New Thyristors for High Power Applications

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Modern power electronics industry is developing in a lot of directions. Despite the rapid development of fully controlled power semiconductor switches (IGBT, IGCT) usage of high power thyristors with extra load power in many applications is still technically legitimate. Recently interest for such thyristors is shifting to the devices produced on the basis of semiconductor elements with 4″ – 6″ (100-150 mm) diameter.

JSC «Proton-Electrotex» conducted research and development activities in order to manufacture the new generation of thyristors based on 4″ (100 mm), have increased reliability, increased safe operating area and improved performance. At present company is completely prepared for series production of such thyristors with blocking voltage from 1800 V up to 6500 V.

General characteristics of thyristors are shown in the table below.

Part Number	I_{TAV}, A	I_{TSM}, kA	V_{DRM} V_{RRM}, V	I_{DRM} I_{RRM}, mA	tq, µs	Max diameter/ contact diameter/ housing height, mm
T193-5000-18 T393-5000-18	5 000 [85 °C] 5 000 [78 °C]	94	1 800	300	400	150/100/26 150/100/35
T193-4000-28 T393-4000-28	4 000 [94 °C] 4 000 [90 °C]	75	2 800	300	500	150/100/26 150/100/35
T193-3600-36 T393-3600-36	3 600 [91 °C] 3 600 [86 °C]	72	3 600	300	630	150/100/26 150/100/35
T193-3200-44 T393-3200-44	3 200 [91 °C] 3 200 [86 °C]	60	4 400	300	800	150/100/26 150/100/35
T193-2500-52 T393-2500-52	2 500 [98 °C] 2 500 [94 °C]	55	5 200	300	800	150/100/26 150/100/35
T193-2000-65 T393-2000-65	2 000 [99 °C] 2 000 [95 °C]	45	6 500	300	800	150/100/26 150/100/35

For thyristors with large area of semiconductor element one of the problems is guarantee of reliable electrical and thermal contact of silicon wafer with molybdenum disc. There are two ways to dissipate generated heat from silicon wafer:

1. Alloyed structure, when silicon wafer, which has formed diffusion layers, is connected with molybdenum disc.
2. Fully pressure contact structure, when silicon wafer, which has formed diffusion layers and metallization on anode and cathode side, is pressed between two molybdenum discs. And exceptionally mechanical contact between molybdenum and silicon wafer is guaranteed.

Both methods are widely used by various manufacturers around the world, however both of them have their pros and cons.

Alloyed structure as a benefit has a quality thermal contact of silicon wafer to molybdenum disc from the anode side, which decreases total thermal resistance and improves dissipation of the generated heat.

But as a disadvantage such structure may have bending of semiconductor element with molybdenum disc due to its heating up to high temperatures

(650-680 °C) and cooling in alloying process. Moreover, during uneven heating and cooling bending of semiconductor element occurs, which leads to absence electrical and thermal contact in some areas of semiconductor element, even if assembling the thyristor with heat sink. Bending ratio is defined by difference of heat expansion ratio of alloyed parts and absolute value of temperature and thermal profile of alloying process. And the bigger the diameter of the alloyed wafer the higher the bending. On semiconductor elements alloyed with 100 mm diameter of molybdenum disc bending reaches 100-120 μm (figure 1). Bending of the semiconductor element generates residual mechanical strains, which may lead to reduction of load cycle capability and value of surge current. That is why for such thyristor structure quality of connection technology of silicon wafer with molybdenum disc is extremely important. This technology should guarantee absence of localization of mechanical strains over the interface of molybdenum disc and silicon wafer – only in this case a high quality thermal contact between semiconductor element and housing is possible.

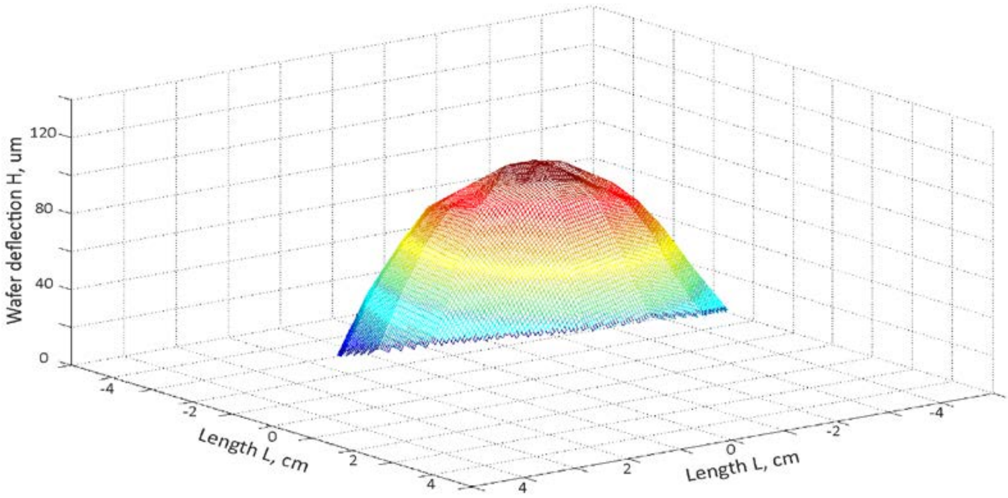

Figure 1. Bending of semiconductor element with molybdenum disc after alloying process.

Absence of above described bending is one of the advantages of pressure contact structure, since heating up to high temperatures and cooling of semiconductor element are excluded, which allow to achieve high value of surge current and good load cycle capability even with shift from nominal mounting force during assembling of thyristor with heat sink.

Excessive thermal resistance from the anode side in comparison with similar characteristic of alloyed semiconductor elements is one of the disadvantages of such method, which degrades the dissipation of generated heat. It is also important to consider that the area of gate electrode in semiconductor element is not under external pressure during assembling of thyristor with heat sink, because in cathode layer area of gate electrode is open to exclude short circuit failure of cathode and gate electrode. In such a way, pressure contact semiconductor element from the anode side has an area under gate electrode, which is not pressed to molybdenum disc what leads to worsen heat dissipation.

As a result thyristors with fully pressure contact structure have certain limitations of safe operating area. In such a way some situations may occur when a certain sequence of separate safe modes can cause conditions of thyristor failure. For example, during long period operation in on-state with low anode current flowing only through auxiliary thyristor, due to absence of heat dissipation in this area a local heating occurs up to temperature, which do not exceed maximum allowed, and area of main thyristor remains cold. If operating mode anticipates consecutive high rate of rise of anode current up to the level not exceeding maximum allowed, then due to temperature difference of the main and auxiliary areas of thyristor, auxiliary thyristor doesn’t turn-off after turn-on of the main one. In addition, level of auxiliary thyristor current will exceed safe limit, which will lead to inadmissible overheat of auxiliary thyristor area and heat breakdown.

As a result of investigations Proton-Electrotex nowadays has a technology of flawless alloying of semiconductor element with molybdenum disc for silicon wafers with diameter up to 100 mm. With help of such technology it is possible to produce semiconductor elements alloyed with molybdenum disc (100mm in diameter) with bending 45 – 55 µm (figure 2), which allows to guarantee good electrical and thermal contact between semiconductor element and housing during assembling of thyristor with heat sink, if all mounting force guidelines are correctly followed (70÷90 kN).

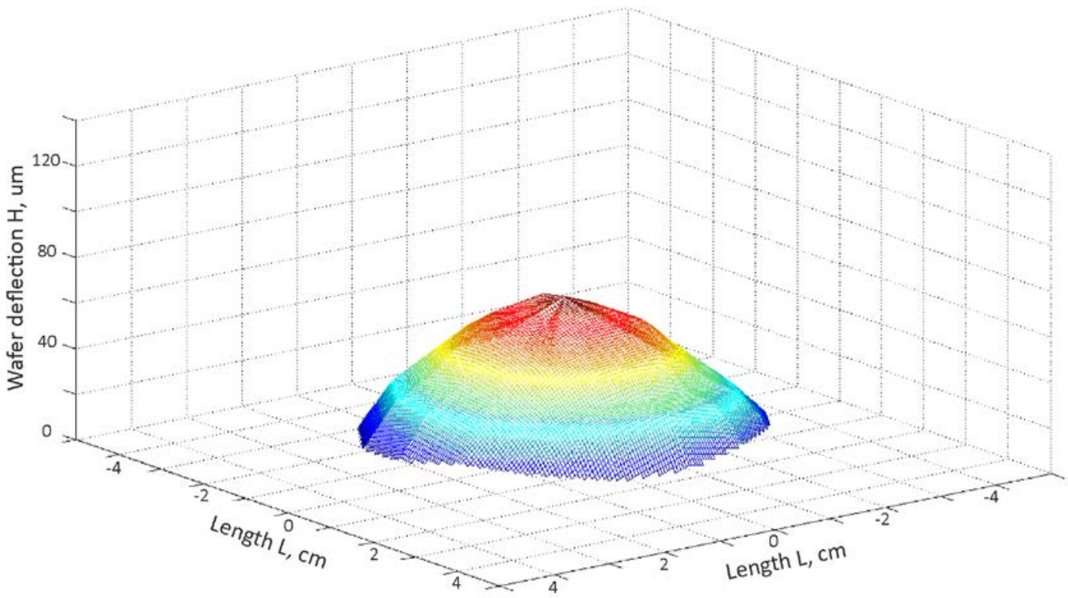

Figure 2 – Bending of semiconductor element with molybdenum disc after flawless alloying process.

That is why during development of new generation thyristors alloyed structure was used, which allows to guarantee absence of dead spots of safe operating area for the whole range of anode currents including modes with highly nonlinear change of anode current, and also guarantee high load cycle capability and value of surge current.

Technology of alloying of silicon wafer with molybdenum disc, which is used in Proton-Electrotex, is applicable up to 100 mm diameter, and above it alternative methods should be used to joint silicon wafer and molybdenum disc. Nowadays new developments are in progress in terms of new technology of jointing silicon wafer with molybdenum disc known as sintering, when instead of solder alloy nano silver paste is being used. Sintering process is going at relatively low temperatures (200-250 °C) and simultaneous control of external force about 0,6 kN/cm^2. As a result minimal bending of semiconductor element is being formed. Such approach includes advantages of both above described methods and aligns disadvantages. Using this technology it is possible to produce semiconductor elements jointed with 100 mm molybdenum disc with bending 25–30 µm (figure 3).

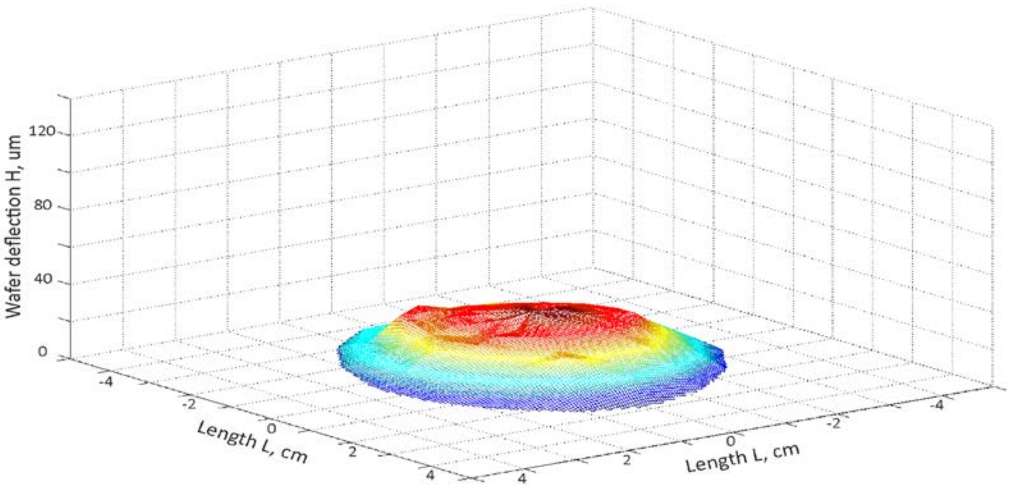

Figure 3 – Bending of semiconductor element with molybdenum disc after sintering process.

At the moment there are some test samples of thyristors produced using this technology, which are being tested right now. Moreover, some work is in progress to lower costs of semiconductor elements jointed with molybdenum disc using sintering to finally put this technology into series production.