Wide-Bandgap Semiconductor Devices for Automobile Applications

M. Sugimoto (1), H. Ueda (2), T. Uesugi (2), and T. Kachi (2)
(1) TOYOTA MOTOR CORP.
543, Kirigahora, Nishihirose-cho, Toyota, Aichi, 470-0343, JAPAN
TEL Int+81-565-46-3304 FAX Int+81-565-46-3382
E-mail : sugimoto@masahiro.tec.toyota.co.jp
(2) TOYOTA CENTRAL R&D LABS., INC.
Yokomichi, Nagakute, Aichi-gun, Aichi, 480-1192, JAPAN

Recently, in addition to the exhaust gas problem of urban areas, the environmental problem has grown into CO_2 problem of the earth scale, and it has become a pressing issue. It is necessary to reduce the amount of CO_2 emission furthermore by the development and improvement of hybrid vehicles (HVs), electric vehicles (EVs) and fuel cell vehicles (FCVs). These vehicles need high power inverters, in which a Si Insulated Gate Bipolar Transistor (IGBT) is used now.

Figure-1 shows the road map of power density. Their power density has increased year after year. The inverters installed in Toyota hybrid vehicles of Prius and RX400h have very high power density as shown in the figure. However, HV and FC of the new generation will require much higher density with lower energy loss, smaller size and lower cost. These requirements are close to or over the theoretical limit performance of Si IGBTs. Table 1 shows that wide-bandgap semiconductors have advantages clearly compared with Si, that leads us to develop novel power switching devices made of wide-bandgap semiconductors.

Figure-2 shows the new Toyota's HVs need high motor power with high power source voltage. To realize HV systems of the new generation, devices used there will have to achieve the following performances, (1) high current operation, (2) low on-resistance, (3) high temperature operation, (4) high breakdown voltage, (5) normally-off operation and (6) large Safety Operation Area.

First, to know a possibility of GaN as a power device, we fabricated GaN power HEMTs. Figure-3 shows the drain current reached over 8A [1]. A thermograph image of figure-4 shows a GaN HEMT could be operated at more than 300 degree C [2]. These results indicated that GaN power devices were promising for future automotive systems, especially operated in high temperature circumstance.

At the conference, I will refer to a vertical operation device and an enhancement-mode device.

All the results here using GaN are really encouraging us to realize high performance small size inverters for the future automobile.

[1] M. Sugimoto et al., "A Study of MIS-AlGaN/GaN HEMTs with SiO_2 Films as Gate Insulator", ISPSD 2005 Tech. Digest, pp307-310, 2005

[2] H. Ueda et al., "High Current Operation of GaN Power HEMTs", ISPSD 2005 Tech. Digest, pp311-314, 2005

[3] T. Kachi et al., "Vertical device operation of AlGaN/GaN heterostructure field effect transistor fabricated on GaN substrates", ICNS 2005 Th-P-139, 2005

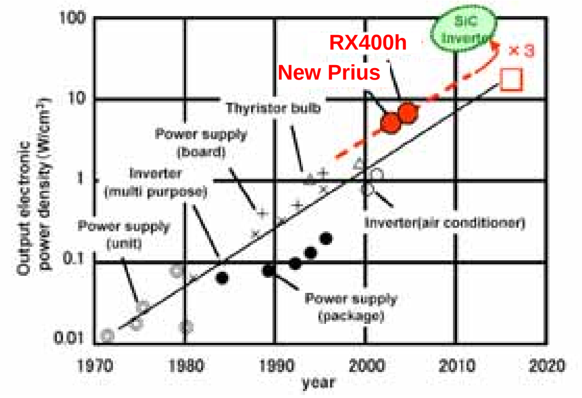

Fig.1 Road map of output power density

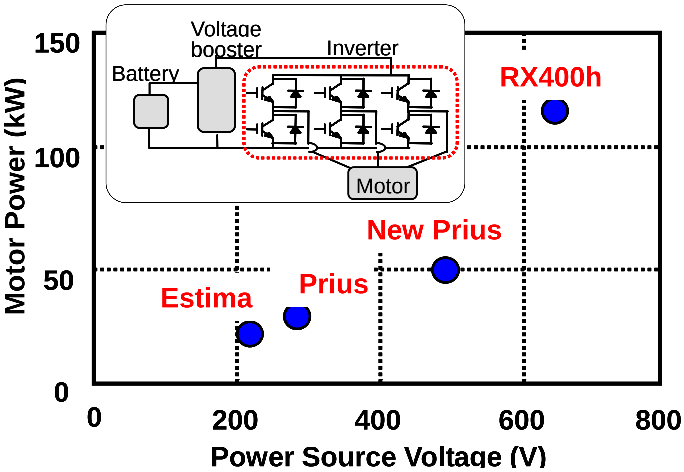

Fig.2 Power source voltage vs. Motor power

Table 1 Figures of merit of various semiconductors

	Si	GaAs	4H-SiC	GaN
JFM	1	11	410	790
KFM	1	0.45	5.1	1.8
BFM	1	28	290	910
BHFM	1	16	34	100

JFM : Johnson's figure of merit for high frequncy devices = $(EbVs/2\pi)^2$

KFM : Keyes's figure of merit considering thermal limitation= $\kappa(EbVs/4\pi\varepsilon)^{1/2}$

BFM : Baliga's figure of merit for power switching = $emEg^3$

BHFM : Baliga's figure of merit for high frequency power switching = μEb^2

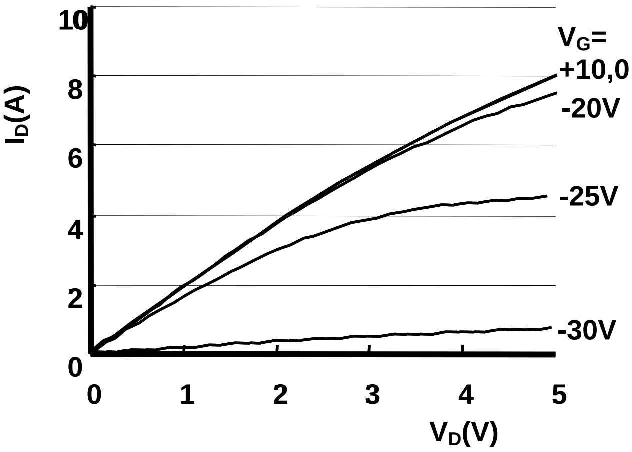

Fig.3 Drain current-drain voltage characteristics

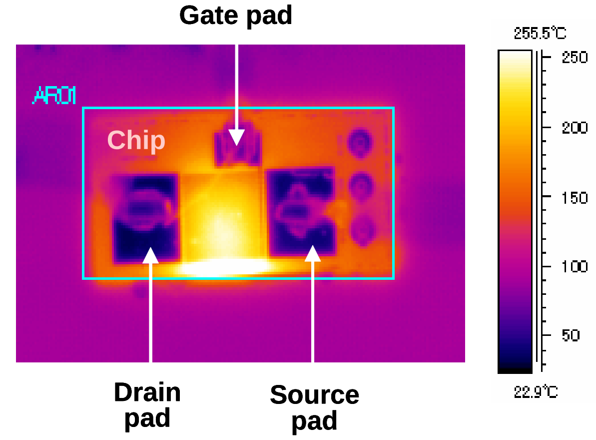

Fig.4 Thermograph image under high current operation