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# Reduction of Ron in Vertical Power-MOSFETs due to Local Channel Doping

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#### Abstract

In this work we present a new approach for the reduction of the on-state resistance in silicon Power-MOS devices. A vertical short channel transistor on an epitaxial layer results in a conventional reduction of the channel resistance. The main benefit of the vertical arrangement is a further distinct reduction of the  $R_{On}$  by using local channel doping.

#### Introduction

For "Smart-Power" application MOSFETs with breakdown voltages between 12V and 40V are essential. An important figure of merit is the breakdown voltage  $V_{BD}$  and the on state resistance  $R_{On}$  of the device [1]. The  $R_{On}$  which limits the minimum amount of power dissipated in the device mainly consists of two parts corresponding to the structure of the device [2]: The resistance of the epi-layer  $R_{epi}$  under the switching transistor and the channel resistance  $R_{ch}$  of the switching transistor itself. In devices with breakdown voltages in the range between 12V and 40V (e.g. for automotive or mobile application) the contribution of the channel resistance is about 80% to the whole on-state resistance. In this work we present a new approach to solve the trade-off between breakdown and current handling for power MOSFETs in the mentioned application segment.

#### Simulation

The positive influence of the local channel doping on the device performance of sub 100nm MOS devices has already been investigated [3]. To evaluate the influence of local doping in the channel various simulations were made using device simulation (ATLAS II) with energy balance models. In the case of homogeneous doping, the threshold voltage was adjusted by the amount of channel doping, in the case of local doping an intrinsic channel with a local doping layer of about 3nm width is used. In the homogenous doped case the channel is confined to the Si/SiO<sub>2</sub> interface whereas in the local doped device the channel is spread out in the bulk (figure 1).





The local doping reduces carrier interface and impurity scattering. Therefore carrier mobility is increased, which results in higher on-state currents in the device (figure 2).



Fig. 2: Simulation of the on-state current for a homogeneous and a local doped device ( $V_G$ - $V_T$ =2.0V).

# **Device Fabrication**

Various devices with different channel doping profiles (homogeneously and locally doped) and different length of the epitaxial layer were fabricated according to the process sequence depicted in figure 3.



Fig. 3: Complete process sequence for the devices.

After deposition of the epitaxial active layer sequence the active devices were structured by using photolithography in combination with dry etching by  $SF_6$ -plasma. It should be mentioned that only the active layers were etched, leaving the drift zone untouched. After the mesa etching, the gateoxide was formed with a thermal oxidation process at 800°C, resulting in an oxide thickness of 10nm. After the oxidation, phosphorous doped poly-silicon was deposited by means of chemical vapor deposition.

The gate electrodes were formed by structuring this layer with dry etching in  $SF_6$  plasma. The next step was the

passivation of the devices by using a LPCVD deposited silicon-nitride layer with a thickness of about 150nm. Then contact holes were defined with photolithography and etched with  $CF_4$  dry etching process.

For metallization a sputtered titanium/aluminum layer was structured using a lift-off process in combination with wetchemical etching.

# **Device characteristics**

Epitaxial layers of 340nm, 680nm and  $3\mu m$  on commercial available n<sup>+</sup>-wafers were used for the driftzone.

The input characteristics as shown in figures 4 and 5 show that although a short channel MOSFET is used, the DIBLeffect is negligible.



Fig. 4: Transfer characteristics of a homogeneously doped device



Fig. 5: Transfer characteristics of local doped device

From the output characteristics, where typical examples are shown in figures 6 and 7, the following behavior can be concluded and is summarized in figure 8.



Fig. 6: Output characteristics for a homogeneous and local doped devices

As in conventional devices, with the thickness of the driftzone layer the breakdown voltage increases.



Fig. 7: Breakdown characteristics of local channel and homogeneous doped device.

A distinct advantage of the local doped devices is the much better current drive. From the linear region of the I/Vcharacteristics the channel resistance was determined by subtracting the measured epi-layer resistance. The channel resistance  $R_{Ch}$  of these locally doped devices is reduced by a factor of two, compared to conventionally doped devices. This results in a significant reduction of the total on state resistance  $R_{On}$ .



Fig. 8: Channel Resistance vs. Breakdown voltage for different epitaxial layer thickness.

#### Conclusion

The feasibility of a vertical short channel MOSFET in combination with a conventional driftzone for power-MOSFETs is demonstrated. Local channel doping reduces the channel contribution to the  $R_{On}$  by nearly a factor of two, well below the value of the silicon limit for homogeneously doped power MOSFETs.

# References

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