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Analysis of Lattice Temperature in Super Junction Trench Gate Power MOSFET as Changing Degree of Trench Etching

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Abstract—**Super junction trench gate power MOSFETs have been receiving attention in terms of the trade-off between breakdown voltage and on-resistance [1]. The vertical structure of super junction trench gate power MOSFETs allows the on-resistance to be reduced compared with conventional Trench Gate Power MOSFETs. The heat release of devices is also decreased with the reduction of on-resistance. In this paper, Lattice Temperature of two devices, Trench Gate Power MOSFET and Super junction trench gate power MOSFET, are compared in several temperature circumstance with the same Breakdown Voltage and Cell-pitch. The devices were designed by 100V Breakdown voltage and measured from 250K Lattice Temperature. We have tried to investigate how much temperature rise in the same condition. According as temperature gap between top of devices and bottom of devices, Super junction trench gate power MOSFET has a tendency to generate lower heat release than Trench Gate Power MOSFET. This means that Super junction trench gate power MOSFET is superior for wide-temperature range operation. When trench etching process is applied for making P-pillar region, trench angle factor is also important component. Depending on trench angle, characteristics of Super junction device are changed. In this paper, we focus temperature characteristic as changing trench angle factor. Consequently, Trench angle factor don't have a great effect on temperature change.**

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Index Terms—**Super junction trench gate MOSFET, conventional trench gate MOSFET, lattice temperature, trench angle**

I. INTRODUCTION

Power MOSFETs have attracted attention since the use of the power converters and electronics has increased [2, 3]. Due to the demands for large voltage for trains and automobile, power MOSFETs have been developed to be more delicate and sensitive. Accordingly, the super junction structure has been proposed. This structure has superior characteristics in terms of on-resistance and breakdown voltage [4, 5]. In order to achieve the best electrical characteristics, temperature flow should be improved. And there are two Super Junction structures classified in fabrication process. The First one is multi-epi process Super Junction MOSFET, and the second one is trench filling Super Junction MOSFET. However, the trench filling process is the simplest and more suitable for making high-aspect-ratio device 6]. In the trench filling process, by reducing the trench angle, the on-resistance of trench filling Super Junction can be enhanced [7]. The on-resistance is not only changing component, but other components are also changed.

In this paper, Super junction power MOSFETs are compared with conventional power MOSFETs regarding heat release. And as changing trench angle factor, we observe how heat release is changed. For fair comparison, the gates of both devices are trench structures, which reduce JFET resistance. Extracting the result is made by using TSUPREM and MEDICI simulation.

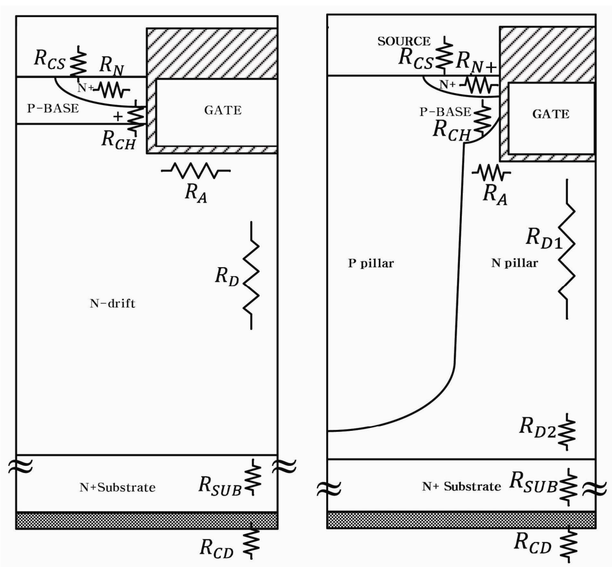
II. COMPARISON OF TEMPERATURE RISE

1. Theoretical Analysis

Before measurement, trench gate super junction power MOSFETs are fabricated by the trench filling fabrication process [8]. In terms of on-resistance, the trench filling fabrication process is better than the multi-epi fabrication process [9].

Joule heating, also known as resistive heating, is one of the reasons why heat is released. Since heat release is proportional to the resistance, it is necessary to compare the resistance of both devices. The trench gate power MOSFET is shown in Fig. 1(a) with its internal resistance. This device is considered to be connected in series in the current path between the source and drain. From the top of device, the components are the source contact, source region, channel, accumulation, drift region, N+ substrate, and drain contact resistance. The drift region resistance has the largest resistance.

The components of the on-resistance for the trench gate super junction MOSFET are illustrated in Fig. 1(b). This MOSFET is similar to the power MOSFET, but the resistance contributed by the drift region is reduced. Although the drift region resistance is divided into two components, it is much smaller than the drift region of the power MOSFET due to the high doping concentration in the drift region.



(a) Conventional Power MOSFET (b) Super Junction MOSFET

Fig. 1. On-resistance components in the conventional power MOSFET and super junction MOSFET.

2. Simulation Analysis

In the experiments, the breakdown voltage of both devices is 100V, and the length of the cell pitch is 2.25 µm. The other design parameters are shown in Table 1. Devices are monitored by applying heat at the heatsink. The heatsink is located at the bottom of the device. Since a certain temperature is applied to the devices, the temperature at the heatsink tends to show a similar temperature. Two devices, a power MOSFET and a super junction MOSFET, are measured at temperatures ranging from 250 K to 400 K. As shown in Fig. 2, the top area of the trench gate power MOSFET released more heat than the bottom area. This result is expected, and the junction area slightly under the top area has more heat. In Fig. 1, 300K is applied the heatsink, and the temperature difference between the top and bottom is 2.31 K. It is not mentioned specifically in this paper that if this is applied to the planar fate power MOSFET in the same conditions, the temperature difference between the top and bottom is 8.92K. This result supports the expectations of the relationship between on-resistance and heat release.

Fig. 2 shows how much heat is released at the trench gate super junction MOSFET. The graph shape is very similar to the graph of a conventional power MOSFET. The top area has high temperature compared to the bottom, which is the same as in a conventional power MOSFET. But, the temperature difference between the

Table 1. Design parameters of two devices

Design Parameter		Conventional Power MOSFET	Super Junction MOSFET
Cell Pitch(µm)		2.25	
Gate Length(µm)		1.125	0.2
N- drift Region	Thickness (µm)	8.0	6.5
	Doping Concentration (cm^{-2})	4.9 x 10^{15}	20.2 x 10^{15}
P base Region	Doping Concentration (cm^{-2})	1.7 x 10^{13}	2 x 10^{13}
P pillar Region	Length (µm)	-	0.25
	Thickness (µm)	-	5.0
	Doping Concentration (cm^{-2})	-	2.07 x 10^{15}

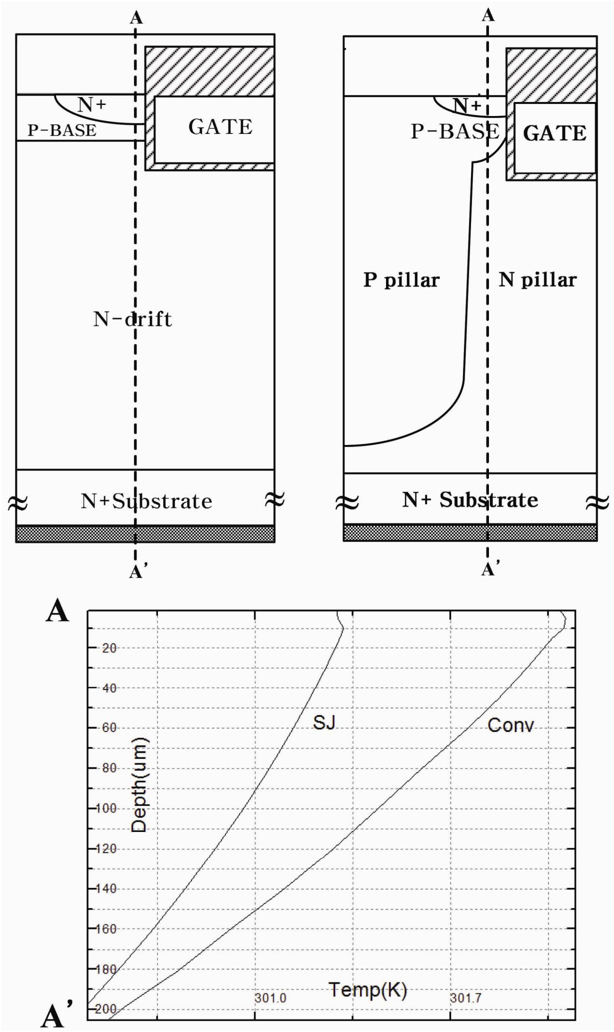


Fig. 2. Structure and temperature distribution of Conventional Power MOSFET and Super Junction MOSFET in the 10-V gate voltage, 0-V source voltage, and 20-V drain voltage.

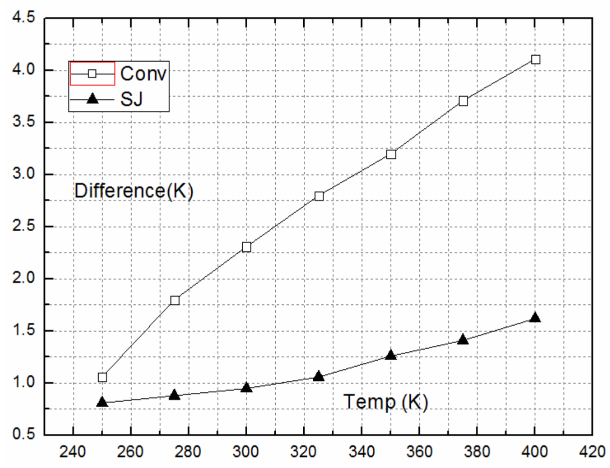
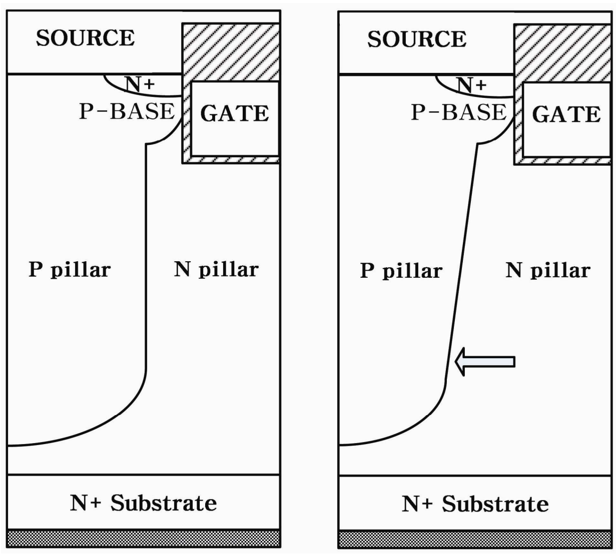


Fig. 3. Temperature difference of two devices.



(a) 90° trench angle (b) decreasing trench angle

Fig. 4. Structure change as decreasing trench angle.

top and bottom is 0.95 K, which is smaller than in a conventional power MOSFET. The results of varying the temperature applied to the heatsink are shown in Fig. 3. With rising temperature, the temperature difference between the top and bottom is increased.

III. Temperature Change Depending on Degree of Trench Etching

1. Simulation Analysis

The trench angle is important component for making trench filling Super Junction MOSFET due to its relation to the on-resistance. A smaller trench angle is necessary for improving the on-resistance [10].

As shown in Fig. 4, p-pillar region is changed as decreasing trench angle. When the trench angle parameter is 90°, N and P pillar meet vertically and widths are similar as shown in Fig. 4(a). As decreasing angle, P pillar region decrease. For this reason, the characteristics of device are changed. In this paper, the temperature difference between top and bottom of device is measured at various trench angles. The bias condition for simulation are 10-V gate voltage, 0-V source voltage, and 20-V drain voltage. The trench angle is changed from 90° to 89.1°. In the actual process, the smallest interval of trench angle is only 0.1°.

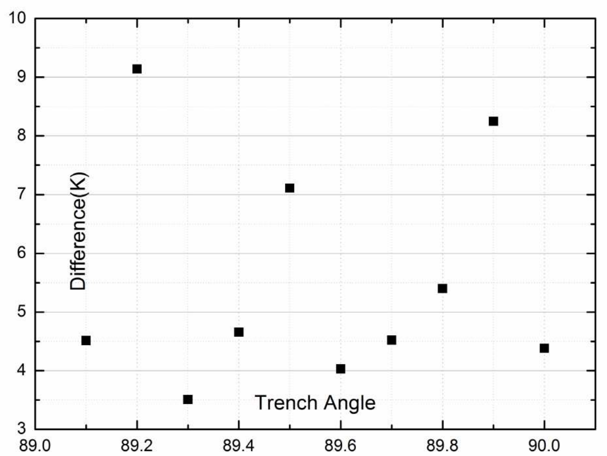


Fig. 5. Temperature difference as changing trench angle.

2. Result Analysis

In the all cases of trench angle parameter, the top area of Super Junction MOSFET released more heat than the bottom area. And the junction area slightly under the top area has more heat, again. The result of simulation measurement is shown in Fig. 5. The maximum temperature difference is shown at 89.2. To see the correlation, the coefficient of correlation(r_{xy}) is used,

$$r_{xy} = \left(\frac{\sum_{i=1}^{n}(x_i - m_x)(y_i - m_y)}{(n-1)s_x s_y} \right) \quad (1)$$

m_x, m_y are the average value of each, x is the trench angle parameter, and y is the temperature difference in this paper. And, s_x, s_y are the standard deviation of each. If $r_{xy} > 0$, the result has the positive correlation. If $r_{xy} < 0$, the result has the negative correlation. And If r_{xy} is zero, this means that the result has no tendency. In this measurement, the coefficient of correlation is 0.0152. This coefficient of correlation is close to zero. Consequently, this means that there is no correlation between temperature difference and trench angle.

IV. CONCLUSIONS

Heat is one of the important components that should be considered for stability. According to the results of simulation, the super junction MOSFET is superior to the conventional power MOSFET regarding heat. And as changing trench angle, there is no tendency of temperature change. In this paper, we analyzed a situation in which the drain voltage is at a maximum value. Devices are often used as power switches in circuits for energy conversion and management applications. To operate as switch devices, there is a moment when recombination occurs. At that time, more heat is generated than the resulting values of this paper. And we have compared only one cell pitch structure. In all package devices, we can expect that influence of the temperature gets become bigger.

Also, the breakdown voltages of the power MOSFET and super junction MOSFET were fixed to 100V, 600V. However, the amount of heat released will increase when breakdown voltage exceed 100V. In order to fabricate a high-breakdown-voltage device, power MOSFETs have to be made as long-drift-region devices, which involves rising heat.

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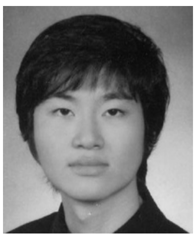

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