More Power for a Greener World

Regenerative and green energy sources will drive power electronics over the coming decades, this is the conclusion of many keynotes and presentations at PCIM 2012. The most important European power electronics event closed on May 10 with 263 exhibitors, 6.874 visitors and 744 conference delegates - the highest numbers recorded so far. Besides new semiconductor technologies and devices such as Gallium Nitride (GaN) and Silicon Carbide (SiC) new assembly and interconnect technologies for power modules gained a lot of interest.

More than 230 papers have been presented at the conference, out of this four outstanding papers were awarded for three young engineers and one for the best paper. The three Young Engineer Award winners received prize money, whilst the Best Paper Award winner received prize money and an invitation to the PCIM Asia 2013 Conference in Shanghai - the latter sponsored by Power Electronics Europe and Semikron.

The three winners of the PCIM Young Engineer Award were Johannes Kolb, Karlsruhe Institute of Technology, Germany for 'Operating Performance of Modular Multilevel Converters in Drive Applications'; Hari Babu Kotte, Mid Sweden University, Sweden for 'A ZVS Half Bridge DC-DC Converter in MHz Frequency Region using Novel Hybrid Power Transformer'; and Marek Siatkowski, University Bremen, Germany for the paper 'Construction of a High Force Density Linear Motor with a Passive Stator using Transverse Flux Technology'.

The winner of the Best Paper Award was Keiji Okumura, Rohm Co., Ltd., Japan, for the paper 'Ultra low On-Resistance SiC Trench devices'. This paper presented next generation Silicon Carbide (SiC) planar MOSFETs, trench structure Schottky diodes, and trench MOSFETs. The newly developed SiC planar MOSFETs have suppressed the degradation of parasitic PN junction diodes even if forward current penetrates into the PN junction diodes. Secondly, SiC Schottky diodes are attractive devices to reduce switching losses in high voltage applications. And SiC MOSFETs with a double-trench structure have improved reliability of the device while maintaining ultra low on-resistance due to the fact that the new structure effectively reduced the highest electric field at the bottom of the gate trench, preventing gate oxide breakdown.

This paper complemented PEE's Special Session 'High Frequency Switching Devices and Technologies for Green Applications' which focused on Gallium Nitride and Silicon Carbide application trends.

Renewable energies stimulate power electronics

The global electrical energy consumption is still rising and there is a steady demand to increase the power capacity. It is expected that it has to be doubled again within 20 years. "The production, distribution and use of the

BPA handover to Rohm's Keiji Okumura at PCIM 2012 opening ceremony by Semikron's Uwe Scheuermann (left), PEE Editor Achim Scharf and Scientific Advisory Board Chairman, Prof. Leo Lorenz (right)

"Power electronics is playing an essential role when integrating renewable technologies like PV and wind energy systems into the future Grid structure", Frede Blaabjerg emphasized in his keynote

energy should be as technological efficient as possible and incentives to save energy at the end-user should also be set up. Two major technologies will play important roles to solve the future problems. One is to change the electrical power production sources from the conventional energy sources to renewable energy resources. Another is to use high efficient power electronics in power generation, power transmission/distribution and end-user application, where power electronics are changing from being a minor energy source to be acting as important power sources in the energy system", underlined Frede Blaabjerg from Aalborg University (www.et.aau.dk) in his keynote on 'Grid Integration of Renewables'.

The wind power has grown to a cumulative worldwide installation level of 200 GW with over 39 GW of newly installed wind power capacity in 2010. Now there are predictions that the installed capacity could grow one order of magnitude to 2300 GW by 2030, according to a study published by the Global Wind Energy Council and Greenpeace International. The worldwide penetration of wind power in 2010 was around 2 %. China was the largest market in 2010 with over 19 GW installed and in general EU, USA and China are sharing around one third each of the total market.

The most used generator type is changing from an induction generator to Permanent Magnet Synchronous Generators (PMSG), where a full scale power conversion (FSC) is necessary. However, the cost of permanent magnets are becoming a challenge for this concept. All wind turbine manufacturers are using a step-up transformer for connecting the generator to the grid. Today the DFIG is still dominating the market but in the future FSC is expected to take over.

The annual installation of PV power has increased to above 5 GW in 2005 to roughly 40 GW in 2010. The annual growth rate is still very high (>30 %) especially for the last four years. As in the previous years the vast majority of new capacity was installed in EU with Germany as dominating the market followed by Spain and Italy. The USA market is also growing fast. "The most progressing technology is wind power but PV power plants are also emerging rapidly now and the technology has the highest growth rate. The applications of power electronics in various kinds of wind turbine generation systems are showing that the wind turbine behavior and performance are significantly improved by using power electronics and will be able to enable a muck more flexible grid structure. Wind turbines are able to act as a contributor to the frequency and voltage control in the grid by means of active and reactive power control using power electronics. The same will be the case for PV power plants and the standards will be changing in the next years. Thus, power electronics is playing an essential role when integrating renewable technologies like PV and wind energy systems into the future Grid structure", Blaabjerg emphasized.

"Our new mAgic sinter materials provide novel interconnect solutions for DCB devices with operation temperatures above 150°C and enable designs with higher power density", stated Thomas Krebs, Head of Microbond Assembly Materials at Heraeus

Towards lower losses and higher operating temperatures

Power module manufacturers are faced increasingly with the challenge to deal with higher temperatures of 175°C or more for Silicon power chips inside the modules, SiC and GaN are capable for even higher temperatures. In a power module the chips are normally soldered on their backside to the substrate, usually direct bonded copper (DBC) via soft solders with melting points below 250°C. This die attach spreads the generated heat to the DBC and from that the heatsink. The electrical connections on the upper side of the chips are realized by ultrasonic bonded aluminum wires. Both die attach and bonding are becoming more and more the weak points for power modules in demanding applications such as transportation (hybrid electric vehicles) or renewable energies which call for long lifetime of the power electronics and thus for high reliability.

The melting point of today's soft solders used for die attach is between 183°C (SnPb) and 220°C (SnAg). As long as the (junction) temperature of the power chips is well below the melting point of the solder material the connection between chip and substrate is reliable, but an increase up to 175°C (standard for new IGBTs) or above leads to a significantly decrease of the solder interconnect stability and thus reliability. Early failures due to solder fatique or brittle fracture can occur.

This creates a demand for new interconnection materials that can fulfill the reqirements of higher temperature stability, thermal conductivity and increased reliability when compared to lead-free solders. For the die attach two techniques have been developed recently, silver sintering and diffusion soldering or bonding (the latter is used in Infineon's latest PrimePACK power modules).

New sinter materials for DCB power modules

Sintering of silver (Ag) particles comprises a silver powder applied between chip and substrate, which is pressed (> 40 MPa) under moderate temperature (> 250°C) to form a compact Ag joint. This low temperature joining technology (LTJT) provides high thermal and electrical conductivity as well as long lifetime of the modules at temperatures > 150°C. "However, design and process constraints currently hamper the quick implementation in production lines, because special sintering presses are needed and the process is not compatible with pressure and temperature sensitive dies", said Thomas Krebs, Head of Microbond Assembly Materials at Hanau-based Heraeus **(www.heraeus-contactmaterials.com)**. At PCIM the company introduced its new so-called mAgic micro-silver sinter materials (paste and adhesive) as an alternative for solder and LTJT materials in DCB power modules with operation temperatures above 150°C.

The sinter paste is formulated mainly with silver powder and solvents, it can be sintered with low or even no pressure. The resulting sintered joint is a porous structure of silver particles without organic residues, which are also sintered to the die and substrate surface. "This sintered structure ensures low electrical resistivity and high thermal conductivity as well as high adhesion strength. The high silver melting point above 960°C allows to raise the operating temperature to 150°C and more without the risk of joint degradation", Krebs stated.

The sinter adhesive consists of silver powder in a polymer matrix and are processed in a pressure-free curing step. The pores and open spaces in the resulting joint are filled with cured resin. "The sintered particles exhibit thermal and electrical conductivities comparable to solder, what enable the mAgic adhesive to be used in low to medium power DCB devices. Also the temperature stability is significantly higher compared to solders", Krebs pointed out.

The pressure sintering process consists of paste printing, pre-drying at 60°C for up to 15 min, die placement in the dried paste and sintering at 250°C for up to 3 min in a press at 10 (LTS 043) to 30 MPa (LTS 016 paste). The total processing time is 15 to 20 minutes. Dies up to 100 mm_ can also been sintered in a convection oven with a defined temperature profile. "In contrast to LTJT sinter pastes our new sinter pastes can be processed in pressure assisted or even no pressure steps at low temperatures without drying channels for die sizes up to 100 mm_ on DCB substrates metallized with Ag and NiAu. The mAgic sinter materials provide novel interconnect solutions for DCB devices with operation temperatures above 150°C and enable designs with higher power density", Krebs concluded.

Diffusion soldering and copper bonding allows for higher temperatures

Infineon **(www.infineon.com)** follows the second alternative approach in which the phase formation reaction of the intermetallics during soldering is utilized to form a high melting point bond. "Depending on the process parameters the resulting joints consist of one or more intermetallic phases with melting points well above 400°C", stated Infineon's Head of Packaging Technology Karsten Guth recently. For the copper-tin (Cu-Sn) combination the joint can be realized by the compounds Cu3Sn and Cu6Sn5 which have much higher melting points and mechanical strength than Sn-based soft solder.

To create pure intermetallic joints with a remelting temperature greater 400°C a rapid solidification of Sn-Ag solder within seconds is applied. "The whole volume of low melting solder is consumed by the solidification process resulting in a high melting bond between chip and substrate. Depending on the ratio of the two different intermetallic phases, that are formed in the copper-tin system, the homologous temperature for these joints ranges from 0.50 to 0.69", Guth explained. Result is a 30-60 fold increase of the power

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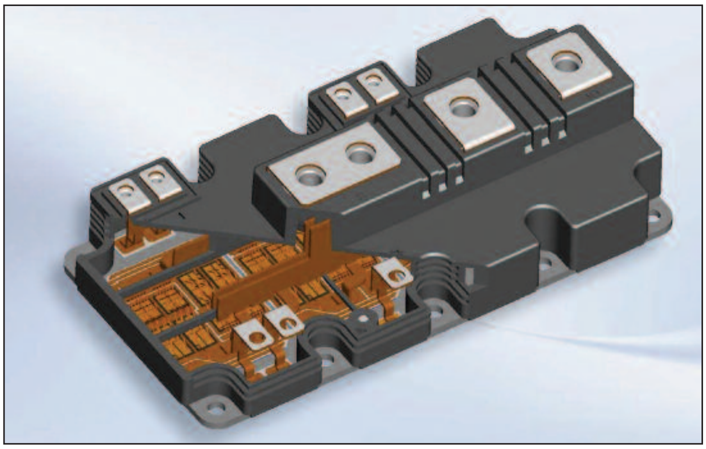


First PrimePACK power module featuring IGBT5 and .XT technology Source: Infineon

cycling capability even for an increased junction temperature. "During our tests it appeared that the substrate layout sepcific influence on the heat distribution has got more impact on the module's lifetime than the technology itself. Accordingly, both sintering and diffusion soldering are qualified to meet the requirements of next generation power module packages", Guth stated. Diffusion bonding is one of the key technologies in Infineon's so-called .XT technology, along with a copper layer on the top of the chip to allow copper bond wires instead of aluminum.

At PCIM 2012 Infineon's Division President Industrial Power Control (IPC) Helmut Gassel introduced IGBT5 and .XT as the beginning of a new era in IGBT chip and internal packaging technologies. "We are in the final stage of qualifying our IGBT5 chips featuring .XT technology. First lead customers of our power modules already have received samples, volume production of PrimePack power modules featuring IGBT5 and .XT die attach and copper bonding techniques is scheduled for 2013. Also some external power modules manufacturers have been sampled with IGBT5 chips", Gassel stated.

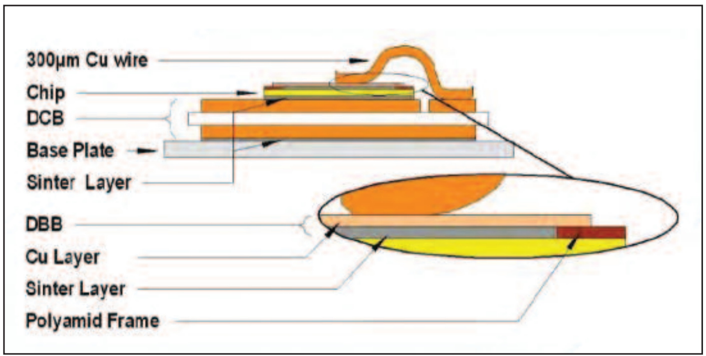
Besides diffusion soldering for the die attach copper bonding is the second major step in .XT for achieving higher reliability and power cycling capability of power modules due to the intrinsic lower electrical resistance and higher thermal conductivity of copper. "The copper finishing of the chip surface is a prerequisite for copper bonding, here we can look at a long track record of copper finishing of DCB substrates. Tests and simulation have shown that even under harsh environmental conditions this copper connections withstands corrosion. We will offer external power module manufacturers willing to implement IGBT5 chips the choice to use this advanced die attach and bonding or to stay with conventional aluminum bonding. The respective wafers will be supplied. All in all IGBT5 is qualified for operating temperatures up to 175°C, output power and power density increases by up to 25 percent or lifetime by a factor of ten. And last but not least .XT supports junction temperatures of 200°C", Gassel concluded.

Copper bond contacts on sintered metal buffer

Danfoss Silicon Power **(www.danfoss.com)** follows a different approach. "Copper wire bonding maintains the design and process flexibility of the current Al wire bonding method but Cu wires demand a much more robust top metallization in order to protect the power semiconductor against chip crack and damage of the fine structures under the bond pad. In some applications, soldering of the die is successfully substituted by low temperature sintering or by diffusion soldering. The combination of a reliable die attach technique as well as a reliable top contact technology is a necessary and promising solution for significantly increased power module reliability", explained Ronald Eisele, Prof. at University of Applied Sciences Kiel **(www.fh-kiel.de)** and Danfoss advisor.

The result is Danfoss Bond Buffer (DBB) technology, which mainly consists of a thin copper foil which is sintered onto the upper surface of the semiconductor. Sintering is also used to replace the soldering between the die and the DBC substrate. "The design of the DBB was dimensioned for the thermo mechanical optimum to reduce the mechanical stress due to CTE mismatch. In addition to the property during bonding to absorb energy and protect the die, the DBB also has thermal and electrical advantages. No silicon cracks after the DBB process were observed. The volume of the DBB forms a thermal capacity which has a positive influence on the thermal impedance. As the copper layer has a large cross-sectional area, which increases the vertical current flow, the DBB provides a uniform current density distribution in the semiconductor. Due to the improved vertical current flow, there is no mandatory need to place a stitch bond on the semiconductor", said Eisele.

Through the integration of the sintering and the DBB technology the main weaknesses of the standard module were eliminated. The solder joint from

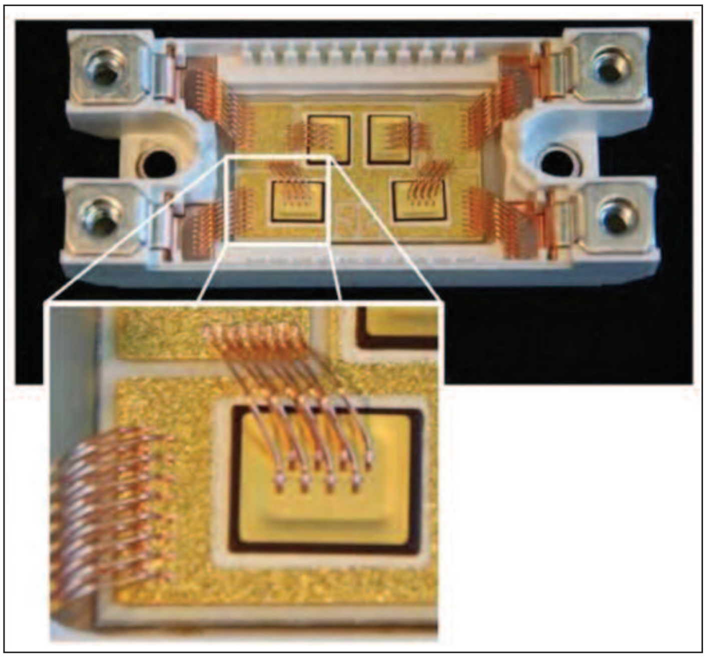


Cross section of Danfoss Bond Buffer (DBB) technology featuring sintering and Copper bonding

the die to the DBC and the Al wires on the die top side were the main bottlenecks in the development of highly reliable modules. The DBB technology is applicable to a large number of standard semiconductors and allows flexibility of the layout due to the bonding technology.

DBB was implemented on a 400 V/150 A rectifier module for testing and benchmarking. The next step is the DBB-application on transistor layouts using a gate pad area and an emitter area (in case of an IGBT) in the same bond buffer. This will extend the beneficial properties also to the gate wire bond. IGBTs as well as MOSFETs are already under first examinations. Extreme current carrying capability can be enabled due to expanded wire cross sections up to 600 µm of each Cu wire.

An other approach using Aluminum-cladded Copper wires has been introduced by Semikron (see our feature 'Extension of Operation Temperature Range to 200°C Enabled by Al/Cu Wire Bonds').



DBB 400 V/150 A rectifier module

Speakers of PEE's Special Session in the final Q&A featuring MicroGaN's Ertugrul Sönmez (left), Cree's Bob Callanan, ABB's Iulian Nistor, IR's Michael A. Briere, and Fairchild's Peter Haaf

Focus on Green Applications with SiC and GaN

PEE's Special Session "High Frequency Switching Technologies & Devices for Green Applications" on May 9, 10.00 - 12.30 am focused on WBG (SiC and GaN) power applications. Around 100 delegates were interactively involved in the final discussion after all presentations, an outstanding feature for our PCIM Special Sessions over the past four years. Naturally GaN on Silicon received most of the attention due to its promises to be less expensive than SiC and its possible future capability of handling 1200 V, while SiC is in discussion for decades and thus more mature.

The papers covered "Efficient Power Electronics for the price of Silicon - 3D-GaN Technology for GaN-on-Silicon" by MicroGaN/Germany, "The Status of HV GaN based Power Device Development at International Rectifier", "Comparative High Frequency Performance of SiC MOSFETs Under Hard Switched Conditions" by Cree, "Silicon Carbide BJT's in boost applications" by Fairchild Semiconductor, and finally "Opportunities and Challenges for Wide Bandgap Power Devices in Megawatt PE Applications" by ABB. The presented papers can be found in this and the upcoming PEE issues.