Analysis of Electrical Characteristics According to Fabrication of 500 V Unified Trench Gate Power MOSFET

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This paper investigated the trench process, unified field limit ring, and other products for the development of a 500 V-level unified trench gate power MOSFET. The optimal base chemistry for the device was found to be SF₆. In SEM analysis, the step process of the trench gate and field limit ring showed outstanding process results. After finalizing device design, its electrical characteristics were compared and contrasted with those of a planar device. It was shown that, although both devices maintained a breakdown voltage of 500 V, the Vth and on-state voltage drop characteristics were better than those of the planar type.

Keywords: Power device, Breakdown voltage, Deep trench, Unified technology, Low on-resistance

1. INTRODUCTION

The power MOSFET device uses a drive voltage and a power supply, converter, and motor controller because it was made to deal with large amounts of electricity. The power MOSFET used in an industrial motor drive has a low temperature resistance during operation, which lowers losses in electricity production and raises efficiency. As a result, the materialization of electricity is possible. In addition, the switching characteristic is superb and the input impedance is large, which simplifies the actuation circuit. However, in the case of the high power MOSFET, in order to improve the high electricity characteristic, the specific resistance and thickness of the drift area need to be increased, and there is a problem regarding a characteristic rise in heat resistance following the breakdown voltage. The unified trench power MOSFET uses different technology, a 600 V-based high electricity characteristic, which, when compared to the current planar power MOSFET, has a lower heat resistance. In this thesis, in order to create a unified trench gate power MOSFET that has 1.5 times more chips per wafer and low heat resistance, the trench method, junction termination method, and trench process-related method are introduced, and the semiconductor batch production process is also researched. An optimized unified trench gate power MOSFET was designed, and its electrical characteristics were analyzed.

2. EXPERIMENTAL METHODS

For the development of a 500/600 V-level unified trench gate power MOSFET, securing a unit process is key. In terms of developing the trench gate, there is the trench etching method, and low concentration doping can be used to create a structure for the unified field ring. The trench etching process is a key step in improving the trench gate, especially because the shape control and surface control of the trench decides the internal pressure insulation and electrical efficiency of the gate source. So, the equipment (including gas chemistry and recipes) needs to be examined thoroughly before testing. In the trench level process, the first step is to decide on a gas chemistry that fits the goal design. The gas chemistry that fits the current design of an aspect ratio over 5:1 with a trench depth of 3.0–4.0 μm consists of NF₃ base, Cl₂/O₂ base, SF₆ base, etc. The NF₃ has a slow processing
time but its surface condition is superior, which makes it ideal as a leakage current surface, and the SF$_6$ has a high etch rate and oxide film selection rate, so more process testing was done.

3. RESULTS AND CONSIDERATIONS

3.1 Step process and design of junction termination, field ring, and trench gate using the 500/600 V-level unified process

Table 1 shows the test results of the trench profiles from the specific gas chemistry. This result is the organized testing each type of gas chemistry. NF$_3$ and Cl$_2$/O$_2$ chemistry have no problems in the profile slope area. However, the mask oxide thickness is not suitable for the etch rate and oxide film for a trench over 3.0 μm. The SF$_6$ base has an etch rate of 15,000 Å/minute, which showed superior results in development. In addition, the slope was 89°, which will be good for electrical flow. In the test results, thus, the optimal base chemistry to achieve the desired results is SF$_6$.

Table 2 and Fig. 1 show a profile change for the rest of the important factors of the SF$_6$-base chemistry, and the reasons for determining the final process conditions.

3.2 Step process, batch process and optimal process for developing 500 V-level unified trench gate power MOSFET

Figure 2 displays the layout development results of the device unit cell. The unit cell is designed in a stripe pattern, the unit cell pitch is 8.25 μm, and the trench depth is 1.0 μm. The N+ source is 1.0 μm, the poly to CNT is 2.0 μm, and the poly to N+ is 0.5 μm. In the chip surface standard that was given, the threshold voltage ($V_{th}$) and heat electricity drop had a satisfactory maximum pitch, but the ruggedness characteristic was improved, which means that a test to determine the optimal pitch needs to be done owing to price competition. Next, the developed goal device and its final mask plan are shown. Evaluation of the goal device requires a greater than 20 A high-current evaluation system and a module package.

Table 2. SF$_6$ base profile control.

Table 1. Trench profile according to gas chemistry.

<table>
<thead>
<tr>
<th>Classification</th>
<th>SEM Image</th>
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<tbody>
<tr>
<td>Cl$_2$/O$_2$, Base</td>
<td><img src="image1" alt="Cl$_2$/O$_2$, Base SEM Image" /></td>
</tr>
<tr>
<td>HBr/NF$_3$ Base</td>
<td><img src="image2" alt="HBr/NF$_3$ Base SEM Image" /></td>
</tr>
<tr>
<td>SF$_6$ Base</td>
<td><img src="image3" alt="SF$_6$ Base SEM Image" /></td>
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Fig. 1. The electrical characteristics of planar NPT IGBT, planar FS IGBT, and trench FS IGBT (a) $V_{th}$, (b) $B_{V}$, and (c) $V_{ce-sat}$.

Fig. 2. Unit cell design of the unified trench gate power MOSFET.
3.3 Considerations of batch process of 500 V unified power MOSFET

Figure 4 shows the last step in the batch process: the final cross-sectional diagram. In the batch process, trench etching and P-base implantation and other ion injections used to create the body are important processes for creation of the 500 V-level unified power MOSFET. Before this important step, a step process evaluation simulation was conducted to create a process technology for the trench gate unified power MOSFET. The unified trench gate power MOSFET’s wafer’s $V_{th}$ process distribution is shown in Fig. 6. The process development shows that the unit cell’s $V_{th}$ distribution value was 2.9 V.

Figures 9 and 10 show the developed 500/600 V-level unified trench gate power MOSFET and the correct development test of the field ring as assessed by SEM. The trench gate was found to be etched 0.5 μm less, and had a $V_{th}$ value of 2.9 V, not 3.5 V. However, it satisfies the safe $V_{th}$ level of between 2.5 V and 3.5 V.

Figures 11 and 12 compare the $I_d$-$V_g$ and $I_d$-$V_d$ of the 500 V level unified power planar gate and trench gate MOSFET.
Figures 13 and 14 compare the characteristics of the 500 V level unified power planar gate and trench gate type MOSFET’s BV and Id-Vd. There was little change in BC, but the heat resistance of the trench gate improved.

4. CONCLUSIONS

This thesis analyzed the trench process, unified field limit
ring, and other developed products of a 500 V level unified trench gate power MOSFET. The optimal base chemistry for the device was found to be SF₆. In SEM analysis, the step process of the trench gate and field limit ring showed outstanding process results. After finalizing device production, the planar device and the device’s electrical characteristics were compared and contrasted, which showed that although both devices maintain a breakdown voltage of 500 V, the threshold voltage and on-state voltage drop characteristics were better than those of the planar type.

REFERENCES


