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### ► To cite this version:

Stéphane Alves, Frédéric Morancho, Jean Michel Reynes, J. Margherita, I. Deram, et al.. Experimental validation of the "FLoating Island" concept: A 95 Volts Vertical breakdown voltage FLIDiode. 7th International Seminar on Power Semiconductors (ISPS'04), Aug 2004, Pragues, Czech Republic. pp.47-50. hal-01005655

**HAL Id: hal-01005655**

**<https://hal.science/hal-01005655>**

Submitted on 13 Jun 2014

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# Experimental validation of the “FLoating Island” concept: A 95 Volts Vertical breakdown voltage FLIDiode

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## Abstract

*In this paper, the “FLoating Island” concept has been implemented on silicon: a FLIDiode has been built for the first time. Experimental results confirm the predictive 2D simulations: this new diode exhibits an important breakdown voltage (about 95 Volts) with a N<sup>-</sup> epitaxial layer doping concentration ( $1.1 \times 10^{16} \text{ cm}^{-3}$ ) usually dedicated to 50 Volts devices. These measurements validate the “FLoating Island” concept and the efficiency of the original edge cell that will be used in the FLIMOS technology: it can be expected that the specific on-resistance of the FLIMOSFET will be drastically reduced compared to the conventional VDMOSFET.*

**Keywords:** Floating Island, FLIMOS, Superjunction, Breakdown Voltage, Specific On-Resistance

## INTRODUCTION

The power MOSFET is a very important device in many power electronics applications for its well-known intrinsic advantages: high input impedance, short switching time and thermal stability. The increase in electronic contents in today’s automobiles requires a higher voltage, and 42 V batteries will be the most satisfactory standard. The incentive of this work is to address the rising need of this class of MOSFETs in Automotive applications. Thus, 85V power MOSFET will be the emerging device of choice for these applications. In power electronics circuits, the power MOSFET is mainly used as a switch, in which the specific on-resistance  $R_{\text{ON,sp}}$  and the breakdown voltage  $BV_{\text{dss}}$  are the two most important parameters to be considered. Actually, to reduce the conduction losses in a MOSFET, its specific on-resistance must be reduced. The Vertical Double diffused MOSFET structure — VDMOSFET — (Fig. 1) is widely used as a power MOSFET. This structure is based upon the double diffusion of the P-body and N<sup>+</sup> source regions using the edge of the polysilicon as a masking boundary. The voltage handling capability of this structure is given by the breakdown voltage of the “P-body/N-epilayer” junction, that is strongly dependent on the thickness and the doping of the

lower doped region (i.e. the N<sup>-</sup>epilayer region in the case of N-channel VDMOS transistors) [1].

Today, advances in process technology have improved transistor’s packing density and consequently transistor’s specific on-resistance. However improvements in specific on-resistance have been limited by material and breakdown voltage, which required a relative thick and lowly doped epitaxial layer. Recently, several MOSFET configurations have been proposed to reduce specific on-resistance while keeping a high breakdown voltage: P Floating Islands devices [2], [3], [4] and Superjunction devices [5].

P FLoating Islands unipolar devices — FLIMOSFET [2], Opposite Doped Buried Regions (ODBR) MOSFET [3] and P-buried layer Schottky Barrier Diode [4] — have recently caught the attention of many researchers because they are good challengers of Superjunction devices under 600 Volts [2]; furthermore, the technology needed to manufacture such as devices is less complex than the Superjunction devices technology [4].

In this paper, new Vertical N-channel FLIMOSFETs dedicated to automotive applications (12 V / 42 V dual batteries, i.e. below 100 V breakdown voltage devices) are proposed; these FLIMOSFETs comprise only one P floating island between drain and source: it will be shown that, even in low voltage applications, they exhibit a better ”specific on-resistance / voltage handling

capability” trade-off than the conventional Vertical DMOSFETs. Then, the “Floating Island” concept will be experimentally validated by the realization of a Floating Island Diode (FLIDiode).

## FLOATING ISLANDS MOS PRINCIPLE

### Principle.

Schematic cross-sections of the conventional Vertical DMOSFET (VDMOSFET) and the newly

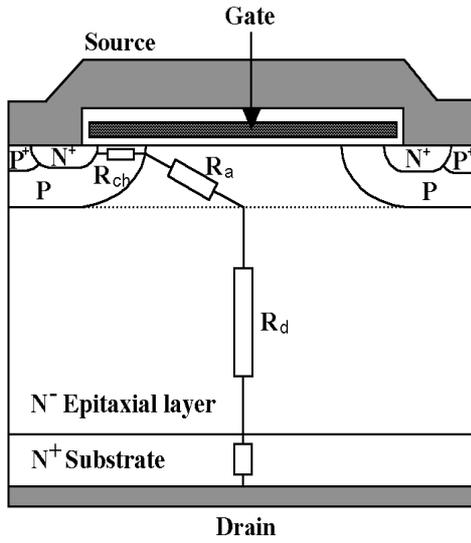


Fig. 1: Conventional Vertical DMOSFET.

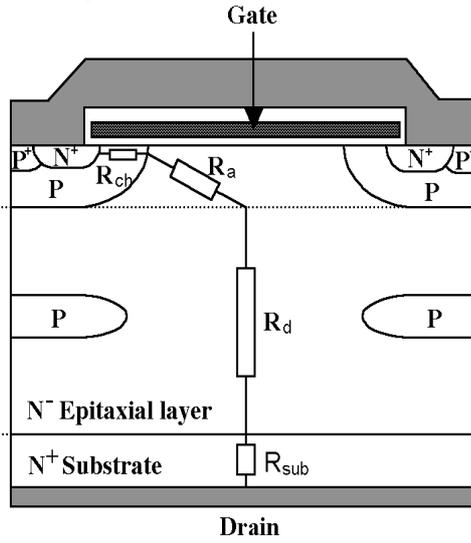


Fig. 2: Vertical FLIMOSFET with one Floating P buried layer between drain and source.

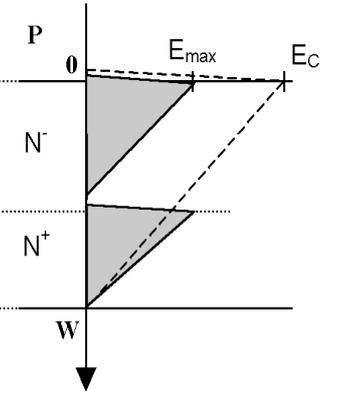


Fig. 3: Electric field distribution in the conventional VDMOSFET and in the FLIMOSFET.

In other words, to reach the same blocking voltage as with a conventional VDMOSFET, the  $N^-$  epitaxial layer doping concentration of the FLIMOSFET can be strongly increased.

### Device parameters.

For instance, when the voltage handling capability of the two devices is about 85 V, the  $N^-$  epitaxial layer doping concentration required is equal to  $5.5 \times 10^{15} \text{ cm}^{-3}$  for the conventional VDMOSFET and to  $1.1 \times 10^{16} \text{ cm}^{-3}$  for the FLIMOSFET.

## RESULTS AND DISCUSSION

In order to validate the “Floating Island” concept, it has been decided to study and to realize a FLIDiode. This study concerns the reverse behavior of the FLIDiode compared to a conventional  $PN^+N^-$  Diode. The main device parameters of the two Diodes are given in Table 1. Compared to the conventional Diode, the main

developed Vertical FLIMOSFET are shown in Fig. 1 and 2. The essential difference is the introduction of a P buried layer (called Floating Island) in the  $N^-$  epitaxial layer; this P buried layer is located under the PHV/ $N^-$  plane junction in order to divide, under reverse bias conditions, the maximal electric field in two parts (Fig. 3), allowing the improvement of the breakdown voltage for the same  $N^-$  epitaxial layer doping concentration.

	Conventional VDiode	Vertical FLIDiode central cell	Vertical FLIDiode edge cell
$N^-$ epitaxial layer thickness ( $\mu\text{m}$ )	4.75	4.05	4.05
$N^-$ Epitaxial layer resistivity ( $\Omega\cdot\text{cm}$ )	1.05	0.50	0.50
Floating P maximum doping concentration ( $\text{cm}^{-3}$ )	--	$10^{17}$	$10^{17}$
Lateral Floating P maximum doping concentration ( $\text{cm}^{-3}$ )	--	--	$10^{19}$

Table 1: Main device parameters of the conventional 91 Volts Diode and the Vertical 95 Volts FLIDiode.

difference is the introduction of a P buried layer in the  $N^-$  epitaxial layer.

Concerning the OFF-state, it should be noted that 2D simulations confirm what we expected (Fig. 4): the maximal electric field is divided in two parts located around the two junctions (i.e. the P-body/ $N^-$ epilayer and the P-buried layer/ $N^-$ epilayer junctions); Figure 4 shows the doping concentration (Fig. 4a), electric field distribution (Fig. 4b) and potential distribution

(Fig. 4c) at breakdown in the central cell of the FLIDiode.

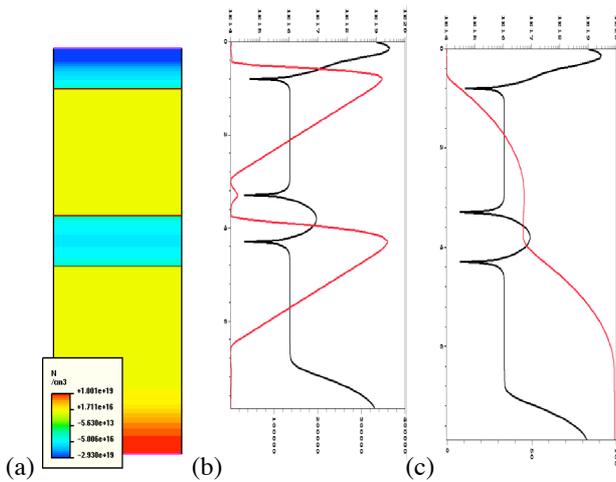


Fig. 4: FLIDiode : Doping concentration (a), Electric field distribution (b), and potential distribution (c) at breakdown.

The schematic cross-section of the edge cell of the FLIDiode is presented Figure 5.

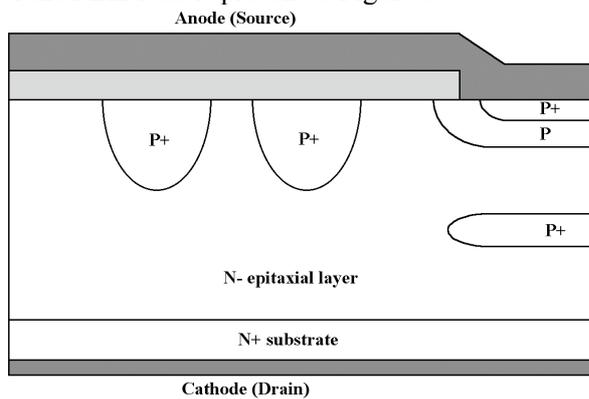


Fig. 5: Edge cell of the Vertical FLIDiode.

In our study, the simulated FLIDiode breakdown voltage of the central cell is about 95 V (Fig. 4c); the breakdown voltage of the edge cell is also 95 V. At breakdown, this structure is in non punch through configuration. The breakdown occurs in the P<sup>+</sup>N<sup>-</sup> junction and the electric field is math linear by parts. The electric field is divided by the P<sup>+</sup> floating islands. We can also observe that the potential is parabolic by parts, and is sustain by the N<sup>-</sup> layers. In fact, it can be observed that there is no voltage drop in the P<sup>+</sup> floating islands.

In the edge cell, two lateral P Floating Islands are introduced in the N<sup>-</sup> epitaxial layer and the positions of the two lateral P Floating Islands have been optimized: the optimal position is obtained when the maximums of the electric field in the three Floating Islands and at the PHV cylindrical junction are equal. Figure 6 presents the doping concentration for the edge cell of the Vertical FLIDiode. Figure 7 shows 2D simulation

of the electric field distribution at breakdown for the edge cell of the Vertical FLIDiode. The lateral Floating Island depth is very important: the more the lateral Floating Islands are deep, the more the potential lines are pushed away in the volume. Then the breakdown occurs at the PHV plane junction.

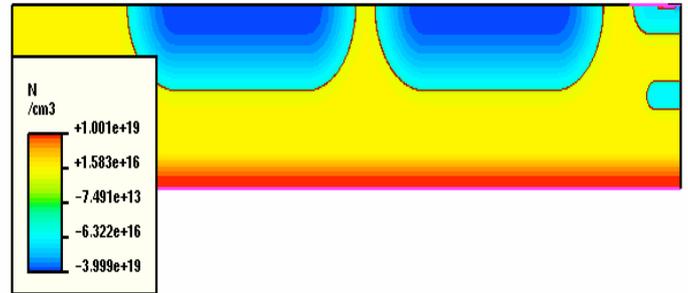


Fig. 6: Doping concentration for the edge cell of the Vertical FLIDiode.

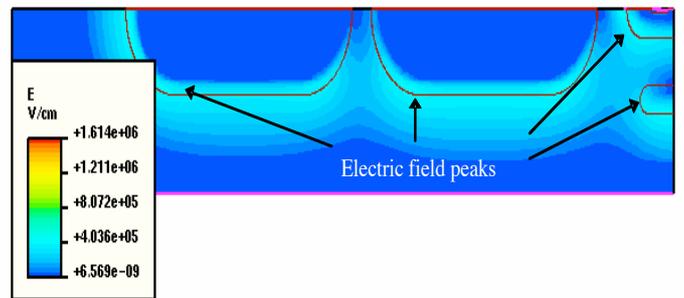


Fig. 7: Electric field distribution at breakdown for the edge cell of the Vertical FLIDiode.

FLIDiodes have been implemented on silicon: Figure 8 shows the variation of the voltage handling capability versus the second epitaxial layer thickness: a wide operating area higher than 85 Volts is obtained.

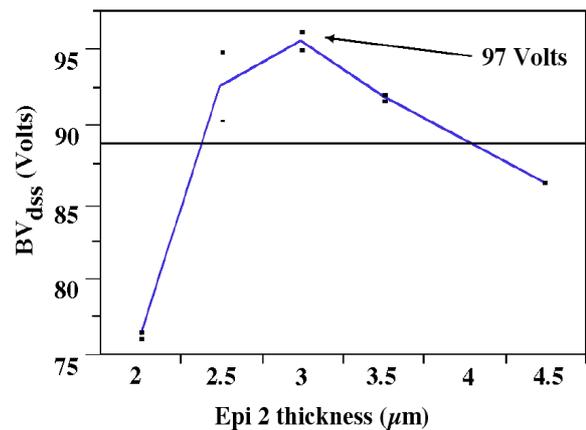


Fig. 8: BV<sub>dss</sub> measurements vs 2nd epitaxial layer thickness.

This work validates the Floating Island concept and the efficiency of the edge cell: this new Diode exhibits an important breakdown

voltage (about 95 Volts) with a  $N^-$  epitaxial layer doping concentration ( $1.1 \times 10^{16} \text{ cm}^{-3}$ ) usually dedicated to 50 V devices.

Figure 9 shows the  $BV_{dss}$  measurements of the conventional Diode (50 Volts) and the Vertical FLIDiode (97 Volts), for the same  $N^-$  epitaxial layer doping concentration ( $1.1 \times 10^{16} \text{ cm}^{-3}$ ).

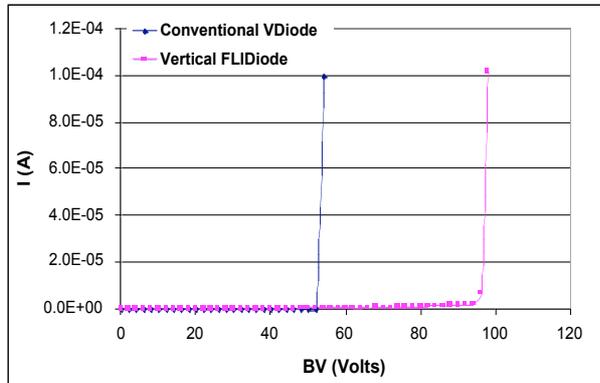


Fig. 9:  $BV_{dss}$  measurements of the conventional Diode and the Vertical FLIDiode.

The  $V_f$  measurements presented Figure 10, shows that the P Floating Island is fully “transparent”, compared to the conventional Diode (50 Volts) and the Vertical FLIDiode (97 Volts). The P Floating Island has no impact on the  $V_f$ .

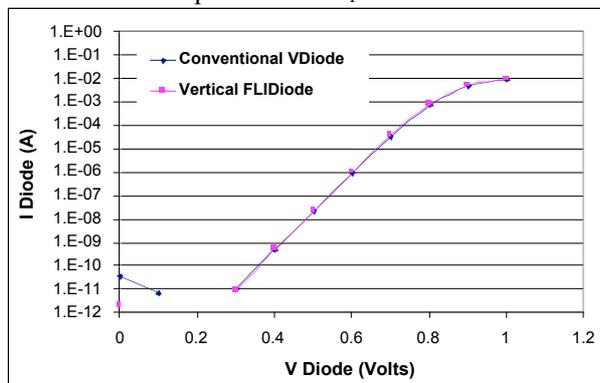


Fig. 10:  $V_f$  measurements of the conventional Diode and the Vertical FLIDiode.

The next step of this work is to implement this concept on Vertical MOSFET: with this high epitaxial layer doping concentration, it can be expected that the specific on-resistance of this new MOSFET will be drastically reduced compared to its equivalent conventional VDMOSFET [5], [6]. This Vertical MOSFET will use the same edge cell as the Vertical FLIDiode. The technology process is now in progress for the FLIMOSFET using more particularly multi-epitaxy layers (see the SUPREM doping profile, Fig. 11). This Vertical MOSFET will use the same edge cell as that of the Vertical FLIDiode.

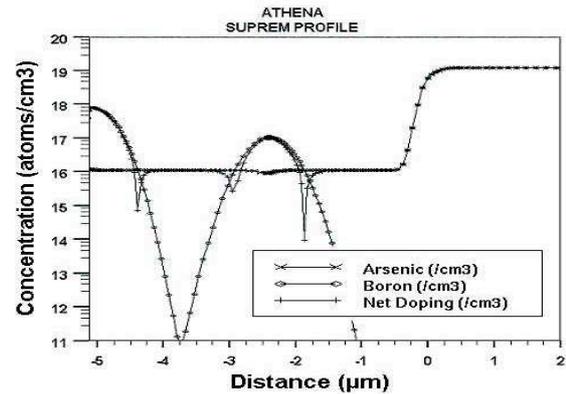


Fig. 11: SUPREM profile of the new developed FLIDiode. ‘0  $\mu\text{m}$ ’ corresponds to the substrate / 1<sup>st</sup> epitaxial layer interface. ‘- 5.15  $\mu\text{m}$ ’ distance corresponds to the surface of the device.

FLIMOSFETs become interesting when increasing the breakdown voltage. For instance, for the same breakdown voltage (about 85 Volts), compared to the conventional VDMOSFET, it has been shown that the specific on-resistance of FLIMOSFET is strongly reduced (33 %) when using P floating squares [6].

## CONCLUSION

In this paper, the “Floating Island” concept has been implemented on silicon, and a FLIDiode has been built for the first time. These experimental results confirm the predictive 2D simulations: this new diode exhibits an important breakdown voltage (about 97 Volts) with a  $N^-$  epitaxial layer doping concentration ( $1.1 \times 10^{16} \text{ cm}^{-3}$ ) usually dedicated to 50 Volts devices. These measurements validate the “Floating Island” concept and the efficiency of the original edge cell that will be used in the FLIMOS technology: it can be expected that the specific on-resistance of the FLIMOSFET will be drastically reduced compared to the conventional VDMOSFET.

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