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Drain Current Optimization for a Very High Voltage Fast Switch Device with Bipolar Mode FET Structure

P.G.Fallica, G.Ferla, A.Galluzzo, S.Musumeci, S.Bellone[1], G.Cocorullo[2]
ST - Microelectronics, Stradale Primosole 50 Catania Italy
(1) University of Naples Via Claudio 21 Naples Italy
(2) IRECE-CNR Via Claudio 21 Naples Italy

Abstract This paper presents the results of an investigation of the effect of the gate doping level on the current gain of Bipolar Mode Field Effect Transistors (BMFET). Analysis carried out on BMFET structures with different gate doping levels demonstrates that, contrary to that which is observed for the base of the BJT, the current gain improves with gate doping up to a value of about $5x10^{18}$ cm^{-3} .

1. Introduction

In recent years a novel power device structure, called BMFET (1), has been proposed for power switching applications. As shown by its elementary cell in figure 1, it consists of several interdigitated N+ sources, sorrounded by P+ gate stripes and realized in a high resistivity epilayer. As discussed in (1), the features of the BMFET structure compare favourably with those of other devices capable of high power handling, like BJFET , IGT , BSIT and BJT. This paper reports on the fabrication of power BMFET's with different doping levels of the gate region. By treating the minority carrier transport in the gate region in terms of an effective recombination velocity at the gate-epilayer boundary of this region, the experimental dependence of the current gain on the gate doping level is explained on a theoretical basis.

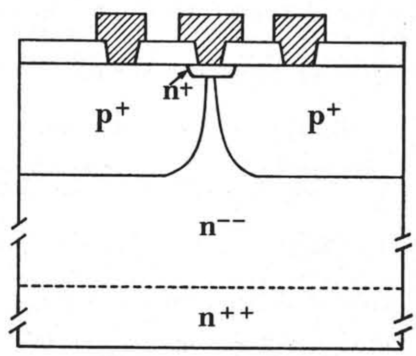

Figure 1 - Structure of the BMFET.

2. Analytical model of the BMFET

The current amplification of the BMFET, in the range of high currents, is a consequence of the conductivity modulation effect into the epilayer. This effect is related to the injection of minority carriers from the gate region and to the corresponding accumulation at the NN+ source transition. As a consequence, a plasma region is originated in the epilayer below the gate and the source.

The following equation (2) , expresses the current gain h_{FS} :

$$h_{FS} = \frac{4\ q\ D_n\ A_D}{(A_S S_S / N_D + A_G S_G / N_D)\ I_D W^2} \qquad (1)$$

where: Dn is the diffusion constant of the electrons in the epilayer, W is the epilayer thickness, I_D is the drain current, A_D, A_S and A_G are the areas of drain, source and gate, S_G is the effective recombination velocity of the gate layer.

3. Performance versus doping

It is interesting to compare the eq.1 with the analogous expression relative to the gain at high level injection of the BJT. The main difference is the dependence of the gain on the doping levels of gate and source zones. In the case of the BJT the gain is proportional to the ratio of the Gummel numbers which are, in their turn, proportional to the doping levels of emitter and base. In the BMFET the gain, on the contrary, is connected to the sum of two quantities $S_S.A_S$ and $S_G.A_G$ that are inversely proportional to the Gummel numbers. As a consequence an increase of the base doping, in the BJT case, always turns itself into a decrease of the gain. In the case of the BMFET the gain grows with the gate doping, over a large range. This is explained bearing in mind that the electrons are injected from the source into the low doped epilayer and from epilayer into the gates, so that, the injection efficiency of the source is little influenced by the gate doping: the gate is placed laterally to the source region. So what is important in the BMFET is the ability to repel the electrons (which would form an unwanted base current). In order to repel the electrons from the gate it is necessary that the doping is high. On the other hand if the gate doping is too high it decreases the life time of the electrons in this region,

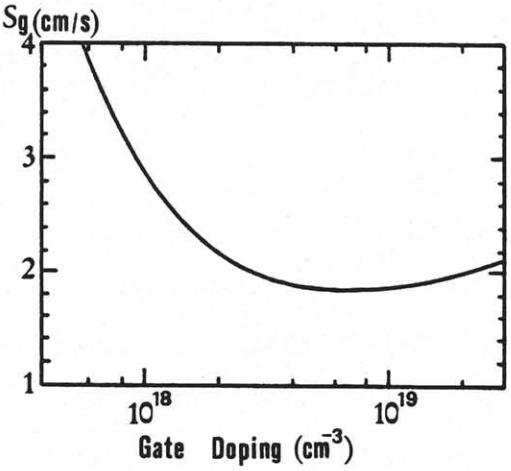

Figure 2 - Recombination velocity vs. gate doping

the BGN and the Auger recombination occurs, and so the recombination current of the gate increases (see figure 2).

4. Experimental

Devices with blocking voltages of 1000 and 1500 V, with various gate doses and with various source doses have been made. The figure 3 shows the results compared with the predictions of an analytical model. A first set of devices has been made with a 1000 V epi and a source with deposited phosphorus. Four gate implant doses have been studied: 8E14, 2E15, 5E15, 7E15 at/cm². The dose of

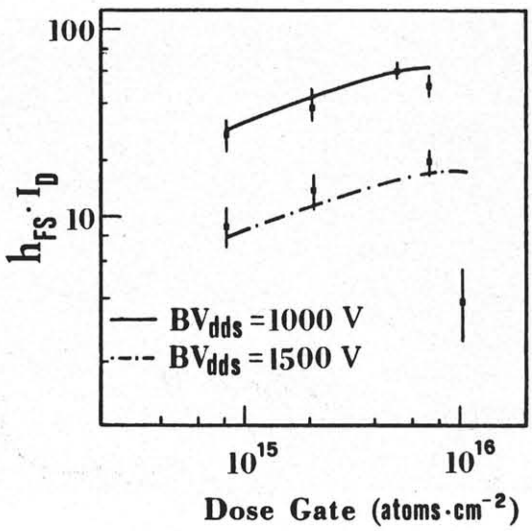

Figure 3 - Merit factor vs. gate doping

8E14 was that used in the first prototypes of BMFET. Instead of the gain, the merit factor $h_{FS} . I_D$ is shown. There is a growing trend with the gate dose which is that predicted by the analytical model. It is important to notice that increasing the dose from 8E14 to 5E15 doubles the current gain. Another set of devices has been made with a 1500 V epi and a source with implanted arsenic. In this case, the agreement with the analytical model is good except for very high doses, where the gain falls.

The partial disagreement between experimental data and analytical model is due to the lateral diffusion of the boron under the source which creates a kind of associated base. This lateral diffusion increases with the increase of the dose. This is shown by the numerical two dimensional simulation (see figure 4). A further set of devices has been made where besides the dose of gate implantation also the time of diffusion has been varied for a fixed depth. Depth has been reduced in such a way as to avoid, whatever the dose,the formation of the associated base at the center of the source. The results are shown in figure 5. In this set of devices the gain does not fall with high concentrations, on the contrary it has a continuously increasing trend as the analytical model predicted.

A further set of devices has been made to study the influence of the source doping. They are devices with a 1500 V epi, with an

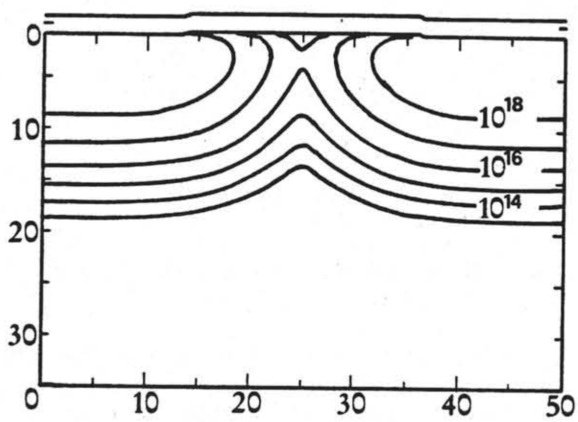

Figure 4 - Lateral diffusion of the boron

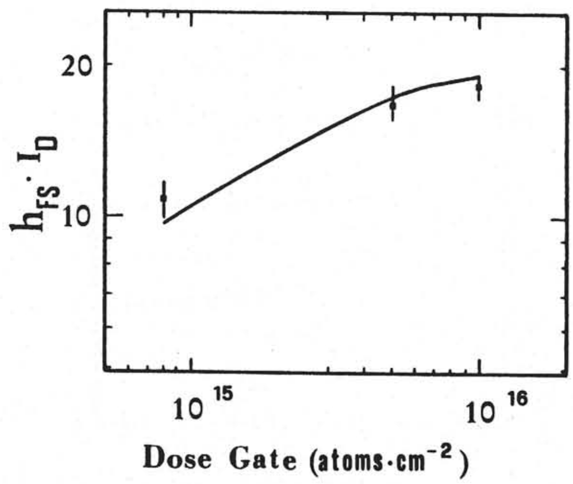

Figure 5 - Merit factor vs. gate doping

implanted arsenic source with various doses. The experimental results show, see figure 6, that the gain is little influenced by the dopant concentration in the source, which is opposite to what happens in the BJT.

5. Dynamic characterization

Such an optimized structure has been studied from the dynamic point of view. In figure 7

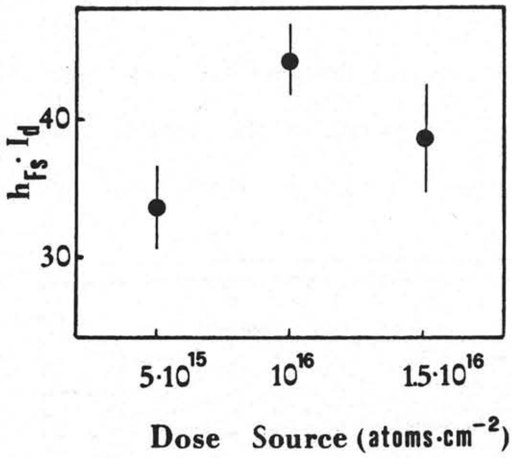

Figure 6 - Merit factor vs. source doping

the trend of storage and fall times for the 1000 V device and for 1500 device are reported. Figure 8 shows the turn-off of a BMFET with an inductive load.

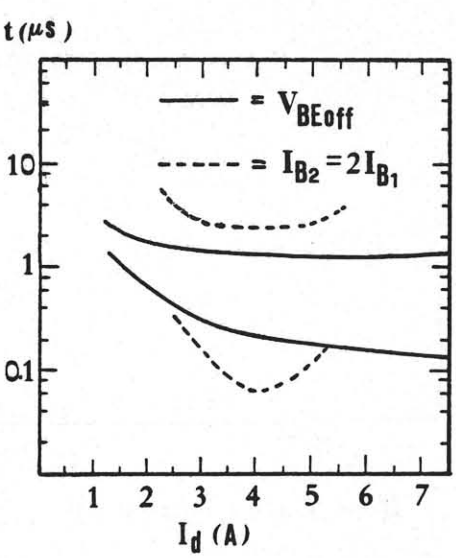

Figure 7 - $t_{storage}$ and t_{fall} vs. I_D

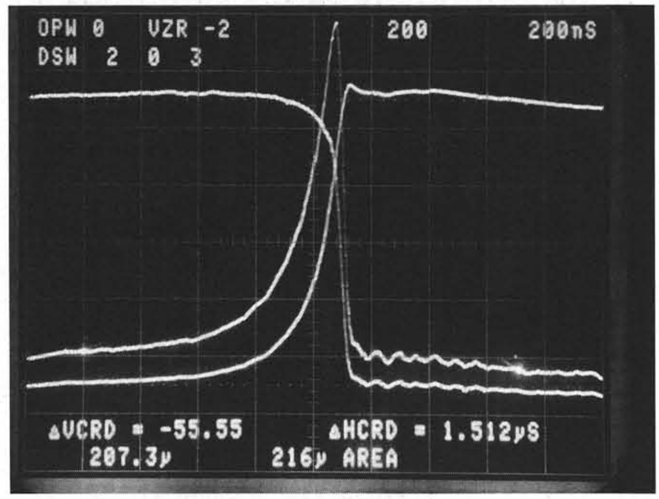

Figure 8 - Turn-off of a BMFET. I_D, V_{CE} and energy loss are shown.

5. Conclusions

With these considerations (gate doping variation, substitution of phosphorous with As, reduction of the source depth, reduction of the gate depth) the structure of the BMFET has been optimizated as regards the current, without loosing the blocking proprieties with zero gate bias. The current capability is now comparable, or little better, than the analogous cellular BJT (with double level of metal and which, therefore exploits 100% of the Si area). To this we can add a simple manufacturing technology, shorter switching times and full Reverse Bias Safe Operating Area.

6. References

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