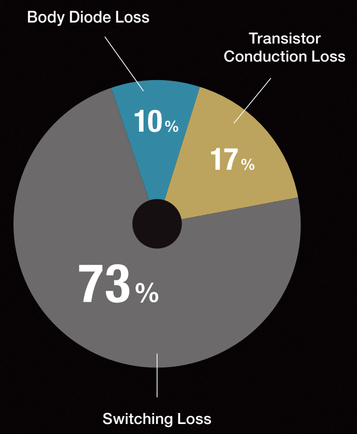
The next stage in power semiconductors has begun

The Impact of Silicon Carbide

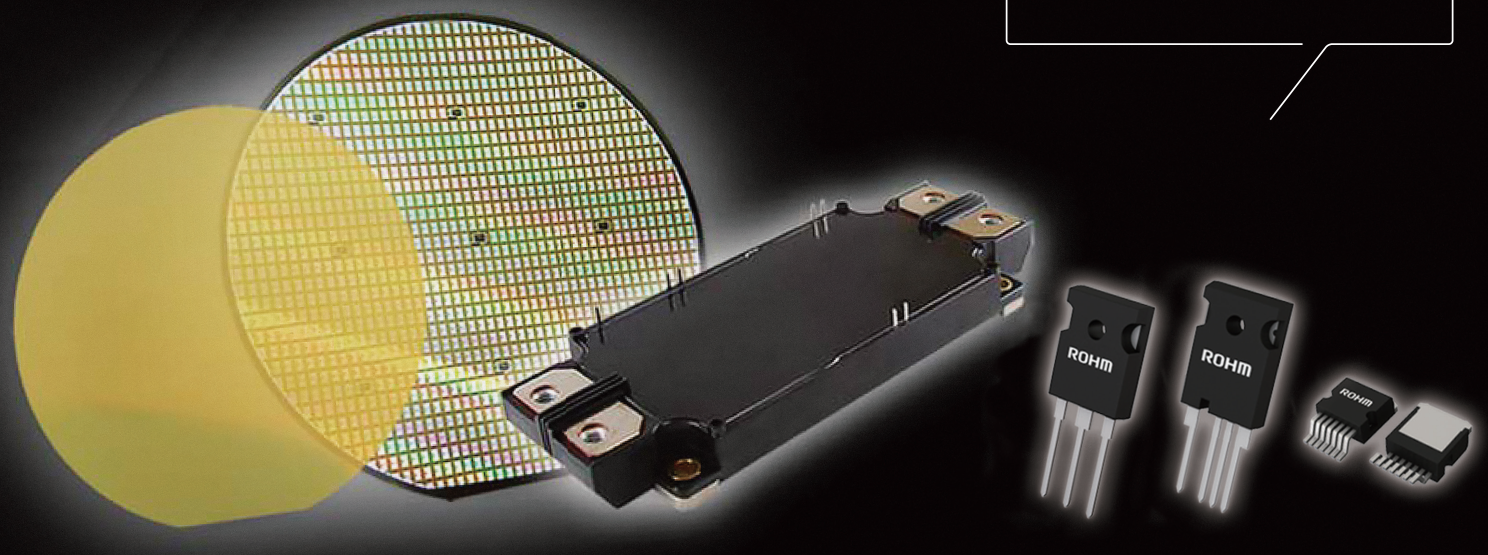
SiC power semiconductors are quickly attracting attention
as a next-generation electric powertrain technology.
However, in addition to the difficulty in handling SiC,
the application of SiC in vehicle drive applications imposes strict requirements.
As such mass production is limited to just a few manufacturers.
One of them is ROHM, a pioneer in SiC power semiconductors.

*Source: Motor Fan illustrated Vol. 188 Author: Ippei Takahashi

Inverter Loss Breakdown



The above shows the breakdown of energy loss generated by power semiconductors when used in inverters for motor drive. Switching loss, which accounts for the majority, occurs mainly in the transition state between ON and OFF. This is the area where the effects of SiC power semiconductors (SiC MOSFETs) is most apparent.

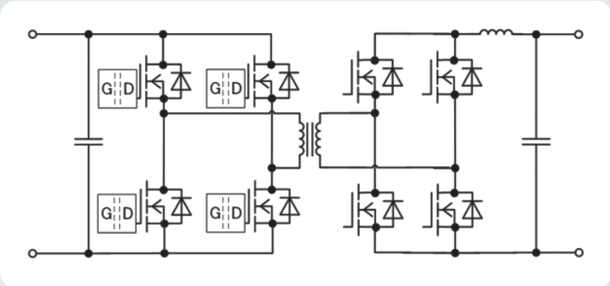


One technical issue that will determine the future of EVs, which run solely on electricity stored batteries, is improving the efficiency of electric power utilization. For example, more efficient use of battery power will make it possible to extend the cruising range at the same battery size or maintain the cruising range while reducing battery size. In particular, the downsizing of batteries, which leads to a reduction in energy required for driving and consequent weight reduction, can bring about a 'positive spiral' of high efficiency. And now that the energy density and cost reduction of lithium-ion batteries have reached a plateau and the problem of securing manufacturing resources is becoming more apparent, SiC power semiconductors are garnering attention as a reliable source of power.

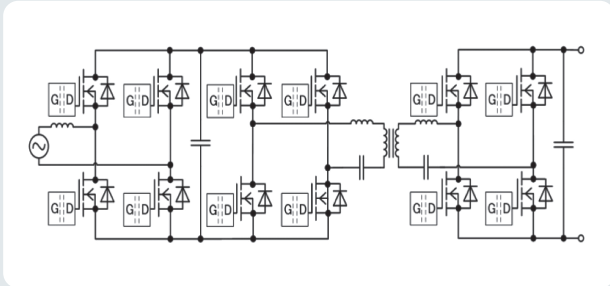
Power semiconductors are key electronic components that play an important role in inverters which convert DC stored in the battery into AC required by the motor. They are 'gateways' through which electricity flowing from the battery to the motor passes, but the elements (semiconductors) used in this power conversion process are subject to losses. As shown in the pie chart above, losses are mainly classified into three types, but what all of them have in common is that they end up as heat, so we can roughly consider them synonymous with resistance.

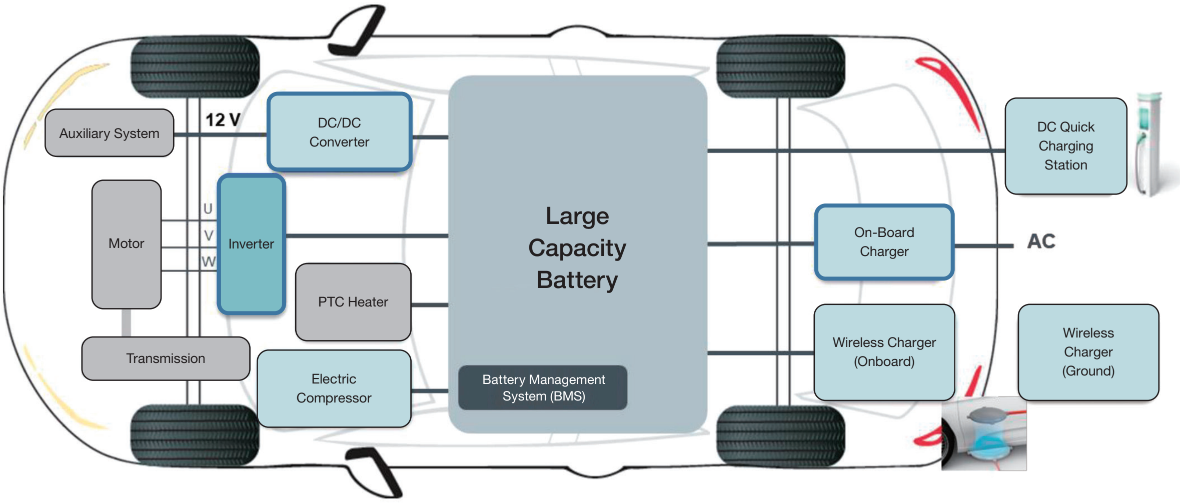
Originally, the rapid electrification of vehicle powertrains in recent years was due to the success of power semiconductors called IGBTs (Insulated Gate Bipolar Transistors). IGBTs are silicon power semiconductors formed on a silicon substrate. In contrast, SiC power semiconductors, which are expected to play a role in the powertrains of next-generation EVs, utilize a MOSFET structure formed on an SiC substrate. It is important to note that SiC power semiconductors (SiC MOSFETs to be precise)

DC/DC Converter

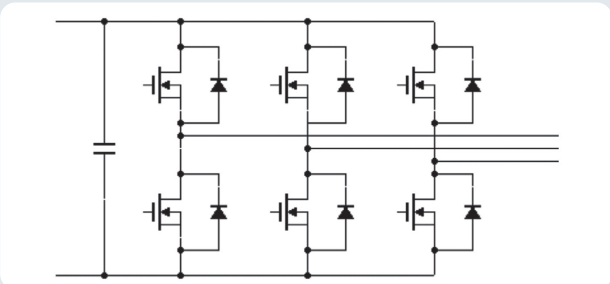


On-Board Charger





Inverter



Key Automotive Applications for Power Semiconductors

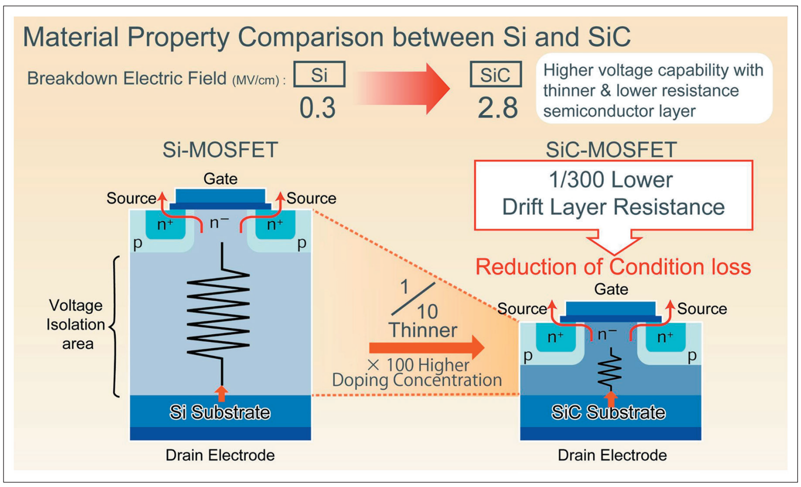
Power semiconductors are generally applied in the three areas shown in the diagram above. For example, the onboard charger rectifies and boosts the voltage from the 100-200V AC household power to DC and supplies it to the drive battery, the DC/DC converter steps down the voltage of the drive battery for the 12V battery to power auxiliary equipment, and the inverter converts the DC of the drive battery into AC at a frequency based on operating conditions. As both power conversion blocks are carried out at high voltages, replacing conventional silicon IGBTs currently used with SiC MOSFETs is expected to bring benefits such as improved efficiency and the miniaturization of auxiliary equipment.

Structural Comparison: SiC vs Silicon

SiC semiconductors, which possess 10 times the breakdown electric field of silicon, can provide enough voltage capability to withstand equivalent voltages at 1/10th the thickness. In both Si IGBTs and SiC MOSFETs, current flows in the vertical direction, so reducing the thickness of this section (called the drift layer) translates to a smaller resistance during conduction. In fact, it is estimated that the resistance value can be reduced by as much as 300 times.

are superior to their silicon counterparts in terms of withstand voltage and loss. And by a wide margin as well.

Featuring high voltage resistance that enables ONOFF switching operation while withstanding the several hundreds of volts required for EVs and HEVs, SiC power semiconductors can ensure the same performance as silicon at only 1/10th the thickness. This means that the distance through which current passes is also reduced to 1/10th, making the electrical resistance proportional to the distance astoundingly small.

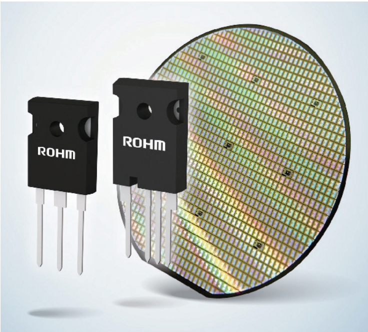


"ROHM's latest 4th Gen SiC MOSFETs deliver the lowest ON-resistance per unit area through advanced technology utilizing a trench gate structure. At the same time parasitic capacitance, the source of switching loss, has been reduced. This translates to a 40% performance improvement in ON-resistance and 50% lower switching loss compared with 3rd Gen SiC MOSFETs. Switching loss in particular account for more than 70% of the losses generated by SiC MOSFETs in traction inverter applications, so minimizing this can contribute to significantly improved efficiency," says Tamegai.

The superior response of SiC MOSFETs is a key factor in reducing switching loss. ROHM has developed a unique method to further speed up the rise time of the voltage relative to the control signal, and in the graph, the slope of the rising voltage is made to be more 'vertical', reducing the area of the slope (integral value of voltage change) that causes loss. In an inverter where switching (ON/OFF operation) is repeated at high speed, the number of times switching loss occurs means that even a small loss can build up to a non-negligible level.

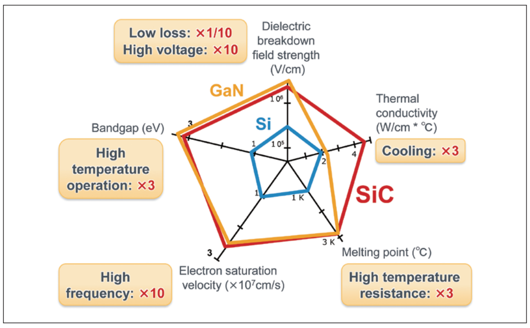
Incidentally, superior response enables higher frequency operation, leading to smaller coils, capacitors, and other components used to smooth out the waveforms of voltage and current. And as the size of these components greatly affect the size of the inverter, they also contribute to greater miniaturization. SiC's high temperature resistance is also advantageous to downsizing. Compared to silicon power semiconductors, SiC enables stable performance at temperature exceeding 100°C (actually up to 175°C but the package and wiring cannot withstand this), allowing the cooling structure to be simplified by changing from water to air cooling and reducing the size of the heat sinks.

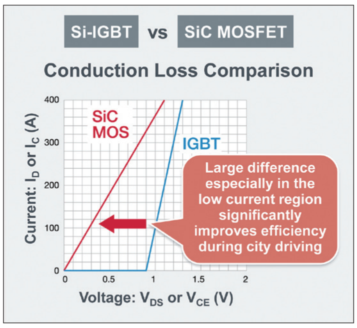
"SiC MOSFETs provide a number of benefits,



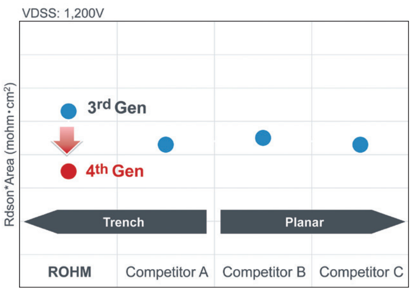
Material Properties and Advantages of SiC

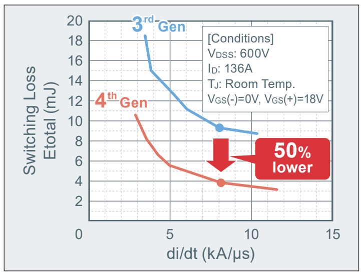
At the bottom left is a spider graph comparing the properties of materials used in power semiconductors. The dark orange line shows that SiC significantly exceeds Si, which is currently the mainstream material, in all aspects, including excellent thermal conductivity approximately twice that of GaN (Gallium Nitride). By taking advantage of the high voltage resistance (dielectric breakdown voltage) of SiC and using a simpler MOSFET structure (with one less PN bonding layer) than IGBTs, the disadvantage of IGBTs, namely knee voltage (where the current does not rise until around 0.8V), can be avoided while supporting the high voltages and currents utilized in EVs and HEVs. This makes it possible to significantly improve efficiency in the low current region often used in urban driving.

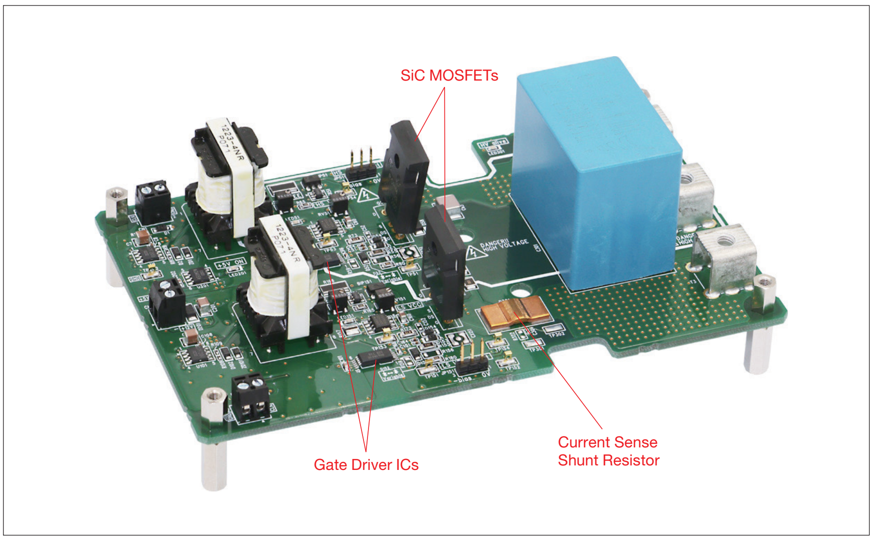


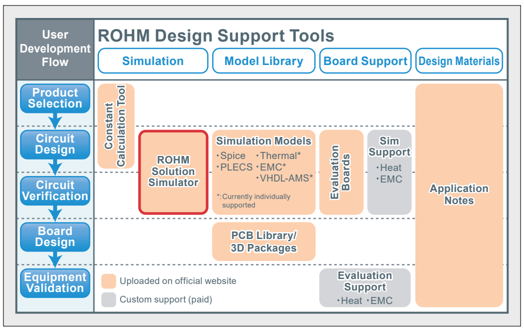


When forming MOSFETs there are two basic structures, a planar type that corresponds to the amount of current in the lateral direction and a trench type defined by a groove construction. ROHM is one of the few manufacturers that offer SiC MOSFETs with a trench structure, and has further advanced this design in its 4th Gen models to achieve the industry's highest level of normalized ON resistance (Ron-A: ON resistance per unit area). Switching losses have also been reduced by about half.

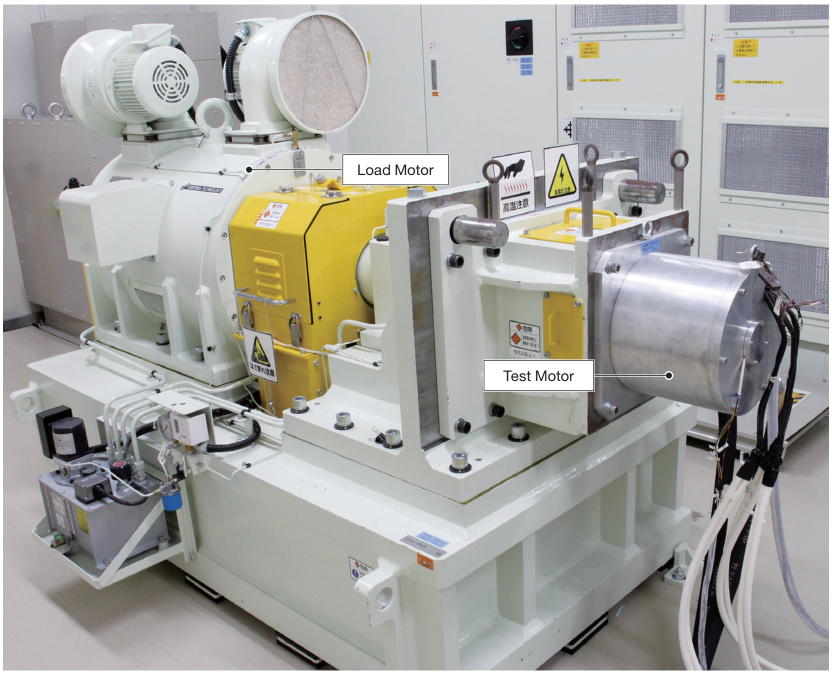


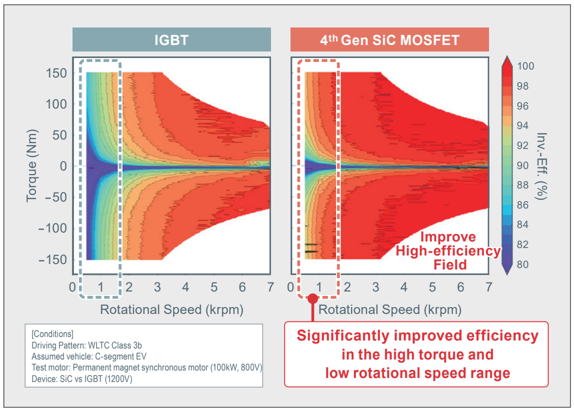






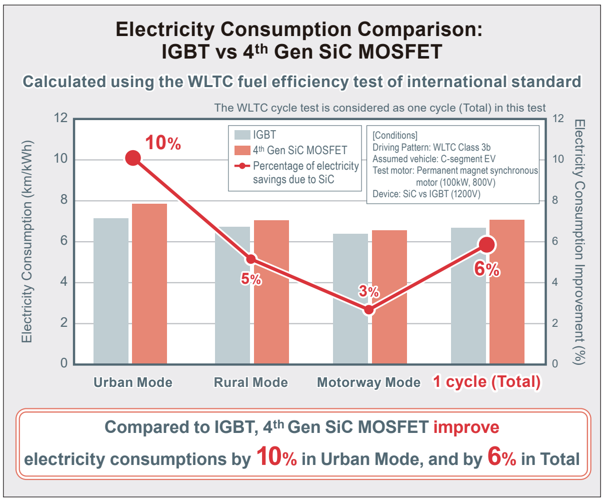
To maximize the performance of SiC MOSFETs that operate at high speeds, users need a number of design tools in the development flow, as the design must take into account characteristics such as minute electrical behavior in the electrical components and substrates. ROHM offers a variety of solutions, including circuit simulators using SiC MOSFET design models and evaluation boards for actual equipment verification. We also provide support for module design.

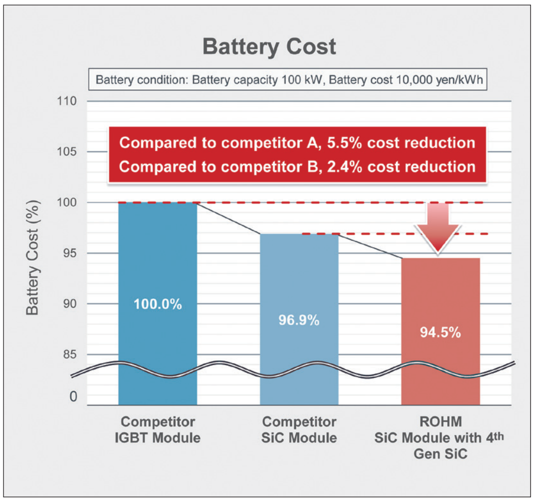




The figure above compares the motor efficiency distribution when IGBTs and ROHM's 4th Gen SiC MOSFETs, respectively, are used in a traction inverter application. Since both the power and regenerative sides are shown, the contour section is in the form of a torque curve of the motor that folds back on the lower side as well. The warm color range indicating higher efficiency is clearly wider for SiC, and extends to the low RPM/high torque regions corresponding to the normal operating area. The photo on the left shows ROHM's in-house motor bench facility (for generating motor load) used to evaluate the performance of 4th Gen SiC MOSFETs for traction inverters. Modules containing power semiconductors are connected to the end of the test motor.

The bar graph on the left shows the electricity cost obtained during testing, assuming driving modes based on WLTC, with the line graph indicating the electricity cost improvement rate of the 4th Gen SiC MOSFETs over IGBT. As you can see, the urban mode shows the highest improvement rate, raising the overall percentage. The graph on the right compares the cost of batteries required to achieve the same cruising distance based on electric power costs for the different types of power modules used. Power modules equipped with ROHM's 4th Gen SiC MOSFETs can reduce costs by 55,000 yen vs IGBTs and 24,000 yen vs competitor's SiC products.





including low loss high-frequency operation, but to maximize performance it is necessary to understand their characteristics and use them appropriately. For example, the effects of inductance is aligned when optimizing the routing for bonding and other wires from SiC MOSFETs (chips) in power modules. Of course, these effects are quite small, but it is important to keep in mind that even the smallest time increments can have an impact," remarks Tamegai.

For EVs, ROHM provides gate driver ICs (an intermediary that sends control signals to power semiconductors while insulating the high voltages of several hundred volts or more handled by power semiconductors from flowing into the control circuits) for driving MOSFETs along with support for designing modules using SiC MOSFETs (chips).

Since ROHM obtained qualification under the AEC-Q101 automotive standard for SiC in 2012, the company has built a track record for SiC MOSFETs, primarily in automotive chargers and DC/DC converters. ROHM's latest 4th Gen SiC MOSFETs further reduce loss without compromising durability and reliability (short-circuit withstand time), making them ideal for vehicle traction inverters. At the same time, high efficiency is ensured under a wide range of operation conditions. Of particular note is superior efficiency in the high torque, low rev range often used during urban driving.

"ROHM 4th Gen SiC MOSFETs improve total electrical consumption by 6% when driving in WLTC mode compared to IGBTs. Considering to the urban area alone, the effect can be as much as 10%. Improving electricity consumption can achieve the same range with a smaller battery capacity. In terms of battery cost, this can lead to a reduction of 55,000 yen compared to IGBTs (converted to a battery cost of 10,000 yen/kWh) and 24,000 yen vs SiC MOSFETs from other companies," says Tamegai

ROHM controls everything from wafer fabrication to processing and packaging. We have begun offering 4th Gen SiC MOSFETs in both chip and package (discrete) form factors that improve power efficiency in EVs.

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