn}, X_{jp}, P_{p0}, N_{n0}\}$.

In the full paper, these expressions will be physically detailed. In this digest, only the mathematical aspects are developed. $E(x,a)$ is computed by an iterative process with a convergence criterion[2]. To compute such a complex expression, namely a double integral expression, the paper proposes to apply the Adaptive Simpson method (ASM) [3].

## III. GRADIENT CALCULATION

Accurate gradients are very important for the convergence of gradient based optimization algorithms [3]. The paper formulates the gradients of $F(a)$ according to any physical parameter $X$ where $X \in a$. From Eqn. (1) to Eqn. (3), the derivatives of $F(a)$ according to $X$ are defined by equations (4) and (5), where the multiple integrals are also computed by ASM[4]. Such an approach is time consuming, but is more accurate than a finite difference computation [3].

(4) $$\frac{\partial F(a)}{\partial X} = \int_{Begin(a)}^{End(a)} \frac{\partial g_2(x,a)}{\partial X} dx + \frac{\partial End(a)}{\partial X}.g_2(End(a),a) - \frac{\partial Begin(a)}{\partial X}.g_2(Begin(a),a)$$

(5) $$\frac{\partial g_2(x,a)}{\partial X} = \left(\frac{\partial \alpha_N(x,a)}{\partial X} + \alpha_N(x,a).\left[-\left(\int_{Begin(a)}^{x} \frac{\partial g_1(y,a)}{\partial X} dy\right) + g_1(Begin(a),a).\frac{\partial Begin(a)}{\partial X}\right]\right).e^{-\int_{Begin(a)}^{x} g_1(y,a)dy}$$

## VI. OPTIMIZATION ALGOTHM AND RESULTS

This section presents a design problem of an integrated VDMOS using several algorithms:

- a deterministic algorithm: SQP [4].
- some genetic algorithms: Evolution Strategy (ES) algorithm [5], Restricted Tournament Selection (RTS) with the self-adaptive Simulated Binary Crossover (vSBX) [6].

The optimization results are presented in Table 1. In the optimizations, the acceptable absolute accuracy of the objective function is 0.1. Fifty optimizations have been carried out by each genetic algorithm with different algorithm parameters to choose - see Table 1 - (the generation, the children and the number of parents for ES algorithm, the generation, the individuals -or children- for RTS-vSBX algorithm). SQP algorithm is applied several times with different initial values of physical parameters. The best results of SQP algorithm is shown in Table. 1. As foreseeable, SQP gives a local optimum.

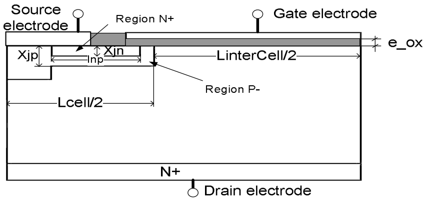


**Figure 1**. Geometry of a half VDMOS cell

**Table 1. Optimization results with different algorithms (ng generations, ni individuals, ni children and np parents)**

| Algorithm | ES(ng=500, nc=40, np=6) | ES(ng=600, nc=40, np=6) | RTS-vSBX (ng=500, ni=40) | RTS-vSBX (ng=600, ni=40) | SQP |
|---|---|---|---|---|---|
| Objective Function (Joule) | **9.92** | **9.86** | **10.03** | **9.82** | **13.91** |
| Calculation time (minute) | **46** | **45** | **56** | **57** | **107** |
| Avalanche constraint $F(a)$ | **0.00107** | **0.00079** | **0.00287** | **0.00195** | **0.00064** |
| $L_{cell}$.1e-4 (cm) | 52.56 | 52.17 | 57.46 | 51.95 | 31.45 |
| $L_{interCell}$. 1e-4 (cm) | 52.59 | 52.20 | 57.48 | 52.77 | 78.77 |
| Number of cells $N_{cell}$ | 3000 | 3000 | 2895 | 3000 | 2530 |
| $L_{np}$. 1e-4 (cm) | 5.14 | 5.55 | 5.00 | 6.60 | 10.00 |
| e_ox. 1e-7 (cm) | 58.7 | 53.5 | 55.2 | 53.9 | 120.00 |
| $X_{jn}$. 1e-4 (cm) | 0.96 | 0.97 | 1.07 | 1.14 | 0.9 |
| $X_{jp}$. 1e-4 (cm) | 6.00 | 6.00 | 6.00 | 6.01 | 6.00 |
| $P_{p0}$.1e16 (at/cm$^3$) | 5.5 | 6.5 | 7.6 | 8.3 | 7.00 |
| $N_{n0}$ . 1e19 (at/cm$^3$) | 15.0 | 5.2 | 7.7 | 6.7 | 10.0 |

In our case, these optimization algorithms give a range of optimal solutions for a same objective function value. Comparing these solutions, there are huge differences between physical parameters carried out by different optimal solutions and small differences between geometrical parameters. A discussion on these parameters will be presented in the full paper.

## VI. CONCLUSION

In the paper, several aspects of the integrated power semiconductor device modelling for sizing by optimization are discussed. The avalanche phenomenon is well computed. Finally, several optimization algorithms are compared.

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