Using "Adaptive Resurf" Technique and Field Plate Working to Improve the Safe Operating Area of n-type Drain Extended MOS Transistors

B. Bakeroot*, P. Moens**, M. Vermandel* and J. Doutreloigne*

* ELIS-TFCG/IMEC, University of Gent, Sint-Pietersnieuwstraat 41
B-9000 Gent, Belgium, benoit.bakeroot@elis.rug.ac.be
** Alcatel Microelectronics, Westerring 15, B-9700 Oudenaarde
Belgium, peter.moens@mie.alcatel.be

ABSTRACT

Using TCAD, an n-type DEMOS (Drain Extended MOS) has been developed in a standard $0.35\,\mu$m CMOS technology. The devices are optimised towards a Safe Operating Area (SOA) of $60-65\,V$ using an n-type "adaptive resurf" implant under the field oxide. In this work, only two additional masks are added to the standard process flow (one ntub mask as well), rendering the implementation very cost-effective.

In this paper it is shown that the optimal dose and layout of the adaptive resurf implant will strongly be determined by the SOA–breakdown voltage trade-off. Moreover, it is shown that the optimal dose is dependent on the size of the device, especially on the field plate length.

Keywords: MOS transistor, SOA, adaptive resurf, field plate, TCAD

1 INTRODUCTION

Lateral DMOS devices are widely used as output drivers and power switches in power ICs and are usually integrated in a low voltage CMOS platform by adding several additional masks. RESURF (REduced SURface Field) technique is one of the most widely used methods for the design of high voltage, low on-resistance devices. Basically, the RESURF effect distributes the potential lines over a part of the device (mainly under the field oxide) in the lateral direction towards the drain. This results in an optimal spreading of the potential lines at breakdown.

One of the drawbacks of RESURF devices is the restriction of the SOA by the Kirk effect. At high current-density the space-charge of the moving carriers influences the depleted charge, resulting in a shift of the potential lines towards the drain contact. This effect, together with the RESURF action itself, limits the SOA. This restriction can be counteracted by increasing the dopant concentration towards the drain contact [1] and the phrase "adaptive resurf" has been used to describe this method. The present paper explores the possibilities of this adaptive resurf technique in the case of an nDEMOS and the correlation with the device's layout, in particular with the internal field plate.

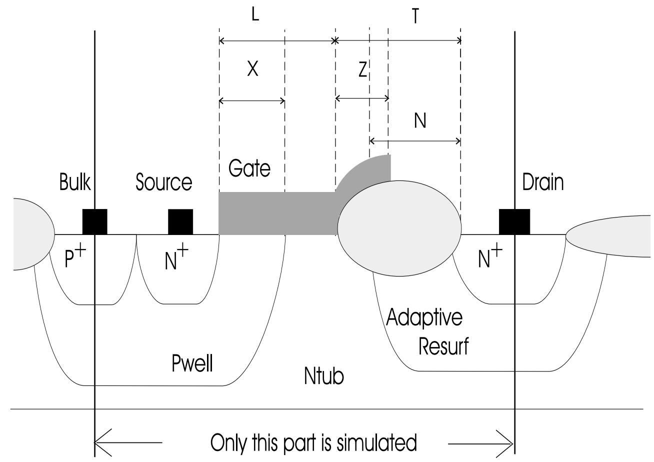

Figure 1: Cross-section of the nDEMOS device

2 PROCESS AND DEVICE DESCRIPTION

The present work is based on the C035 digital CMOS technology from AμE (Alcatel Microelectronics). This is a $3.3\,V$ platform, its process flow consists of twin retrograde wells on a p-type substrate, thin gate oxide ($7\,nm$) and double flavoured gates. Two extra masks are introduced: an ntub mask to achieve RESURF effect and an adaptive resurf (nresurf) mask to improve SOA without seriously degrading the breakdown voltage V_{br}. This nresurf implant will also improve the specific on-resistance $R_{on,sp}$. The ntub dose and energy are carefully chosen in order to get maximum benefits from the RESURF effect and are held constant in this work. Process variations are performed only on the nresurf dose: between $5e11\,cm^{-2}$ and $5e12\,cm^{-2}$, from now on called the "low" and "high" nresurf doses respectively.

A cross-section of the nDEMOS can be seen in Figure 1. Two different layouts have been studied: $t = 3\,\mu m$, $z = 2\,\mu m$ (referred to as "small" devices) and $t = 6\,\mu m$, $z = 3\,\mu m$ ("large" devices). Layout variations were performed on n.

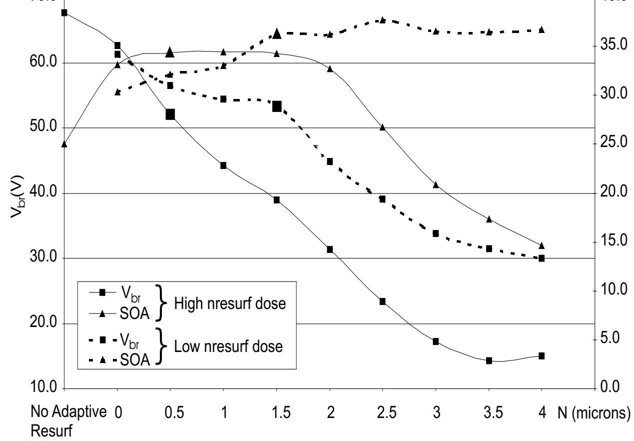

Figure 2: Effect of the nresurf implant dose on V_{br} and SOA for small devices, larger sized data points are the best devices

3 DISCUSSION

In this paragraph, a qualitative discussion on the influence of the adaptive resurf dose and layout on the SOA–V_{br} trade-off for both the small and large devices is given. The discussion focuses on the low and high nresurf doses only, since this covers all cases and gives enough background to understand the quantitative results in the next paragraph.

3.1 Small Devices

Figure 2 shows the influence of nresurf dose and n on SOA and V_{br} for small devices. The SOA[1] is defined as the V_{ds} voltage at which $I_{bulk} = I_{source}/100$ for $V_{gs,max} = 3.3\,V$.

For small devices, both nresurf doses yield similar performances (for different n values, see larger sized data points in Figure 2). $R_{on,sp}$ does not change drastically as well: less than 5%, if a comparison is made between the best devices for both nresurf doses. The breakdown voltage reveals the same trend for both nresurf doses. Since the adaptive nresurf dose disturbs the optimal RESURF dose (i.e. the carefully chosen ntub dose), V_{br} decreases with increasing n. Eventually, the RESURF effect is completely killed. Of course, this trend is stronger for higher nresurf doses.

For the SOA, however, a clear-cut difference in behaviour is simulated. To understand this phenomenon, we use the concept of current flow flux tubes [2]. The electric field profile (EFP) and donor concentration along the mid-current flowline (Figure 3) at $V_{gs,max} = 3.3\,V$ and $V_{ds} = \mathrm{SOA} = 27\,V$ for high nresurf dose are given in Figure 4. This EFP reveals two peaks, the highest one being at the nresurf/ntub transition. The

[1]Actually, this defines only one, but vital, point on the SOA boundary.

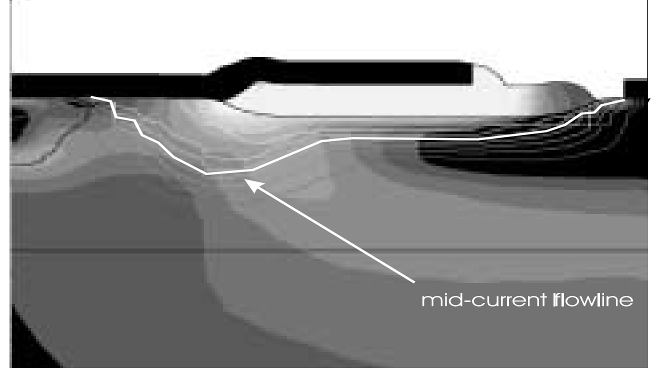

Figure 3: Cross-section of the drift region showing the electric field (between $4e4$ and $4e5\,V/cm$) and the current flowlines at SOA conditions for a small device with nresurf dose=$5e12\,cm^{-2}$ and $n = 2.5\,\mu m$

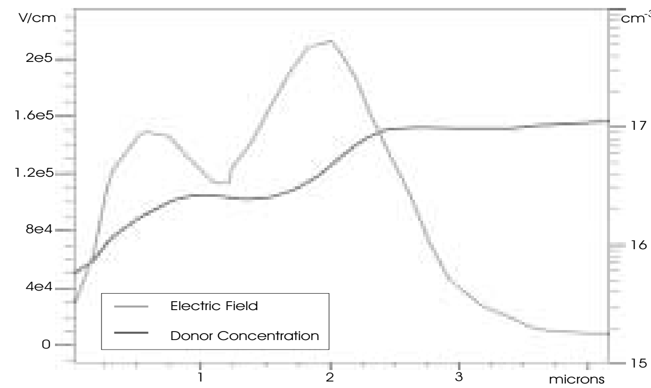

Figure 4: Electric field profile and donor concentration along the mid-current flowline indicated in Figure 3

decreasing SOA values with increasing n (Figure 2) are easily understood: due to the high nresurf dose, the shift of the potential lines (i.e. the Kirk effect) is stopped at the ntub/nresurf transition, causing a second peak in the EFP. If n increases, this second peak approaches the first one (caused by the pwell/ntub junction together with the gate acting as a field plate), resulting in a smaller SOA since the potential lines are bunched together. If a comparason is made between the EFP of Figure 4 and EFPs of a similar device, but with a 10 times lower nresurf dose (Figure 5), it is clear why the SOA does not drop for these devices (Figure 2). Since the nresurf dose is much lower here, the ntub/nresurf transition is not capable of absorbing large potential differences. The electric field at $V_{ds} = 27\,V$ —the SOA condition for the high dose case— is building up over the entire length of the LOCOS, rather than developing a single peak at the ntub/nresurf transition. Eventually, the Kirk effect will force the potential lines to crowd at the ntub+nresurf/nplus transition.

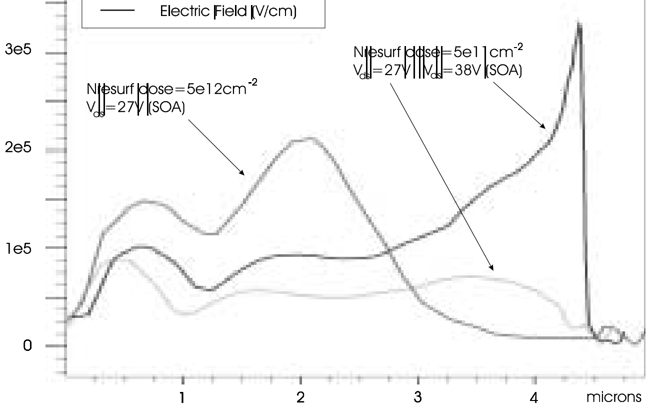

Figure 5: EFPs along the mid-current flowline for small devices with $n = 2.5\,\mu m$ ($V_{gs} = 3.3\,V$)

3.2 Large Devices

Figure 6 shows the influence of nresurf dose and n on SOA and V_{br} for large devices. Although the length of the drift region has been doubled, the breakdown voltages are not. This is due to the fact that in devices such as described here, the field plate working plays an important role. Extending the gate (poly) over the field oxide creates the field plate, the length of this extension is designated by the parameter z. The presence of this field plate forces the depletion layer to extend at the surface beyond the edge of the field plate (if $V_{gs} < V_{ds}$). This reduces the depletion layer curvature and thus the electric field at the pwell/ntub junction. However, a high electric field can occur at the edge of the field plate [3]. This is exactly what happens for these larger devices at breakdown. The electric field is not building up over the entire length of the device, but only between the pwell/ntub junction and the field plate edge, explaining why breakdown does not double in comparison with the small devices. So, higher breakdown voltages for these large devices will only be obtained if z is further increased ($z > 3\,\mu m$).

Of course, the breakdown voltage is not the only figure of interest. It is once again the V_{br}–SOA trade-off that will determine the layout. Indeed, the Kirk effect will have the same influence on these larger devices as it had on the smaller ones: a peak in the EFP will grow at ntub/nresurf transition for high nresurf dose or at nresurf+ntub/nplus transition for low nresurf dose. In addition, due to the field plate working, a peak will grow under the field plate edge at first (see Figure 7). If z is chosen too large, these two peaks will approach and SOA will drop. On the other hand, if z is chosen too small, the field plate working will be killed and breakdown voltage will drop. Therefore, for these large devices (more than for small devices), the field plate length is strongly determined by the V_{br}–SOA trade-off.

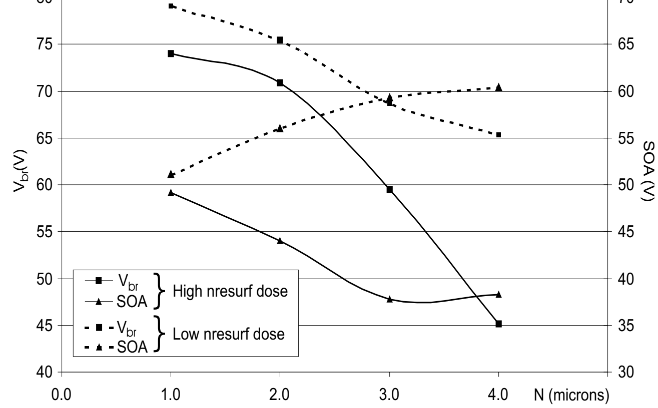

Figure 6: Effect of the nresurf implant dose on V_{br} and SOA for large devices

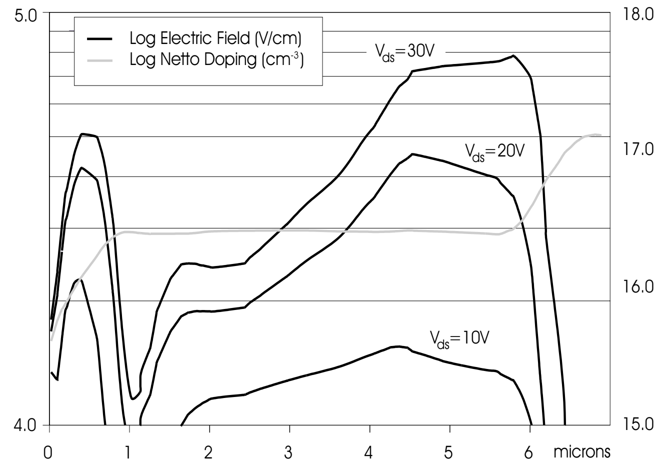

Figure 7: EFPs along the mid-current flowlines for a large device with high nresurf dose and $n = 1.0\,\mu m$ ($V_{gs} = 3.3\,V$). For $30\,V < V_{ds} \leq SOA (= 49.2\,V)$, the EFP will mainly continue growing at the ntub/nresurf transition

This trade-off determines the nature of the nresurf implantation (layout, dose) as well. In order to reduce the number of parameters, the field plate length has been fixed at a value of $3\,\mu m$ ($= t/2$). This choice is a good compromise and will not affect the general conclusions.

All these considerations together explain the trends seen in Figure 6. Only the fact that SOA increases so drastically for low nresurf dose devices, may seem a little odd at first sight. The electric field plate working in combination with the growing nresurf dose between the edge of this field plate and the nresurf+ntub/nplus transition causes the increase in the capability of taking higher potential differences in exactly this region and thus higher SOA values.

It is the little third peak under the field plate edge (see Figure 7) that is responsible for the differences in

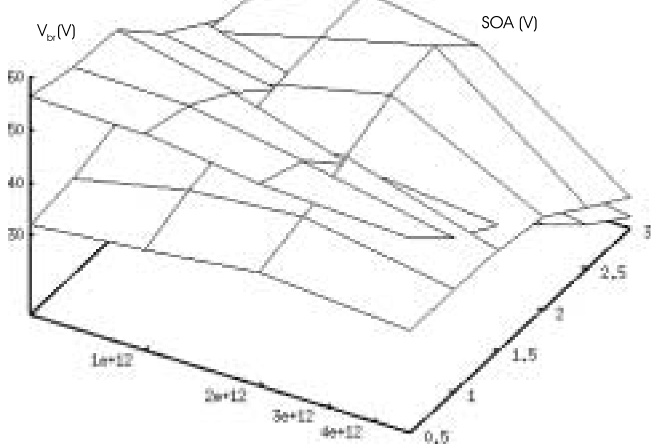

Figure 8: Influence of nresurf dose (cm^{-2}) and n (μm) on V_{br} and SOA for small devices

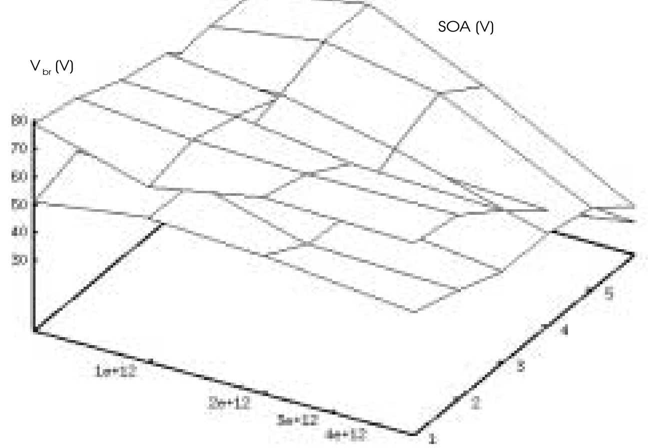

Figure 9: Influence of nresurf dose (cm^{-2}) and n (μm) on V_{br} and SOA for large devices

behaviour between small and large devices and will be the cause for the different shapes of the response surfaces, discussed in the next paragraph.

4 RESULTS

Based on the results in the previous paragraph, a nresurf dose of $5e11\,cm^{-2}$ seems to be the best choice, since this option yields the best small and large devices. An optimisation of this result is presented here for both the small (Figure 8) and large devices (Figure 9).

These response surfaces reveal that for small, respectively large n values, V_{br} will always be higher, respectively lower than the corresponding SOA value. The ideal case being the one where SOA and V_{br} are equal, i.e. the intersection of the two response surfaces. The best devices are found along this intersection line, where SOA and V_{br} have the highest values. For the small devices, the best ones will be found in the region between $(1e12, 2)$ and $(2e12, 1)$. For the large devices, the best ones will be found in the region between $(5e11, 4)$ and $(1e12, 3)$.

An important conclusion that can be drawn from these simulations, is that the best choice for the adaptive resurf implant dose will be determined by the device size. As already explained above, this is due to the increasing field plate working with increasing device size. Another conclusion concerns the layout of the adaptive resurf implant mask: the best choice is to align it with the field plate edge, thus $n = t - z$. If a lighter adaptive resurf dose is chosen, then n can be up to $1\,\mu m$ larger.

5 CONCLUSION

In this paper, it has been proven that the SOA of high-voltage devices can be improved by means of an extra n-type implantation on the drain side. The nature of this implantation (dose, layout) is completely determined by the SOA–V_{br} trade-off. The best choice for the layout being to align it with the field plate edge. Moreover, it has been proven that the field plate working plays an increasing role in large devices and influences the optimal adaptive resurf dose for these devices.

REFERENCES

[1] A. Ludikhuize, "A Review of RESURF Technology," Proc. ISPSD2000, 11-18, 2000.

[2] P. Hower, J. Lin, S. Haynie, et al., "Safe Operating Area Considerations in Ldmos Transistors," Proc. ISPSD'99, 55-58, 1999.

[3] B. J. Baliga, "Modern Power Devices," Krieger, 116-119, 1992.