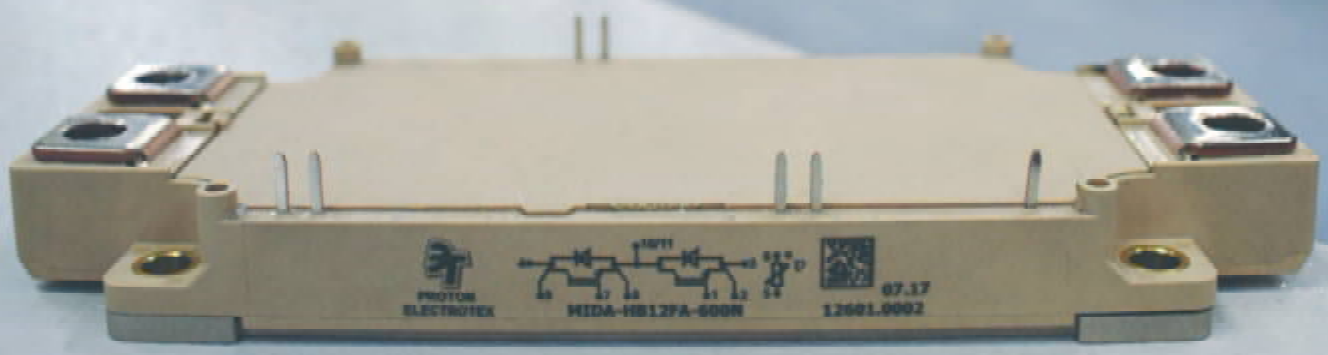
PROTON-ELECTROTEX

IGBT Module Manufacturing Technologies

2017

PROTON-ELECTROTEX
POWER SEMICONDUCTOR DEVICES

IGBT Module Manufacturing Technologies
PROTON-ELECTROTEX, JSC



PROTON-ELECTROTEX, JSC: A. Yu. Boldyrev, A. V. Stavtsev
IVTEC ELECTRONICS, LLC: S. N. Valev

The world is changing rapidly. These changes are most visible in consumer electronics: anyone can differentiate a modern cell phone or TV set from those manufactured in 2000. The last 15 years have changed our habits, working time, and work methods forever. The way the brain perceives information and the fundamental structure of employment in developed countries have also changed. The changes in the component base, studies of material properties, and technology advancements are now preparing the world for a new leap – a change in the power industry practices, which should ultimately lead to a revolutionary abandonment of the fossil fuel in the same way that steam locomotives and furnace heating were abandoned in the past.

According to the International Energy Agency's (IEA) report, primal power generation from renewable sources in 2012 amounted to 13.2% of the world's energy balance. This figure rose to 22% by 2013. It includes wind and hydroelectric power stations, as well as solar power generation of all types.

This explosive growth in "green" energy generation in combination with constant effort to increase efficiency in energy usage by industry and households have created a significant demand for power management systems and components thereof, such as IGBT modules. Those are used in nearly all industrial electric drives and power inverters, including solar, tidal, and wind power plants, as well as in the electric transport.

Further development of highly efficient alternative energy sources will lead to a long-term decrease in fossil fuel share in the total consumption, which in turn will support growth of the "clean power" components' makers. Obviously, only the manufacturers providing reliable supply and high quality of their product will remain in this market as any failure of power supply equipment and systems carries huge risks.

Aleksander Stavtsev.
Technical Director PROTON-ELECTROTEX, JSC
www.proton-electrotex.com

«The success of any company is based on its continuous development; however, its relations with its partners largely influence its growth rate and the quality of its end product. It is worth noting that PROTON-ELECTROTEX, acting in cooperation with its technological partners and using the most advanced designs and process solutions, has been able to rapidly bring its IGBT modules to the market."

It is important to note that heavy power loads and harsh operation environment modes of electric machines require manufacturers of power electronics components (including IGBT modules) to acquire advanced equipment and hire skilled personnel. Full integration of manufacturers of modern electronics into worldwide supply chains, international projects and markets should be supported by the appropriate representation of such companies in their major sales areas. PROTON-ELECTROTEX with its main site located in Oryol, 220 miles south of Moscow, as one of the leaders in Russian power electronics market, meets all the above-listed requirements. In the last three years the company has completely revamped its IGBT modules production site, introduced new corporate management system and developed a new generation of products.

Power modules manufactured by PROTON-ELECTROTEX are now used in many countries thanks to the company's meticulously built network of representative offices and joint projects with the world's industry leaders. PROTON-ELECTROTEX participation in major exhibitions and scientific conferences enables it to monitor global trends in the field of power semiconductors and supply quality products fully compliant with ISO 9001 standards implemented in the company.

The company's production site boasts a full cycle IGBT assembly line meeting every modern standard and a testing facility located in the same building. This arrangement has enabled the company to improve on its internal logistics and reduce the production cycle time. The site cleanroom was fitted with brand new climatic system, which helps to maintain the temperature, moisture, and pressure levels prescribed by clean room environment standards.

Air quality complies with DIN ISO 8573-1 purity class 2.4.1 (see fig. 1)

- compressed air must contain no more than 1 mg/m3 of hard particles with size of not more than 1 μm;
- pressure of the compressed air must be 5-8 bar depending on the choice of equipment;
- the compressed air must be dehumidified to the temperature of dew point not higher than +3°C;
- residual oil contents in the compressed air must not exceed 0.01 mg/m3.

Figure 1. PROTON-ELECTROTEX manufacturing premises

Sergey Valev
Director IVTEC ELECTRONICS, LLC
www.ivtec.ru

"There are clients to whom I have an obligation to go for an extra mile, get fully involved in the process of seeking solutions to their needs, make all possible efforts, and expand the narrow horizons of the laws of physics, chemistry, and mathematics.

Sincerity, transparency, and trust in its colleagues and partners are the recipe for PROTON-ELECTROTEX's success.

This is an example of a properly-built international company, where the whole team works for the success of a common goal, with no lies and primitive formalities, where rationalism and careful planning leave no room for dirty tricks, and where hospitality has become a part of the corporate spirit. I am confident that the future is ours."

Mastering the process of manufacturing the "classic design" of the IGBT module became the first phase of PROTON-ELECTROTEX's development project in 2015 and 2016. After the invention of the principle of IGBT's operations in 1968 and rollout of the first trial samples in the early 1980s, some large industry players (such as Infineon, IR, IXYS, ABB, Toshiba, etc.) have gradually created a "standard range" of dimensions and types of such devices.

The IGBT modules in their current look appeared on the global market over 15 years ago, but they still retain their relevance today thanks to a huge number of standardized mounting seats and dimensions of the terminal units (rectifiers, transformers) where they serve as components.

Like all standardized industrial products, the IGBT modules will retain their current external outlook for at least another 15 years. The market has favorably accepted new players offering standard families of these devices at competitive prices. PROTON-ELECTROTEX has taken its rightful place among these players. Please see Figure 2 for the exterior of the classic design modules.

However, the product's exterior, just like all the other parts, does not determine its content. Although the classic dimensions of the modules have been developed long ago, their stuffing is constantly being improved and optimized in order to boost or upgrade the key features of these devices, decrease their production costs, and increase their qualities and service life cycles.

A comparison of the advanced technology of the classic design modules made 15 years with that of its current version will reveal some significant differences and innovations at every step of the development process.

The common principles of development include:

- **decreased number of process operations; minimization of manual labor and labor**
- **intensity per production unit;**
- **exclusion and reduction of intermediate**
- **reactants and materials (flux, operating tools, accessories);**
- **increased reproducibility and controllability of the production process;**
- **increased process window (robustness).**

The results of the technology's development would be further improvement in the devices' consumer appeal and reduction of their production costs.

This article further analyzes the solutions implemented by PROTON-ELECTROTEX in its production process that maintain the direction of the firm's development.

Figure 2.
PROTON-ELECTROTEX's classic design modules in packages with a base width of:

62 mm

34 mm

PROTON-ELECTROTEX
POWER SEMICONDUCTOR DEVICES

VACUUM SOLDERING

The quality of the end product starts from the first step of the technological process. The first step in the IGBT module manufacturing process is a soldering operation. The soldered seam ensures the mechanical bonding of the components, achievement of the required electrical and thermal conductivity, resistivity to thermal cycling, and, ultimately, plays an important role in the product reliability.

IThe classic convection soldering and vapor-phase soldering with solder paste are gradually giving way to vacuum soldering. The reason behind this trend is the non-uniform warming of the massive heat-conducting elements used in the convection soldering and vapor-phase soldering methods.

There are also certain risks of local overheating and high-temperature gradient when soldering large products due to the different thermal capacitance of the products' elements. The bonding that results from convection soldering is usually non-uniform and has defects. The use of solder paste or other activators during soldering forces manufacturers to apply additional wet cleaning as the fluxes in the paste are chemically active, so their leftovers or remnants may have a negative influence on the product's reliability. Complications in the selection of the soldering fluxes with the required elasticity and resistance to thermal cycling also lead to a reduced service life of the module.

The PROTON-ELECTROTEX team has implemented this process in a different, more modern way: it uses fluxless vacuum soldering with preforms, conductive heating, and surface activation in formic acid vapors.
This approach is used by almost all major manufacturers of power electronics in Russia and across the globe. The approach enables a full use of the product's inbuilt life-cycle resources and increases its reliability thanks to the following features:

Claus Roemer
Sales Director, Department of Soldering Technologies
PINK GmbH Thermosysteme
www.pink.de

«Vacuum soldering in VADU furnaces eliminates caverns and significantly improves quality and reliability of products made by PROTON-ELECTROTEX."

- **Soldering of the whole product in a single move, which, consequently, means less thermal stress for the components that are sensitive to overheating;**
- **The opportunity to choose the best or optimal solder from a wide assortment of solders made from different materials with the required elasticity and melting temperature;**
- **High chemical purity of preforms, compared to pastes;**
- **There is no need for further wet washing;**
- **The soldered seams have high quality thanks to vacuum and, consequently, fewer cavities and voids in the bonds;**
- **Conductive heating: this is when the components with higher thermal capacitance are heated first, specifically, heat dissipator and DCB, and fragile components, such as delicate crystals or chips are heated last. As a result, this leads to a minimum impact of high temperatures on semi-conducting part of the product;**
- **High flexibility in the setting of the soldering temperature regimes and high reproducibility are important to lead-free technologies;**
- **There is a high quality of bonding when used in metallurgy thanks to a more uniform recrystallization of solder, with a common area of defects, including cold soldering, delamination, and cavities (less than 3%).**

All the above-listed features help achieve a low percentage of defects when soldering the IGBT modules, which is PROTON-ELECTROTEX's significant competitive strength. PROTON-ELECTROTEX, when selecting the furnace and all other equipment of the first stage of the project, was guided by the preferences of the industry leaders. This was why it chose the average capacity double-chamber vacuum furnace VADU 200XL manufactured by PINK GmbH Thermosysteme (Germany). According to common opinion of the market players, this furnace has several advantages compared to other systems.

The patented technology for creating a dynamic gap during the heating process and multiple-chamber design with a separate chamber for forced cooling help achieve perfect soldering results in a minimum possible time. The level of vacuum during the VADU furnace process is also adjustable and ensures a stable and repeatable process; there are no splashes of solder regardless of the initial conditions and the thermal mass of loaded products. Vacuum, which is gradually fed directly into the furnace at the moment of the formation of the liquid phase, practically fully removes bubbles from the soldered joint.
The application of a dynamically adjustable gap, smooth adjustment of vacuum, and forced cooling enable it to produce thermal profiles that are compliant with the IPC/JEDEC standards and adapt them in a wide technological corridor to the requirements of the power module manufacturers.

The technical advantages of the VADU series furnaces are widely known and, therefore, there is no point in going into more details about them. It is important that, apart from the inbuilt technological advantages, PROTON-ELECTROTEX's soldering process is carried out with the optimal accessories for power modules.
The choice of accessories and location of the products inside the chamber is a key issue. Some manufacturers are sometimes forced to adapt them to the dimensions of the vacuum chambers, while the furnaces' low thermal performance makes it impossible to use right types of tare and accessories. VADU's accessories are cheap and standardized and their design conforms to the existing range of modules of standard sizes.

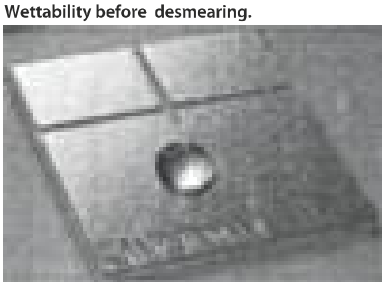
This means that PROTON-ELECTROTEX has developed a working process solution and immediately proceeded to operations without a long phase of adjustment and optimization of the working modes. This approach reflects PINK's high level of cooperation with manufacturers of power electronics and the initial understanding of clients' needs.

PLASMA DESMEARING

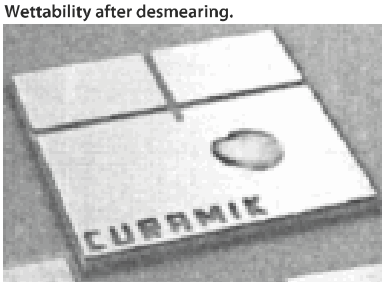
Another important process implemented by PROTON-ELECTROTEX from the very beginning is the use of argon-oxygen plasma for micro-desmearing and surface activation. This is an efficient way to avoid hazardous and poisonous solvents and stabilize the welding, soldering, and coating parameters. The idea of this process is that the ionized gas' molecules in an induced current field and under the vacuum conditions (at a pressure of about 0.1 atm) act at the physical and chemical microlevel and desmear the contaminations and areas of oxidation from component surfaces and activate atoms of the upper layers of component surface. This makes them more prone to bonding with the other components, that is, increasing adhesive properties of the desmeared surfaces. This effect is supported by the improved surface wettability (decreased surface tension force on contact). Please see Figure 3. With the aid of plasma desmearing process, PROTON-ELECTROTEX has managed to quickly optimize the parameters of ultrasonic welding and improve the quality of the module cast molding.

When selecting its equipment, PROTON-ELECTROTEX also made a conscious decision dictated by the product's features. The equipment for plasma desmearing historically came to the assembly process from the semiconductor industry. In the semiconductor industry, it is used in operations that are aggressive to surfaces, such as etching or removing photoresist. This is why frequencies of 13.56 MHz and 2.54 GHz are used for generating high-energy plasma. Consequently, the energy conveyed to plasma at such a frequency may result in overheating and impact the physical features of surfaces, promote spurious chemical reactions, and damage sensitive components of the semiconductor chips. This is why PROTON-ELECTROTEX has chosen a unit that uses plasma generated at a lower frequency (40–50 kHz). It has the following advantages:

Figure 3.
Wettability before desmearing.



Wettability after desmearing.



- **Higher ion density. Low-frequency plasma ensures a higher density of energy per square centimeter compared to high-frequency desmearing. Although it may seem illogical, high-frequency systems for plasma desmearing, in fact, lose a significant portion of energy through heat loss. The amount of the energy lost at a frequency of 13.56 MHz is 850 times higher than the energy lost by a system that operates at a frequency 40 kHz.**

- **Improved efficiency. The efficiency of plasma desmearing is estimated on the basis of the energy used for plasma generation and the amount of energy dissipated into heat. The low-frequency plasma system acts as an ideal condenser with an unlimited capacitive reactance or zero current leak in the waiting mode.**

- **Better uniformity. Low-frequency systems, thanks to a laminar, non-flare stream of plasma, ensure a far more uniform treatment of surfaces, and with the horizontal plasma feed-in, they do not have the kind of shadowing which happens when the products on the top shelves create an obstacle for processing of the products on bottom shelves.**

PROTON-ELECTROTEX's plant has G1000E plasma desmearing unit manufactured by Yield Engineering Systems, which is universal and popular among the manufacturers of super-high-frequency devices, light-emitting diodes, and multi-chip packages.

ULTRASONIC SCANNING

The introduction of the ultrasonic scanning method of inspection was another solution that helped the company quickly achieve the required level of quality and reduce the time of process optimization. Ultrasonic scanning is an indispensable method of nondestructive testing when working with large parts, and it is used both after soldering and at the other stages of module manufacturing, such as the ultrasonic welding of leads.

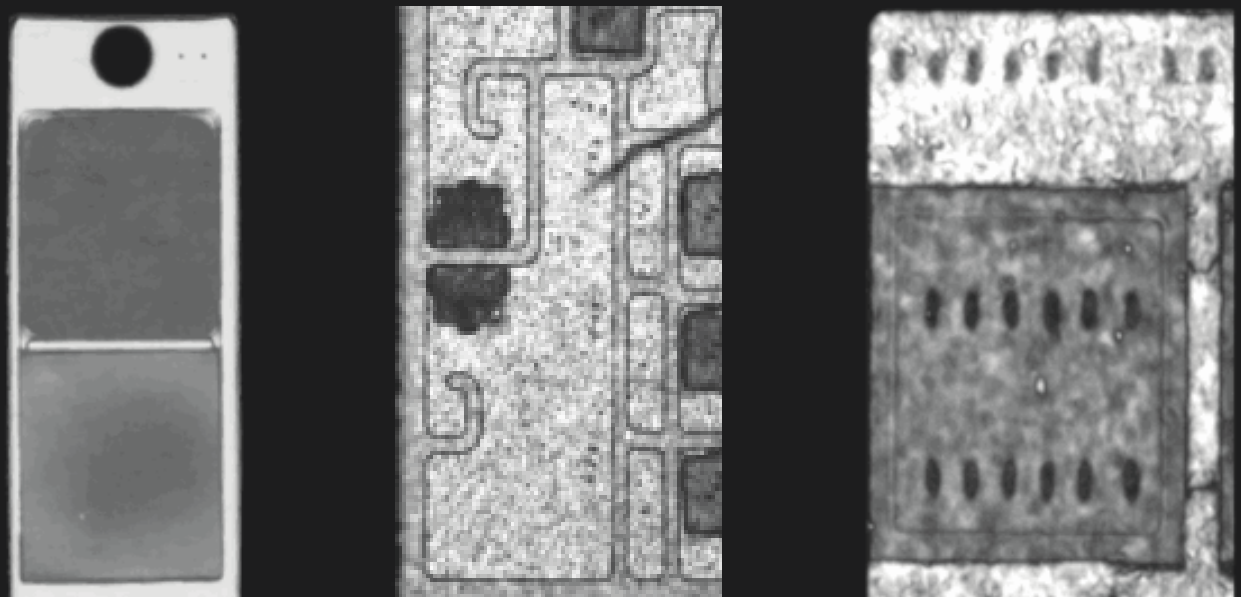
Ernst Eggelaar
CEO
Microtronic GmbH
www.microtronic.de

«... a self-motivated and goal-oriented team with a perfect understanding of physical processes and technologies."

Scanning helps reveal defects at the earlier stages of manufacturing, detect delaminations and faults invisible to any other testing methods, and quickly identify the origin of the defects at the very beginning of the production process thereby preventing the loss of valuable components and time.

PROTON-ELECTROTEX prefers the SONIX ECHO™ device for the ultrasonic nondestructive testing (defectoscopy) and imaging (tomography). This inexpensive acoustic scanning microscope is well-known in the industry. It is a universal tool for controlling the development, production, and analysis of faults in the semiconductor devices. This microscope can find air gaps with a thickness of 0.05+ µm and defects with linear dimensions of 10+ µm. It is especially important to note the capability to detect micro-cracks in ceramics which have resulted from a manufacturing defect and were undetected during the production of the DBC base member.

Figure 4. Ultrasonic scanning of the MIFA module's soldered joint



Stefan Berger
Head of Sales
F&S Bondtec GmbH
www.fsbondtec.com

"Our company, F&S Bondtec, is a supplier of desktop units that are used for ultrasonic welding and bond strength testing. We are extremely excited about the successful implementation of our 56xx platform at PROTON-ELECTROTEX." PROTON-ELECTROTEX's operations cover the whole niche of power modules, which is an actively growing market segment, and we sincerely appreciate its trust in us and our products. It is worth noting that Russia has always been one of the priority markets for F&S Bondtec, which is supported by the longstanding operations of our representative i.V.tec electronics in this country. We are proud of our role as a PROTON-ELECTROTEX's supplier and also of the fact that we have become a part of their successful project."

ULTRASONIC WELDING

Ultrasonic welding of power leads, control leads, and semiconductor chip bonds is a critically vital process, which has replaced the methods of pressed and soldered structures. The modern approach to the production of the classic design IGBT modules minimizes the number of welded and soldered bonds, which has almost practically led to a full displacement of the power leads soldering method. PROTON-ELECTROTEX's ultrasonic welding equipment enables it to flexibly approach the design of the body crossbars, use wires, bands, aluminum and copper conductors of different sections to manufacture all types of high-quality devices that are capable of competing with similar products from the world's leaders.

The company uses different types of ultrasonic welding in its operations: from F&S Bondtec 5650 semiautomatic devices series and F&K Delvotec G5 66000 automatic devices to Schunk DS20/35 systems, which are capable of meeting all the possible needs of the company. Thanks to ultrasonic welding, PROTON-ELECTROTEX's modules have no limitations in terms of service life cycles, which are associated with the degradation of the contact (pressed) and soldered bonds of the conductors inside the devices that were typical for designs of the earlier series of the IGBT modules.

It is probably strange to refer to ultrasonic welding as an innovation. This is because it has been the only method of achieving electric bonding in traditional discrete devices and integrated circuits since the early 1960s. However, welding has more recently become a widely used technology in power electronics, though some of the products are still manufactured with soldering, pressing, or other contact types of bonding of components.

Figure 5. Ultrasonic welding of power leads

Gruber
Head of Sales, Europe
F&K Delvotec Bondtechnik GmbH
www.fkdelvotec.com

«We view our partnership with PROTON-ELECTROTEX in recent years as very successful. We believe PROTON-ELECTROTEX has chosen a very profitable strategy for the promotion of its power modules, which represent a very attractive niche in the electronic devices market. This niche has been growing at rates that more than double the total growth of the semiconductor industry. This trend, along with the ongoing boom in the electric car manufacturing industry, will lead to a more significant increase in the demand for such control systems. We are confident that PROTON-ELECTROTEX, thanks to its portfolio, has created a comfortable starting position that would enable it to acquire a significant share of the market in the future. The company's perfect level of management will help ensure its further growth. We will be very happy to become a part of PROTON-ELECTROTEX's success story."

The F&S Bondtec 5650 and F&K Delvotec G5 66000 ultrasonic welding machines, thanks to their design features, help achieve the maximum reliability of bonds. Both units have multiple functions and parameters control. They reduce the impact of their operator on the manufacturing process thanks to a high level of automation. In addition to these and other advantages, the automatic units for ultrasonic welding have a feedback system for online monitoring of all the processes during welding, auto-diagnostics elements, and auto-calibration, as well as the recording of the welding process, accumulation and control of statistics.

- **The shearing strength of the bonds produced by ultrasonic welding (average value) amounts to 18.9 N;**
- **All the power terminals and bonds between chips have zero defects in terms of creep effect and delaminations during thermal cycling.**

It should be noted that the unit's performance in terms of thick wire of the power modules is not a critical factor: the performance limit was achieved many years ago, and it is connected with the physical time required for the formation of diffusive bonding of metals. This is why the advantages of the welding units and system's selection criteria are mainly connected with the quality and predictability of this process. Ultrasonic welding with the F&S and F&K's units has shown high reproducibility and a wide window of process parameters. The tests conducted by PROTON-ELECTROTEX have shown that the process of welding with a thick aluminum wire in the F&K Delvotec units is well controlled thanks to its ability to ensure precise tuning or setting of the welding parameters and loop geometry.

Generally, the G5 management system controls about 200 welding parameters, which is more than the number controlled by any other unit. However, in most cases, the creation of a program and the operator's activities take place intuitively and involve a minimum number of values. But for the borderline cases, F&K Delvotec always proposes more refined tuning or setting of parameters, which is important in the PROTON-ELECTROTEX's conditions of pilot and multi-product manufacturing.

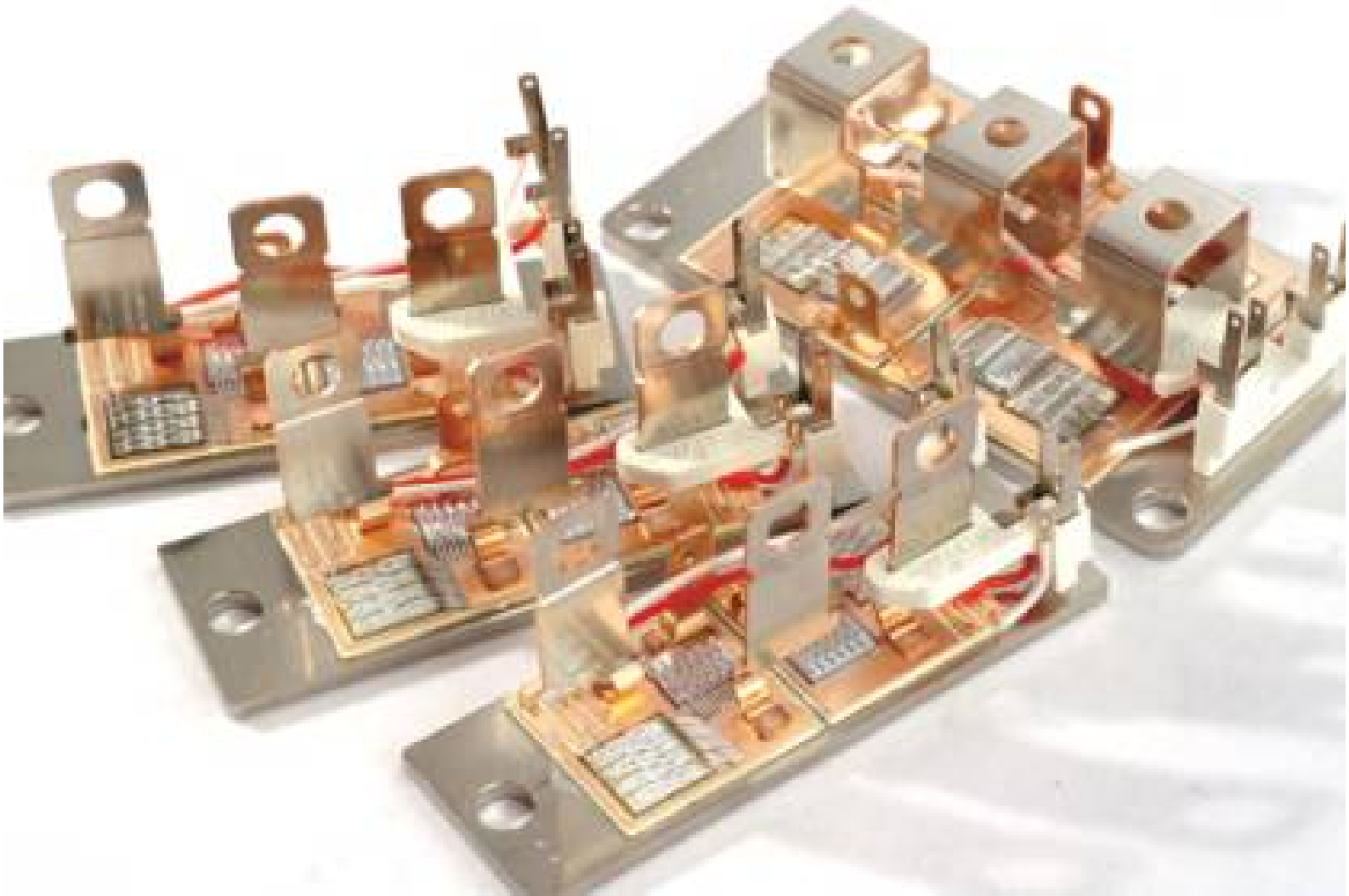
Thanks to the new generation of the BPC system, which is used for active control of the power and length of the welding impulses via an online feedback, we are satisfied with the resilience of the control systems of the units to the changes in the properties of the base components. The control system is flexible and requires minimum intervention from the operators thanks to its intellectual computer vision.

ULTRASONIC WELDING OF POWER LEADS

Jan Fritzges
Head of the Special Purpose Equipment Department
Schunk Sonosystems GmbH
www.schunk-sonosystems.com

«PROTON-ELECTROTEX has been successfully using our systems for ultrasonic welding since 2014. The company, having successfully mastered our proposed process of metal bonds, is now fully prepared to develop and manufacture new product models with improved reliability. This technology is aimed at the future, and I hope very soon we will take an active part in the development of their ever-growing product portfolio."

Ultrasonic welding of terminals ensures an improved current carrying capability and reduced conductivity-related losses. This is achieved through an additional layer of solder metal, which has a different conductivity rate. The data about the absence of any faults in the terminal bonds after thermal cycling could serve as an indicator of such improved reliability. This means the complete elimination of the creep effect at a constant load during the electric thermal cycling, which happens quite often in the soldered structures.



QUALITY CONTROL AND MODULE TESTING FOR RELIABILITY

When furnishing the new plant, huge attention was paid to the formalization and harmonization of the methods of testing the IGBT modules for local and foreign clients. Apart from carrying out the acceptance tests and elimination of supply of defective products, it is also especially important to ensure that clients receive reliable and long-serving IGBT modules. This is why the PROTON-ELECTROTEX's team of developers and technology experts has developed a set of equipment which enables it to perform 100% measurements of product parameters at room and higher temperatures.

All the IGBT modules produced by PROTON-ELECTROTEX undergo scheduled and qualification tests in accordance with the GOST 24461-80 and international IEC 60747-9 standards. To control the static and dynamic electrical parameters of the products, PROTON-ELECTROTEX uses the Schuster units based on the TPS 625 and DTS 758 measurement devices that are custom-designed to its operations' specifications. This equipment is used by almost all the manufacturers of power electronics across the world, which facilitates cooperation and discussion of our tasks with our foreign clients and partners.

When the production and testing lines were commissioned at PROTON-ELECTROTEX, the trial models of the modules were studied and tested in detail so as to compare them with similar modules on sale in Russia and other European markets. The results of the tests performed by PROTON-ELECTROTEX and independent laboratories have proven the right choice of the equipment and process parameters, as well as the high qualification and expertise of the company's engineering and production personnel. This is because the parameters of the company's modules successfully compete with their foreign analogs.

- **The module base is isolated from the current-conducting elements and withstands 4,000 V;**
- **Electric thermal cycling gives the result of about 40,000 cycles at ΔT = 100°C. In this regard, our rates of thermal cycling and electric thermal cycling are as good as those of the leading European manufacturers.**
- **Modules undergo high-temperature storing within at least 1,000 hours at 180°C followed by an insulation check;**
- **1,000 hour waiting-mode tests confirm that the blocking characteristics and leak current IGES are maintained within the normal range.spirit. I am confident that the future is bright for them."**

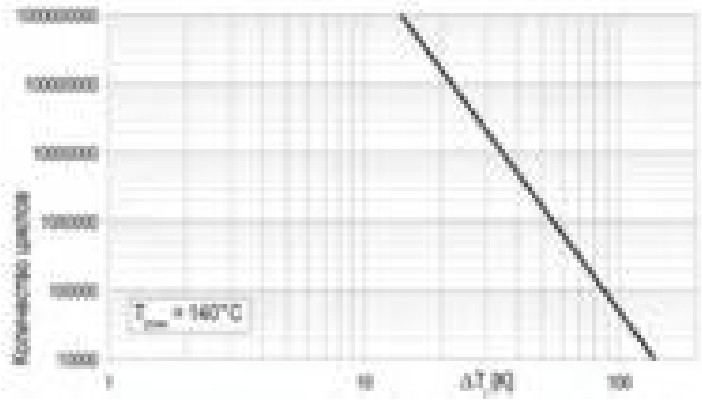


Figure 8. The electric thermal cycling results

CONCLUSION

Acting on the results of the implementation of the first phase of PROTON-ELECTROTEX's long-term development plan, we can confirm that the project is a success. The plant has mastered some really universal technological processes and uses today's best equipment in its operations. It has also created a pool of important personnel and launched serial manufacturing of products that are capable of competing with their analogs on the domestic and international markets. PROTON-ELECTROTEX's policies of transparency, real competitiveness of its products, and building a modern production system and marketing are gradually bringing the company to the position of a major, full-fledged industry player. The plant is already functioning in compliance with the international standards, and it is following all the trends in the development of power semiconductor products. The company has established an in-house engineering center, which ensures the right level of design and production of top quality modules that can compete with their best analogs on the global markets.

Besides, PROTON-ELECTROTEX is constantly improving the quality of its products. The company's ongoing R&D activities are focused on discovering new functions of modules, such as sintering and improvement of modules' thermal features.

However, apart from machines, our project also has a human side. The success of the task executed by PROTON-ELECTROTEX within just two years is built on a strong foundation of relations, trust, and honesty between the company, its equipment suppliers, and industry professionals. We are glad that as we do our jobs, we have received and continue to receive the full support from the equipment manufacturers and their representative offices in Russia.

IGBT modules of PROTON-ELECTROTEX

More than 20 000 modules per month
Maximal capacity

Thousands of IGBT modules
Successfully employed in customers equipment

More than 420 employees
Ensure sustained process of manufacturing and product improvement

Growth of IGBT production volume