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Design Optimization of 1000V Resistive Field Plate

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SUMMARY Resistive field plates achieve high breakdown voltage when merged with an ordinary metal field plate. The optimum design of the structure was studied by a two dimensional device model and experiments. It was found that a properly combined structure realizes not only a higher breakdown voltage for shallow junctions but also a higher area efficiency, compared with conventional guard ring technologies.

1. Introduction

The idea of a resistive field plate (RFP) is old[1],[2]. However, its application to real devices was limited because of the difficulties of making stable high resistivity films. Recent advances in film technologies such as SIPOS and amorphous silicon have made this resistive field plate technology very attractive because of its simple structure and superiority to guard ring structures with respect to area efficiency.

In the present letter, it is shown that the RFP structure can be improved by merging an ordinary metal field plate with the original structure. Especially, an effort was made to realize 1000 V breakdown voltage by the improved structure.

2. 2-D Model Analysis

A 2-D model analysis was carried out on the structure shown in Fig. 1. When the pn junction is reverse-biased, the high resistivity film creates a linearly graded potential distribution on the field oxide. The depletion layer is expanded in such a manner that the electric field is reduced by the distributed surface potential. The metal field plate reduces the peak electric field due to the pn junction curvature, increasing the breakdown voltage. A high breakdown voltage can be realized by optimizing the structure, especially the length of the metal field plate. Breakdown voltages are evaluated by solving the Poisson Eq. (1) and then calculating the ionization integral[3].

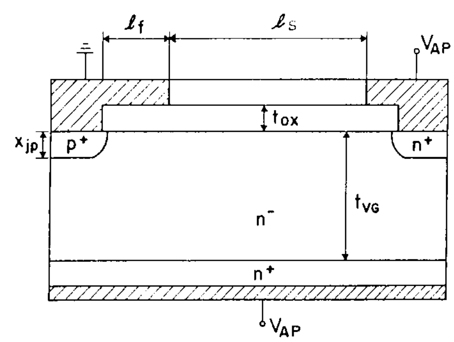

Fig. 1 Schematic diagram of resistive field plate structure.

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$$\Delta^2\psi = -q/\varepsilon(p-n+N) \qquad (1)$$

As the current is negligible under reverse bias, the Poisson equation is necessary to calculate the electric potential. The Newton-SLOR method was used to solve this nonlinear equation. The avalanche breakdown voltage was obtained by considering 10 ionization integral paths which pass through one of the 10 points having the highest to the 10th highest electric fields, because the ionization integral doesn't always take its maximum value when its integral path includes the maximum electric field point. It was assumed that avalanche breakdown occurs when the hole initiated ionization integral reaches unity. In the course of the calculations, the following design parameter values were used and kept constant: p and n layer diffusion depth $=5\mu m$; field oxide thickness, $t_{ox}=1\mu m$; total high resistive film length, $(l_f+l_s)=190\mu m$; epi-layer resistivity $=50\Omega cm$; epi-layer thickness on n^+ layer $=85\mu m$.

The calculated breakdown voltage hardly depended on the oxide thickness, t_{ox}, within the calculated range (0.1 to 1.0μm). However, it depended on the high resistive film length as well as the used ionization constants. In the present calculations, the high resistive film length is chosen to be sufficiently long so that the calculated breakdown voltage is not significantly improved with increase in the high resistive film length. For the ionization constants, data from Van Overstraeten et al.[4] were used.

Figure 2 shows the peak electric field distribution with the field plate length l_f as a parameter. It is seen that the peak field at the pn junction decreases and the peak field at the edge of the field plate increases with increase in the field plate length l_f. When the peak field at the pn junction is as high as that at the edge of the

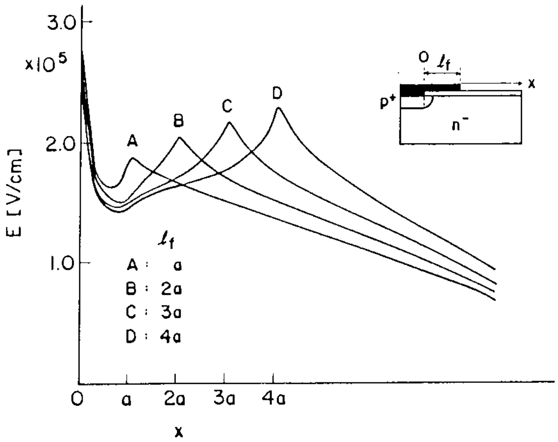

Fig. 2 Peak electric field distribution with metal field plate length l_f as a parameter, VAP=1000V.

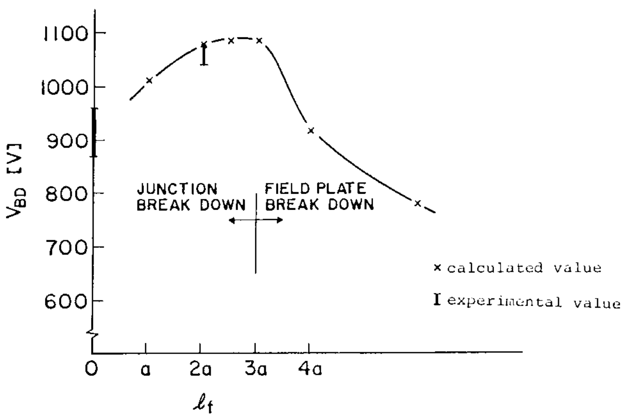

Fig. 3 Breakdown voltage versus metal field plate length l_f characteristics.

field plate, the length of the field plate is an optimum value for the maximum breakdown voltage.

Figure 3 shows the breakdown voltage versus field plate length l_f characteristics. The breakdown voltage becomes maximum when the field plate length is between $2a$ and $3a$, where a represents a standard length. When the field plate length is shorter than the optimum value, avalanche breakdown occurs at the pn junction. On the other hand, breakdown occurs at the edge of the field plate, when the field plate length is too long.

3. Experiment and Discussions

Actual devices were fabricated for the field plate length of 0 and $2a$ in the following manner. After the formations of 5μm deep p^+ and n^+ diffusion regions, a 1μm thick oxide layer was thermally grown and a 1μm undoped a-Si layer was chemically deposited. Aluminum electrodes were then successively formed in the conventional way, simultaneously serving as the metal field plate. Observed breakdown voltages agreed well with the calculated results, and are shown in Fig. 3.

Transient characteristics were also tested by applying the same structure to actual 1000V power MOSFETs, which showed excellent stability. The consumed area for the present junction termination is only 60 % of that for the conventional guard ring technologies using 10μm deep diffusion rings. It is very difficult to achieve more than 1000V by using 5μm deep diffused guard rings.

Thus, the present technology has been well suited for high voltage devices which use only shallow diffusion layers.

4. Conclusions

The resistive field plate structure combined with a metal field plate has been studied by both experiments and numerical calculations. An optimized structure easily achieves 1100V breakdown voltage with only 190μm RFP length as well as with 5μm shallow junctions. Thus, the structure is strongly effective for high voltage devices, which use only shallow junctions, such as power MOSFETs.

References

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