Study on The Issue of Electric Field Concentration in Submodule of Press Pack IGBT

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Abstract: There is a phenomenon that the chips of press pack IGBT (Insulated Gate Bipolar Transistor) meet the requirements of withstand voltage test, but ignition sometimes occurred in the submodules of the same kind of press pack IGBT during the test. In response to this situation, this paper firstly analyzed that the difference of submodules frame lead to different level of electric field concentration. In this paper, quantitative conclusions have been drew by modeling and simulation of the actual situation in COMSOL Multiphysics the multiphysics finite element simulation software.

Index Terms—electric field concentration, press pack IGBT, submodules

1. Introduction
IGBT is a MOSFET and bipolar transistor composite device. It not only has the characteristics of MOSFET, which is easy to drive, but also has the advantages of power transistor, which is high voltage, high current. It is currently being widely applied in electricity transmission, high-speed train traction, industrial drive, clean energy and other fields[1].

During the withstand voltage test of submodules of press pack IGBT (Insulated Gate Bipolar Transistor), there have been problems of electric field concentration at the edges of the chips, which is the so-called “ignition” issue. Since the individual chips (such as 3300V chips) can meet the requirements of that test, it could be considered that the difference of submodule frames make the electric field concentration possible. The imperfection of framework will lead to failure during being used.

In this paper, COMSOL Multiphysics the multiphysics finite element simulation software has been used to create a submodule model and simulate the actual situation. The simulation of the electric field about 3300V submodule found out the cause of the problem and the results provided a reference for specific structural improvements.
2. Simulation modeling

In the actual situation, electric field in the submodule gradually changes from the electrostatic field distribution into electricity distribution when applying a forward turn-off voltage for a long time [2] [3]. So the current field transient simulation was used in COMSOL Multiphysics the multiphysics finite element simulation software. In the current field transient simulation, \( cD \) and \( \sigma E \) were both taken into account, which were known as capacitive (relative permittivity) and resistive (conductivity).

A. Geometry

According to the drawings of submodules of press pack IGBT provided by enterprises, a two-dimensional modeling has been used to truly reflect the electric field inside submodule, through longitudinal cross-section in order. The geometry is shown in Fig.1.

![Fig.1 Geometry](image)

The structure parameters are listed in Table I to facilitate the subsequent use of the analysis. In the simulation model, the thickness of molybdenum (Mo_E) is a variable value, which is \( H \) of four values as 1.5, 2, 2.5, 3. In the analysis that follows, different electric field distributions are obtained through \( H \) of four values, and are reflected in the graph.

| Name                                | Value (in mm) |
|-------------------------------------|---------------|
| Chip Thickness (Si)                 | 0.55          |
| PI Thickness of Chip                | 0.015         |
| Molybdenum Thickness (Mo_E)         | \( H \)       |
| Molybdenum Thickness (Mo_C)         | 1.86          |
| Silver Flake Thickness (Ag)         | 0.20          |
| Framework Height-air gap (PEEK)     | 7             |
| Framework Height-silver flake (PEEK)| 5.75          |
| Framework Height-higher (PEEK)      | 8.9           |
| Molybdenum Width (Mo_C)             | 13.6          |
| Molybdenum Width (Mo_E)             | 9.4           |
| Silver Flake Width (Ag)             | 10.6          |
| Framework Width-inside (PEEK)       | 9.5           |
| Framework Width-silver (PEEK)       | 0.6           |
| Framework Width-outside (PEEK)      | 1.45          |
| Framework Width-right side (PEEK)   | 1             |
B. Material Parameter Settings

Materials of simulation model include molybdenum, silicon chip, polyether ether ketone, polyimide, silver and aluminum. In the withstand voltage test, the space of the structure of the submodule is filled with air.

In order to be close to the real situation, the simulation model of the silicon chip is divided into several parts inside with different electrical conductivity.

Current field transient simulation need to set these relative permittivity and conductivity of the materials. The data is from internal reference data of the software, and it is same to the actual conditions. Material parameter settings are shown in Table II.

| Material Parameter Settings |
|-----------------------------|
| Framework Width (PEEK) | 13.6 |
| Chip Width (Si) | 13.56 |
| PI Width of Chip | 2 |

| Material parameters |
|---------------------|
| Material | Conductivity | Relative Permittivity |
| --- | --- | --- |
| Air | 1/(2e16) | 1.0005 |
| Molybdenum | 1/(53.4e-9) | 1e6 |
| Silicon Chip | 2.3 | 11.9 |
| Polyether Ether Ketone PEEK | 1/(1e14) | 3.2 |
| Polyimide PI | 1/(1e15) | 3.9 |
| Silver | 1/(1.65e-8) | 1e6 |
| Aluminum | 1/(2.83e-8) | 1e6 |
| Ring-like Resistance of Chip | 1/9; 1/(5e1); 1/(2e2); 1/(5e2) | 11.9 |

C. Boundary Conditions

According to the actual situation, the silver flake is set grounding, that is the potential of it is 0V. To the testing chip (3300V), the collector molybdenum potential is set at 3300V.

3. Simulation of the electric field

Various parameters as previously described are set as simulation conditions, the following results are obtained.

In the case of applying a forward turn-off voltage 3300V, the potential distribution can be obtained as shown in Fig 2.
Potential contours distribution of submodule gap are shown in Figure 3 and Figure 4.

Fig.2 Potential Distribution

Fig.3 Contour of Left Frame
Modulus of the electric field in the gap of the submodules are shown in Figure 5 and Figure 6.
Through the above simulation, locations of electric field concentration can generally be found out in the gap of the frame in submodule. Therefore, this paper sets three model lines in the places that may have problems and explores electric field concentration problems by an electric field simulation on the section modulus. An electric field by the modulus simulation cut line, electric field concentration to explore the issue. Location of three lines are shown in Figure 7, Figure 8 and Figure 9.
According to the actual process conditions, the electric field modulus of four different heights (1.5mm, 2mm, 2.5mm, 3mm) of the thickness of H is compared, and the simulation results are shown in Figure 10, figure 11 and Figure 12.
Fig. 10 Modulus of Electric Field on Longitudinal Gap Line

Fig. 11 Modulus of Electric Field on Transverse Gap Line
Due to the large resistivity of the air, the air in the simulation is to withstand the main voltage drop (which is also the actual situation in pressure test). It is generally believed that greater than 3000V/mm the electric field modulus can have “ignition” issue. Therefore, the value of 3000V/mm is used in the comparison.

On the line of longitudinal air gap, if H, the height of small molybdenum plate, is less than or equal to 2.5mm, there will be the problem of electric field concentration.

On the line of lateral air gap, if H, the height of small molybdenum plate, is less than or equal to 1.5mm, there will be the problem of electric field concentration.

On the line of chip surface, if the surface discharge is not considered, there will not be the problem of electric field concentration.

4. CONCLUSION
Through the establishment of a press pack IGBT submodule model, selecting 4 different heights of small molybdenum plate and the actual simulation within the framework of the electric field, it is concluded that the concentration location of electric field, and quantitatively determined suitable parameters of the structural framework.

In the actual test, longitudinal air gap does not appear concentrated electric field, so if only considering the lateral air gap “ignition” issue, it shall be designed by using small molybdenum of which the thickness is at least in 1.5 mm and above, that can meet the requirements.

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