Low Temperature Silver Sintering Improves Reliability of Power Semioconductors

Reliability and lifetime of power semiconductors can be improved by using low temperature sintering on silver-containing layers. It is worth mentioning this technology has many applications - from IGBTs, where this technology allows to ensure a reliable connection chip-DBC, DBC-substrate, DBC–power terminals, to SCR thyristors and their subtypes (PCT, BCT, GTO, etc) where it is required to ensure a reliable connection between the power chip and molybdenum thermal compensator. **Dmitry Titushkin, Alexey Surma, Alexander Stavtsev, and Konstantin Stavtsev, Proton-Electrotex, Orel, Russia**

Sintering of high-powered single-chip thyristors and diodes experience is representing such advantages as improved cycling capacity (3, 4), reduced thermal resistance [2, 3, 4] as well as increased surge current values (1). Moreover, the technology possesses significant benefit of the emitted layer surface injection index values (6). However, to achieve all the above listed advantages one must pay attention to several specific aspects. The sintering technology is based on principles of diffusion welding and plastic deformation of silver particles. The driving force of sintering is to store energy on the surface of silver particles.

Specifically, reduction of silver particles size leads to an increase of free energy of silver particles in not sintered material. Thus an increase of free energy allows to reduce temperature during sintering. The temperature reduction in turn has a positive impact on the degree of residual deformations in silicon structure. However excessive free energy may lead to a very intensive sintering, resulting in internal mechanical stresses and joint cracking. One may eliminate this unfavorable effect with increased connection porosity, as higher porosity means higher elasticity (reduced Young's modulus). However increased connection porosity results in worse joint thermal conductivity having a negative impact on the device's thermal resistance.

Besides that, there is another negative effect of excessive porosity in joint weld porosity relevant only for thyristors and diodes with large area crystals installed in disc cases. When such devices undergo thermal cycling tangential mechanical stresses are transferred from lower and upper copper basements to semiconductor element by forces of friction. In such cases molybdenum thermal compensator as a part of the semiconductor element compensates such influence. However, reduced Young's modulus of the connection results in inability of the molybdenum thermal compensator to fulfill its task and the silicon plate gets damaged. For this reason, semiconductors with large diameter silicon crystals require to ensure such a connection porosity value that would eliminate the possibility of internal stresses during sintering but at the same time would not critically impair thermal resistance and mechanical strength of the connection.

Relation between cycling capacity and joint porosity

For research of the relation between thermocycling capacity and porosity of the joint and determination of the optimal temperature and pressure range during the sintering process experimental samples of 100 mm thyristor dies for repetitive reverse voltage of 2800 V and mean current of 2500 A were produced. Silver films based on silver nanoparticles were used as sintering material. The samples were produced in a temperature range of 195 to 235°C and pressure range 5 to 20 Mpa.

Using the experimental samples thermocycling capacity tests were carried out using thermal gradient from 25 to 150°C (value = 125°C) within a quantity of 100 cycles. The following results were obtained:

- Thermocycling capacity of the samples produced under the temperature less than 220°C did not exceed 10-15 cycles, i.e. the porosity of the result joint was obviously surplus.

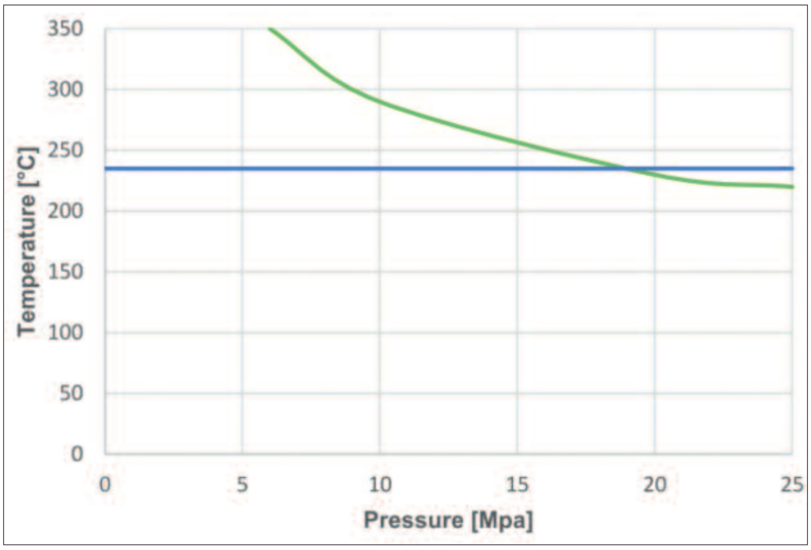
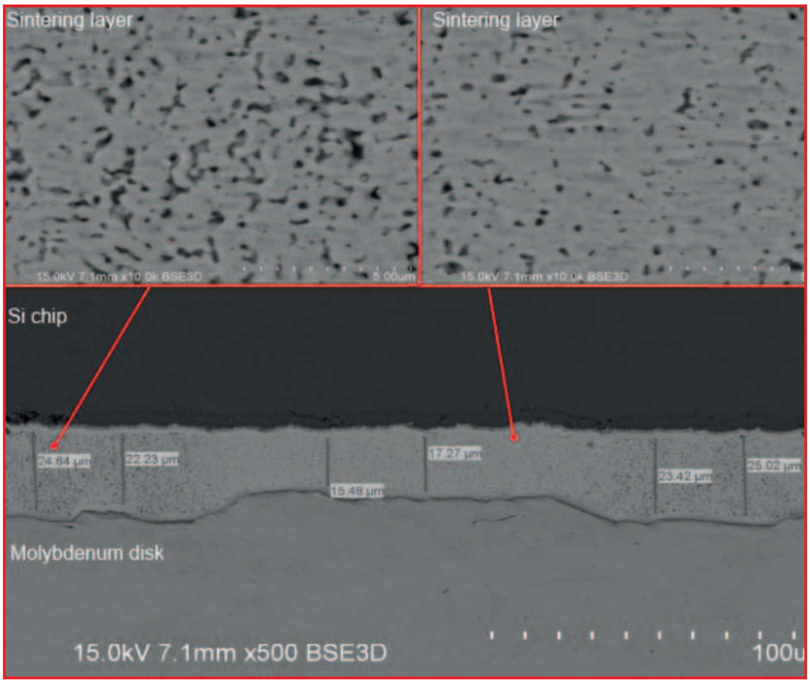
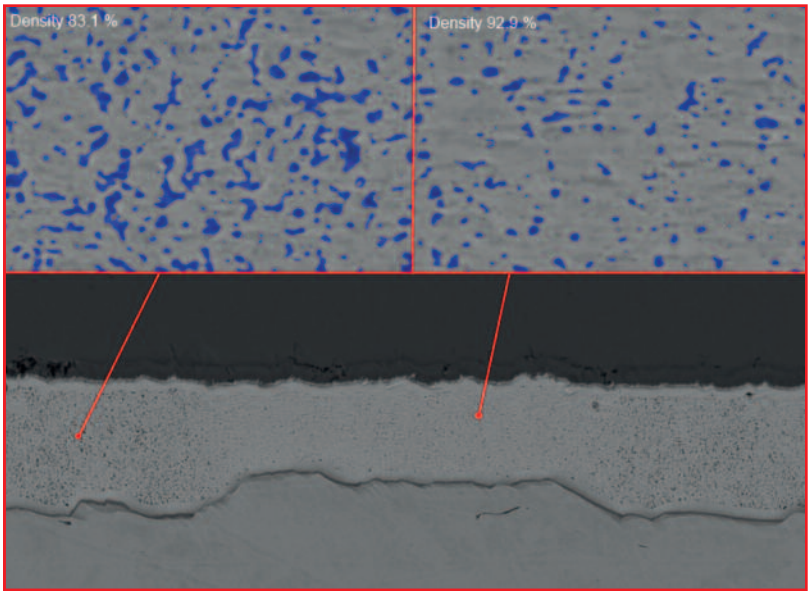


Figure 1: The area of thermocycling capacity of samples (between the lines)

RIGHT Figure 2: SEM-analysis of the sample sintered structure



BELOW Figure 3: Sinter beam density evaluation



- Thermocycling capacity of the samples produced under the temperature of 220-235°C and pressure not more than 10 MPa did not exceed 10-15 cycles as well.
- The increase of pressure up to more than 12 MPa leads to the thermocycling capacity boost.
- For the samples produced under the conditions of 20 MPa pressure and 235°C temperature the destruction and characteristics degradation was not determined.

The test results should be combined with the porosity alterations of the weld produced under various sintering process conditions (Figure 3). It could be derived from the picture that acceptable thermocycling capacity would be achieved providing the condition of weld porosity not more than 7 percent.

Then the samples produced under 20 MPa/235°C were subjected to electric thermal cycling testing using direct current 2500A with temperature gradient between cycles from 55 to 125°C (70°C), 30,000 cycles. There was no damage or properties reduction detected.

The results of the research allow to calculate and forecast the pressure and temperature value range, with which nano material sintering gives an opportunity to achieve a high thermocycling capacity silicon-molibdenum joint for thyristors and diodes with large area crystals, (Figure 1).

Porosity variation related to sintering technology

Usage of silver containing film requires attention to quality of the sintered surfaces. High values of surface roughness make it harder to ensure even distribution of the force during sintering. It is especially important if the sintering technology is used for crystals and molybdenum discs with area of 50 cm^2 or more. Mismatching roughness of the molybdenum disc to that of the silicon plate may cause uneven porosity of the joint weld across the connection area formed during sintering because of uneven pressure distribution. For this reason, usage of sintering for crystals with large area requires special attention to preparation of the molybdenum disc and plate surfaces.

For example, listed below are results of testing of a connection between semiconductor thyristor element with diameter of 100 mm and molybdenum discs with the following roughness values: Ra = 0,9 µm, Rz = 4,6 µm, R_{max} = 9,54 µm. Sintering took place on silver containing films Argomax 8010 with thickness 65 µm at 20 MPa and 235°C (thickness of silver containing joint after sintering within 20 μm). SEM-analysis of the sample was carried out after the sintering (Figure 2).

The image demonstrates that high roughness of the molybdenum disc causes unstable thickness of the joint (from 25 to 15 μm) affecting beam density. Evaluation of the sinter beam density has shown (Figure 3) that one and the same semiconductor has significant fluctuations of the beam density (from 83.1 to 92.9 %) and resulting high variety of porosity (from 16,9 to 7,1%).

Mechanical shear stresses arising during thermal cycles are localized in "harder" areas of the connection with lower porosity, and their amount respectively becomes higher. Thus various thickness of the beam results in significant drop of cycling capacity of the joint.

Conclusions

This article shows the influence of sintering process conditions using silver nanoparticles on the weld porosity and thermocycling capacity, obtained by joining silicon crystals of large area with molybdenum wafers. The relation between the thermocycling capacity of the experimental samples and weld porosity is demonstrated. Moreover, it is proved that a prerequisite requirement for maintaining the thermocycling capacity of thyristors and diodes with silicon crystals of large area in tablet housings is a value of weld porosity not more than 7 percent. Temperature and pressure value range for sintering process of silver-bearing materials based on nanoparticles is defined. This value range allows to calculate and forecast high level of thermocycling capacity of the weld referring to the components mentioned above. Also shown is that surface roughness of connected elements may lead to significant variations of porosity distribution across the area of the sinter beam, what may affect cycling capacity of the connection.

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