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Optimal Design of Trench Power MOSFET for Mobile Application

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This research analyzed the electrical characteristics of an 80 V optimal trench power MOSFET (metal oxide field effect transistor) for mobile applications. The power MOSFET is a fast switching device in fields with low voltage(<100 V) such as mobile application. Moreover, the power MOSFET is a major carrier device that is not minor carrier accumulation when the device is turned off. We performed process and device simulation using TCAD tools such as MEDICI and TSUPREM. The electrical characteristics of the proposed trench gate power MOSFET such as breakdown voltage and on resistance were compared with those of the conventional power MOSFET. Consequently, we obtained breakdown voltage of 100 V and low on resistance of 130 mΩ. The proposed power MOSFET will be used as a switch in batteries of mobile phones and note books.

Keywords : Power MOSFET, Mobile application, Breakdown voltage, On resistance, High speed

1. INTRODUCTION

The Power MOSFET (metal oxide semiconductor field effect transistor) is voltage driven devices, which are used in power supply devices, converters, etc. as switching devices in fields that require high voltage and current [1-3]. For using in mobile application, A power MOSFET should have low on-state resistance for potential use in mobile applications, such that its efficiency can be improved by reducing the power loss under operating conditions [4,5]. This study designed an 80 V planar gate type and trench gate type power MOSFET, and performed simulations for both structures.

In order to analyze the electrical characteristics of the designed power MOSFET such as the breakdown voltage, on-resistance and threshold voltage, we performed 2-D device and process simulations. First, we extracted the process and device parameters for an optimal design. Subsequently, we performed device simulation and analyzed the electrical and thermal characteristics of the MOSFETs. Further, we compared the proposed power MOSFET with the conventional power MOSFET.

2. METHOD OF EXPERIMENT

Figure 1 shows a planar gate MOSFET structure and a trench gate MOSFET structure. In this study, we designed a MOSFET with a basic structure and a trench gate MOSFET such that they have the same breakdown voltage. Therefore, except for the trench gate, this study used the same parameters such as the cell pitch, the concentrations

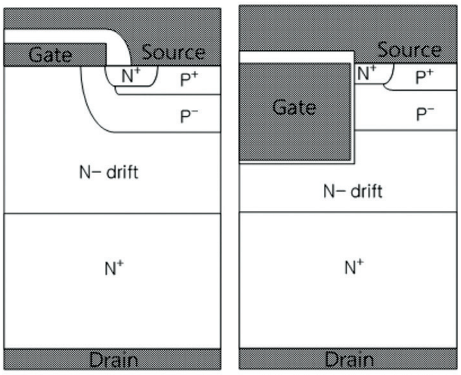

Fig. 1. MOSFET structure in general. (a) Planar MOSFET and (b) trench MOSFET.

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of P-base and drift layer for both the structures. After device and process simulations, we confirmed the trade-off relationship between the breakdown voltage and on-resistance. Moreover, we verified the threshold voltage characteristic according to the size and concentration of P-base via simulation. We confirmed that the breakdown voltage depends on the size and the concentration of Epi layer. The cell pitch of both the devices was 2 μm. The thickness of the drift layer was 30 μm.

3. RESULTS AND DISCUSSION

3.1 Design and analysis of conventional planar gate power MOSFET

The concentration of the N-drift layer, a factor having the biggest effect on the breakdown voltage and other properties, is the most important process parameter.

Figure 2 shows the characteristics of breakdown voltage and on resistance according to the concentration of the N-drift layer. As the concentration of N-drift layer increased, the breakdown voltage decreased and on resistance decreased. i.e., there was a trade-off relationship between the breakdown voltage and on resistance. Table 1 shows the values of the breakdown voltage and on resistance according to the concentration of N-drift layer.

In order to determine the breakdown voltage, we performed an experiment by varying the concentration of the N-drift layer over the range of 4.0 x 10^{15}~ 6.0 x 10^{15} cm^{-2}, while maintaing the other parameters. Consequently, we could confirm that both the on resistance and breakdown voltage decreases as the epi concentration increased as shown in Fig. 2. That is, we could confirm that the on resistance and breakdown voltage were in a trade-off relationship with each other.

In order to achieve breakdown voltage over 80 V, which is the objective of this study, based on the above experiment, we selected the simulation error as 20% and the concentration of N-drift layer as 4.2 x 10^{15} cm^{-2} for the subsequent experiment.

The subsequent experiment analyzed the characteristics of threshold voltage according to the concentration of P-base by setting the concentration of the N-drift layer to 4.2 x 10^{15} cm^{-2} in order to determine the threshold voltage. Table 2 lists the value of threshold voltages according to the concentration of P-base.

In order to determine the threshold voltage, we performed an experiment by varying the concentration of P-base over the range of 1.0 x 10^{13} cm^{-2} ~ 3.0 x 10^{13} cm^{-2} while maintaining other variables constant. Consequently, we could confirm that the threshold voltage increased as the concentration of P-base increased as shown in Fig. 3. We determined that the optimal point between the concentration of P-base and the threshold voltage was 2.8 V and 2.25 x 10^{13} cm^{-2}, respectively.

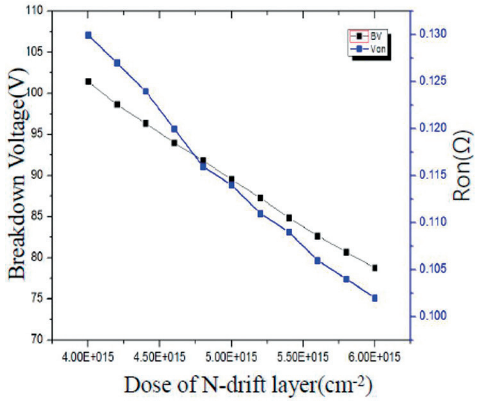

Fig. 2. Characteristics of the breakdown voltage and on resistance according to the concentration of the N-drift layer.

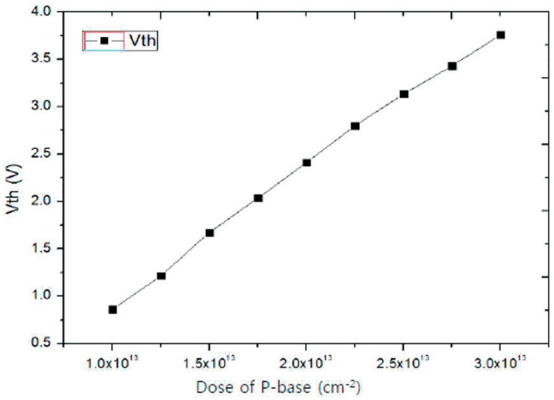

Fig. 3. Characteristics of threshold voltage according to the concentration of P-base.

Table 1. Values of breakdown voltage and on resistance according to the concentration of the N-drift layer.

Cell pitch (μm)	Epi dose (cm^{-2})	Breakdown voltage (V)	Ron (Ω)
2	4.0 x 10^{15}	101.457	0.130
	4.2 x 10^{15}	98.662	0.127
	4.4 x 10^{15}	96.370	0.124
	4.6 x 10^{15}	94.020	0.120
	4.8 x 10^{15}	91.851	0.116
	5.0 x 10^{15}	89.545	0.114
	5.2 x 10^{15}	87.303	0.111
	5.4 x 10^{15}	84.869	0.109
	5.6 x 10^{15}	82.692	0.106
	5.8 x 10^{15}	80.706	0.104
	6.0 x 10^{15}	78.784	0.102

Table 2. Characteristics of threshold voltage according to the concentration of P-base.

Epi dose (cm^{-2})	P-Base dose (cm^{-2})	Vth (V)
4.2 x 10^{15}	1.00 x 10^{13}	0.86171
	1.25 x 10^{13}	1.21612
	1.50 x 10^{13}	1.67477
	1.75 x 10^{13}	2.03614
	2.00 x 10^{13}	2.4114
	2.25 x 10^{13}	2.8005
	2.50 x 10^{13}	3.13412
	2.75 x 10^{13}	3.43294
	3.00 x 10^{13}	3.75956

3.2 Design and analysis of the proposed trench gate power MOSFET

A trench gate power MOSFET was designed with the same device and process parameters as the planar gate power MOSFET such that the breakdown and threshold voltages of the two MOSFETs were the same.

Table 3. Values of breakdown voltage according to the epi resistivity and concentration of P-base.

Epi resistivity (Ω)	P-base dose (cm^{-2})	Breakdown voltage (V)	Vth (V)
1.1	5 x 10^{12}	77.5620	1.504
	1 x 10^{13}	84.0250	2.874
	2 x 10^{13}	92.2230	4.520
1.2	5 x 10^{12}	84.6561	1.588
	1 x 10^{13}	92.9320	2.838
	2 x 10^{13}	100.263	4.548
1.3	5 x 10^{12}	92.3800	1.596
	1 x 10^{13}	100.263	2.846
	2 x 10^{13}	105.781	4.505
1.4	5 x 10^{12}	98.8440	1.624
	1 x 10^{13}	105.781	2.838
	2 x 10^{13}	110.904	4.512

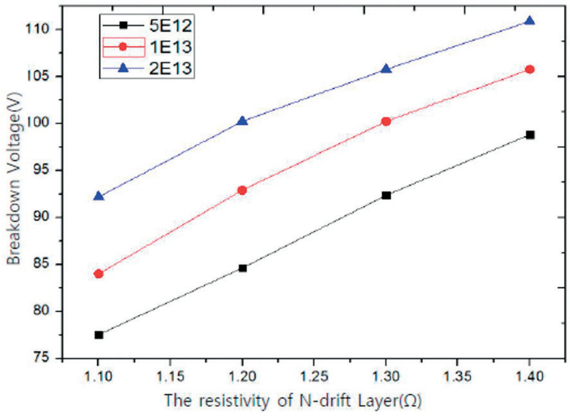

Fig. 4. Breakdown voltage characteristics according to the epi resistivity and concentration of P-base.

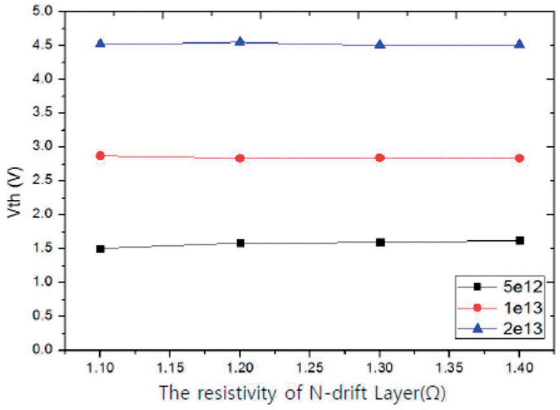

Fig. 5. Threshold voltage characteristics according to the epi resistivity and concentration of P-base.

This experiments was carried out by considering the epi resistivity and concentration of P-base as variables in order to adjust the breakdown and threshold voltages of the proposed trench gate power MOSFET.

Consequently, we confirmed that the breakdown voltage increased as the resistivity increased indicating the same trend as the planar power MOSFET. Further, we confirmed that the threshold voltage was not related to the epi resistivity in Fig. 5, too. Moreover, we performed the experiment by selecting the same breakdown and threshold voltages in order to design this structure with the same parameters as a planar type MOSFET.

3.3 Comparison between the electrical characteristics of the proposed trench power MOSFET and conventional planar power MOSFET

Table 4. Comparison between electrical characteristics of the conventional power MOSFET and proposed power MOSFET.

Classification	V_{TH} (V)	Breakdown voltage (V)	On resistance (Ω)	Cell pitch (μm)
Planer IGBT	2.800	98.5796	0.124	2
Trench IGBT	2.846	100.263	0.122	1
Performance enhancement				50% reduction

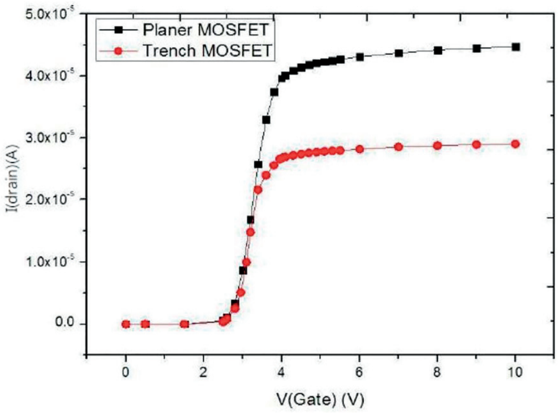

Fig. 6. Threshold voltage characteristics of the proposed trench power MOSFET and conventional planar power MOSFET.

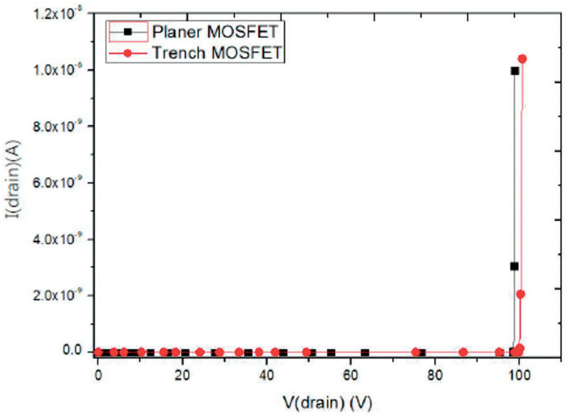

Fig. 7. Breakdown voltage characteristics of the proposed trench power MOSFET and conventional planar power MOSFET.

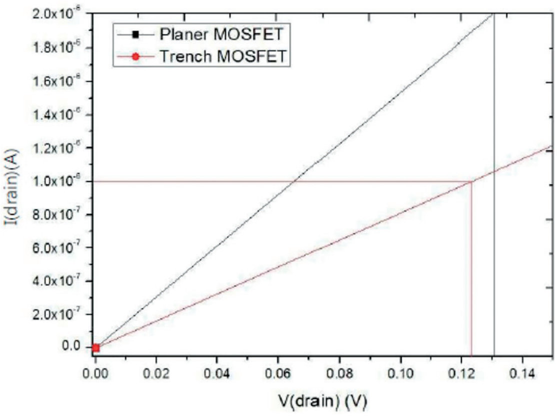

Fig. 8. On resistance characteristics of the proposed trench power MOSFET and conventional planar power MOSFET.

Table 4 illustrates the comparison between the electrical characteristics of the conventional power MOSFET and the proposed power MOSFET.

This section illustrates the comparison between the electrical characteristics of the conventional power MOSFET and the proposed power MOSFET. Figure 6 shows the threshold voltage of the conventional and proposed power MOSFETs. As shown in Fig. 6, the threshold voltage of the proposed power MOSFET was slightly higher than that of the conventional power MOSFET. And as shown Fig. 7, the breakdown voltage of both devices was almost same. But the on-resistance of the trench gate power MOSFET was lower than the conventional device. Figure 8 was shown on resistance characteristics of both devices

4. CONCLUSIONS

This study designed an 80 V grade planar MOSFET and trench MOSFET by performing 2-D device and process simulations.

This study analyzed the relationship between the breakdown voltage and on-resistance caused by the drift resistance according to resistivity of drift layer. subsequently, the breakdown voltage and threshold voltage of the conventional and proposed trench gate power MOSFETs were determined to be almost the same however in case of the on resistance, the proposed power MOSFET was superior to the conventional device. The cell size of the proposed power MOSFET reduced from 2 μm to 1 μm by. The proposed power MOSFET will be used in mobile application such as mobile phones and notebooks.

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REFERENCES

[1] MOSFET Basics - Fairchild Semiconductor, 2000.

[2] G. P. Sim, B. S. Ann, Y. H. Kang, Y. S. Hong, and E. G. Kang, *J. Korean Inst. Electr. Electron. Mater. Eng.*, **26**, 190 (2013). [DOI: http://dx.doi.org/10.4313/JKEM.2013.26.3.190]

[3] T. Laska, M. Munzer, F. Pfirsch, C. Schaeffer, and T. Schmidt, *Proc. The 12th International Symposium on Power Semiconductor Devices and ICs* (IEEE, Toulouse, France, 2000) p. 355. [DOI: https://doi.org/10.1109/ispsd.2000.856842]

[4] Y. S. Hang, E. S. Jung, and E. Y. Kang, *J. Korean Inst. Electr. Electron. Mater. Eng.*, **25**, 276 (2012). [DOI: http://dx.doi.org/10.4313/JKEM.2012.25.4.276]

[5] J. H. Lee, E. S. Jung, and E. Y. Kang, *J. Korean Inst. Electr. Electron. Mater. Eng.*, **25**, 270 (2012). [DOI: http://dx.doi.org/10.4313/JKEM.2012.25.4.270]