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POWER MOSFET

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1. FOREWORD

The range of applications of the power MOSFET is spreading to many areas. Against this background is lowering of the on resistance that was the biggest problem up to now and high blocking voltage devices are approaching the theoretical value by establishment of fine patterning technology and process technology. Currently, these efforts are being poured into low blocking voltage devices.

However, the best way of using MOSFET in each field is beginning to become a problem such as the bipolar transistor in the past. Fuji Electric is commercializing products matched to market needs while performing design, wafer process, quality assurance, and sales activity consistently with Fuji Electronic Components, Ltd. The technology trends, product series, and product design technology development concerning Power MOSFET are described below.

2. TECHNOLOGY TRENDS AND EXPANSION OF APPLICATION

In the switching power supply field, the demand for improvement of the characteristics of power switching devices is unlimited.

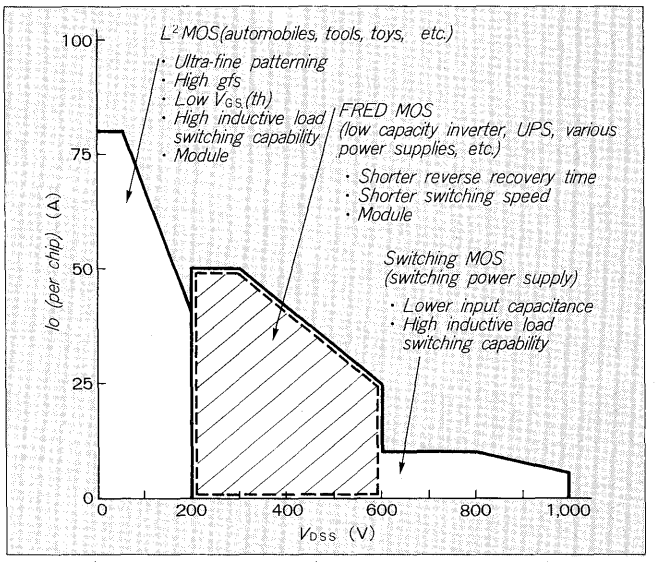
(1) Suppression of switching power loss and improvement of switching frequency
(2) Compensation of lowering of heat dissipation properties by high density mounting by reduction of the generated loss
(3) Direct drive by various IC
(4) Improvement of overvoltage capability when abnormal
(5) Increase of current to reduce the number of parallel devices

Classified by field of application, these demands can be grouped into the following three fields.

2.1 AC100V, 200V switching power supply field

The package of the MOSFET used in these fields is limited to the plastic type represented by the TO-220 and TO-3P. The high drain-source voltage product series is the objective range as shown in *Fig. 1*. The subject of MOSFET

Fig. 1 Power MOSFET technology trend



correspoinding to this are (1) reduction of loss, (2) higher inductive load switching capability, and (3) higher current. Specifically, it is said to be realization of (a) speeding up by reducing the input capacitance and input gate charge, (b) improved withstand capability by pattern design and diffused impurities distribution profile optimization, and (c) a large area chip by reduction of crystalline defects of silicon wafer.

2.2 Inverter and uninterruptible power supply field

Regarding the characteristics demanded of MOSFET used in this field, improvement of the reverse recovery time and reverse recovery switching capability of the reverse diode is demanded besides, of course, the contents demanded for used in the switching power supply field described above. Plastic and module types, such as the TO-220, are demanded as the package.

2.3 Battery power supply application field

Automobile use, etc. demand a device that can supply a low battery voltage to the load at good efficiency and can be directly driven by IC with a 5V power supply and is

strong against surge voltages. That is, provision of a series of low on-state resistance products that can be driven at logic level is urgent business. The capability of devices in this field is limited to 150 to 200V or less.

3. INTRODUCTION TO POWER MOSFET PRODUCT SERIES

An abundant series of Fuji Electric power MOSFET products, from low capability to high capability, are available. These products are widely used from the consumer field to industrial field. These series of products are described below.

3.1 Standard series

The product series developed for uninterruptible power supply equipment, battery power supplies, etc. centered about the switching power supply field, are shown in *Table 1* and *Table 2*. The features of these series realize

(1) High forward transconductance (g_{fs})
(2) Low on-state resistance ($R_{DS(on)}$)
(3) Small distribution gate threshold voltage of variation ($V_{GS(th)}$) by use of the optimum wafer process.

3.2 FII (fast switching) series

The FII (fast switching) series corresponding to the higher frequency of switching power supplies was newly added. Its product series is shown in *Fig. 2*. The features of this series are:

(1) Low input capacitance C_{iss} (reduced approximately 30% compared to old type)
(2) Shorter switching times
(3) VGS=±30V guaranteed

The power supply capacity range was expanded by adding 450V, 500V 30A products, the highest class in the world. TO-220, TO-220F, TO-3P, and TO-3PL packages are also available and a series that meets the desired of users is provided. (*Fig. 3*)

Reduction of the switching times (especially the turn-off time) not only reduced the input capacitance C_{iss}, but also considers improvement of the characteristics deduced from analysis of the turn-off operation. Generally, turning

Table 1 Low voltage type Fuji power MOSFET

Type	Package	Main characteristics		
		V_{DS} (V)	I_D (A)	$R_{DS(on)}$ (Ω)
2SK905	TO-3P	50	45	0.03
2SK906	TO-3P	100	32	0.06
2SK947/2SK900	TO-220/TO-220F	250	12	0.3
2SK948	TO-3P	250	13	0.3
2SK901	TO-3P	250	20	0.15
2SK902	TO-3P	250	30	0.1

Table 2 Fuji power MOSFET for switching power supply

Type	Package	Main characteristics		
		V_{DS} (V)	I_D (A)	$R_{DS(on)}$ (Ω)
2SK949/2SK950	TO-220/TO-220F	500	6	1.2
2SK723	TO-3P	500	7	1.2
2SK724	TO-3P	500	10	0.67
2SK725	TO-3P	500	15	0.38
2SK899	TO-3P	500	18	0.33
2SK897	TO-220F	550	4	1.5
2SK903/2SK904	TO-220	800	3	4.0
2SK954	TO-3P	800	3	4.0
2SK955	TO-3P	800	5	2.0
2SK960	TO-220	900	3	5.0
2SK726	TO-3P	900	3	5.0
2SK727	TO-3P	900	5	2.5

Fig. 2 FII (fast switching) new series

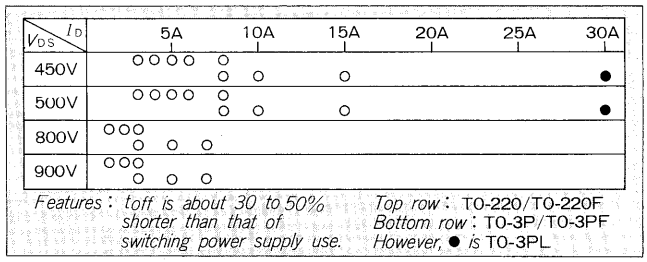


Fig. 3 Plastic package series

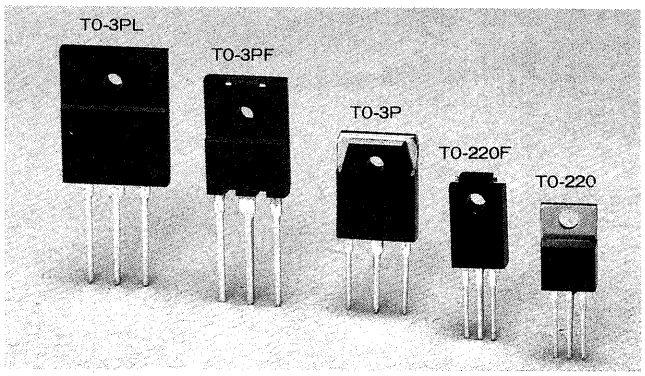


Fig. 4 MOSFET turn-off operation

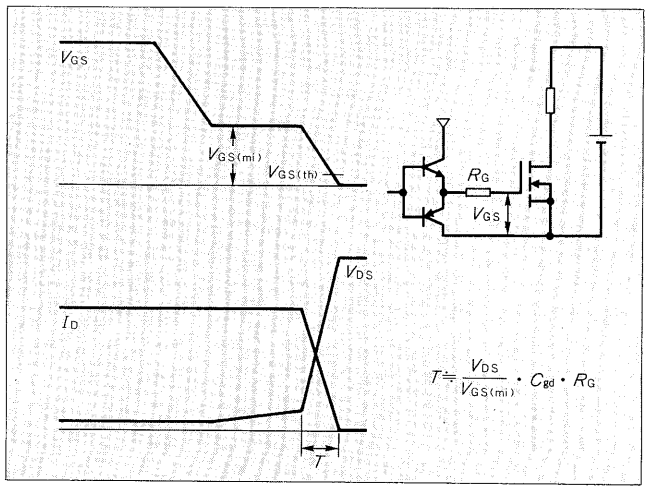


Table 3 FRED MOSFET series

Type	Package	Main characteristics			
		V_{DS} (V)	I_D (A)	$R_{DS(on)}$ (Ω)	t_{rr} (ns)
BUZ360	TO-3P	800	3.6	3.0	250
BUZ361	TO-3P	800	2.9	4.0	250
BUZ380	TO-3P	1,000	5.5	2.0	250
BUZ381	TO-3P	1,000	4.9	2.6	250
BUZ382	TO-3P	400	12.5	0.4	250
BUZ383	TO-3P	400	11.5	0.5	250
BUZ384	TO-3P	500	10.6	0.6	250
BUZ385	TO-3P	500	9.0	0.8	250

Table 4 p-channel MOSFET series

Type	Package	Main characteristics		
		V_{DS} (V)	I_D (A)	$R_{DS(on)}$ (Ω)
BUZ171	TO-220	−50	−7.0	0.4
BUZ172	TO-220	−100	−5.0	0.8
BUZ173	TO-220	−200	−3.0	2.0

off the device without applying reverse bias between the gate and source has the simplest drive circuit and is widely used. *Fig. 4* shows the Miller operation period which generates a switching loss, in particular. This figure shows that the gate-source voltage of the Miller operation period versus the drain current immediately before the actual turn-on operation is important.
This is taken into account and higher speed is realized with this series.

3.3 Other series products

The FED MOSFET and p-channel power MOSFET series are shown in *Table 3* and *Table 4*. The former are high speed with reverse recovery time of 250ns or less and are suitable for motor control inverter circuits.

4. TECHNOLOGY DEVELOPMENT (REDUCTION OF C_{iss})

Recently, of the input capacitance (C_{iss}) components, the C_{gd} (gate-drain capacitance) has a large affect on the drive loss and switching loss, especially in high frequency power switching applications.

The input capacitance C_{iss} of power MOSFET is the sum of gate-source capacitance C_{gs} and gate-drain capacitance C_{gd}. In particular, C_{gd} has a large dependence (Miller effect) on the drain-source voltage and a large effect on switching operation.

From this, the trade-off relationship of the characteristics of the power MOSFET was studied theoretically and a model was made of the relationship between capacitance and voltage and is serving in pattern design and process design. The sectional structure of the analyzed power

Fig. 5 Power MOSFET sectional structure and parasitic capacitance

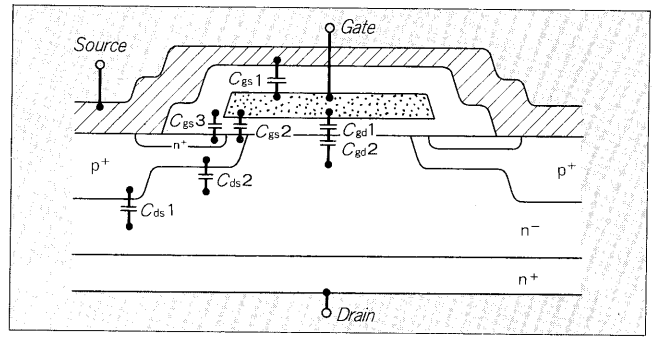


Fig. 6 Capacitance vs. voltage characteristics

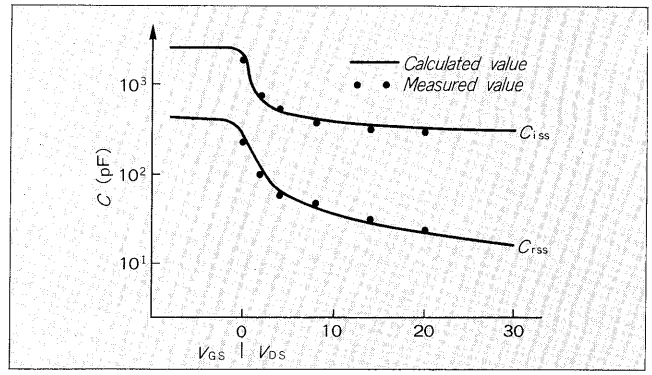
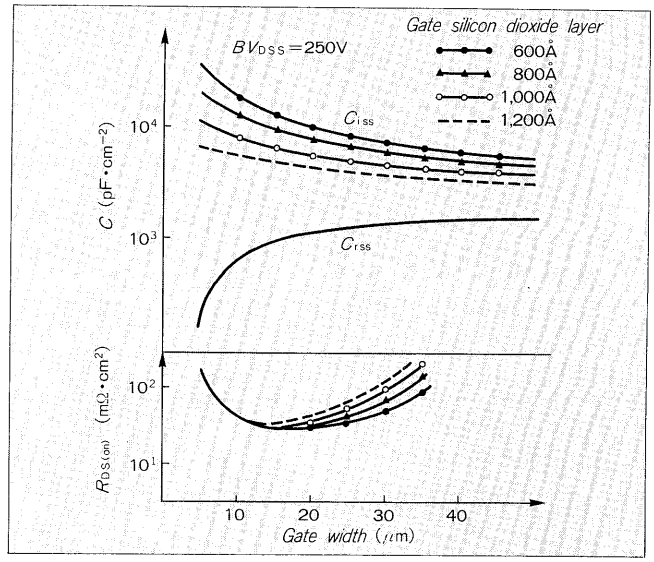


Fig. 7 Gate width vs. capacitance and $R_{DS(on)}$ (calculated value)



MOSFET is shown in *Fig. 5*. *Fig. 6* shows the calculated values and measured values of the capacitance and voltage relationship. Both a in good agreement. *Fig. 7* shows the capacitance value and on-state resistance value when the gate width and gate silicon dioxide layer were made variables at a 250V drain-source voltage. Because the gate width and gate silicon dioxide layer, etc. have a large effect on the characteristics and each has a trade-off relationship, power MOSFET require optimum cell design and process design for each application.

Fig. 8 Gate silicon dioxide layers vs. $V_{GS(th)}$, C_{iss}

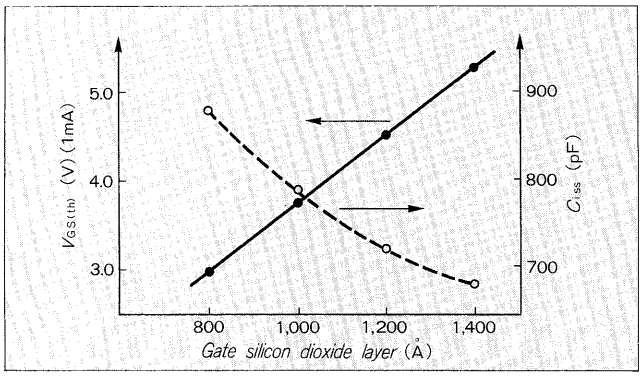
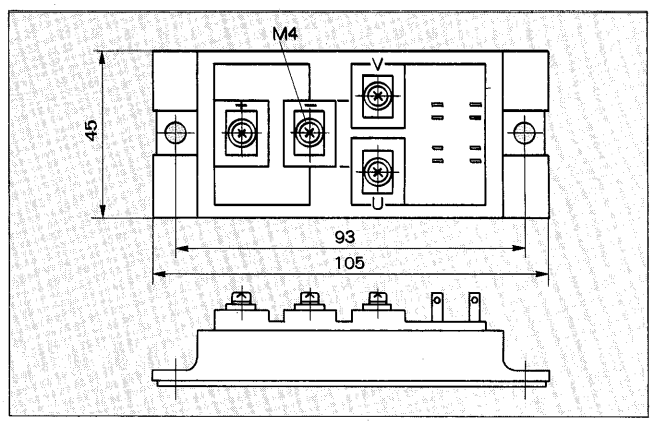


Fig. 9 4MI50F-025 exterior views



The silicon dioxide layer and gate threshold voltage $V_{GS(th)}$ and C_{iss} relationship is shown in *Fig. 8*. The $V_{GS(th)}$ changes largely with the thickness of the gate silicon dioxide layer, $V_{GS(th)}$ can be controlled with the density of the diffused impurities of the channel section. Reduction of the input capacitance C_{iss} requires reduction of not only C_{gd}, but also of C_{gs}. Specifically, (1) the channel length must be made as short as possible and (2) the optimum gate-source protective film thickness, material, etc. must be selected.

5. MOSFET MODULE

Generally, equipment containing transformers and capacitors can be made smaller and lighter by making the operating frequency of the switching power device higher. Of these, because the MOSFET module can easily control high power, even though it is expensive, it applications are expanding due to its overall merits compared to the bipolar transistor.

5.1 Module series

Two types of the new series are introduced.

(1) 4MI50F-025
V_{DSS}=250V, I_D=50A single-phase bridge configuration

(2) 2MI100F-025
V_{DSS}=250V, I_D=100A with two devices

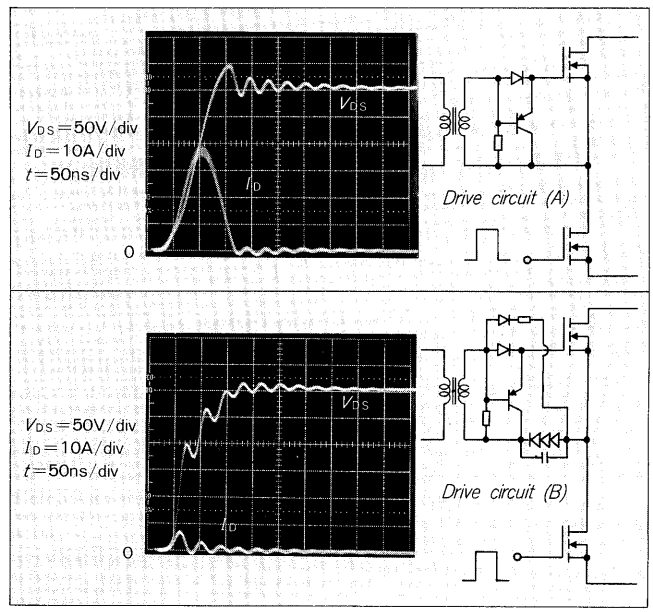
The reverse diode of these is a fast-recovery diode with a 150ns reverse recovery time.

5.2 Drive circuit

When using a switching device in an inverter circuit, the *dv/dt* voltage applied to the main terminals must always be considered. With the MOSFET module, usually a large current change is obtained by connecting multiple chips in parallel. Since an oscillation prevention gate resistor is connected in series at each chip, the MOSFET chips are connected through a resistor even if the module outside gate-source terminals are shorted.

Now then, when a certain *dv/dt* voltage is applied to the module, a current of $C_{gd} \times dv/dt$ flows between the drain and gate and is shunted by the C_{gs} capacitance and series gate resistance. The C_{gs} potential (=V_{GS}) depends on the value of the series gate resistance, but becomes higher than $V_{GS(th)}$ instantly and the MOSFET is turned on instantly. At an inverter circuit, when the MOSFET connected in series are turned off alternately, a certain *dv/dt* voltage is applied between the drain-source of the off device by turning on of the other device. *Fig. 10* shows the drain-source voltage and current waveforms of the above off device when a gate-source reverse bias circuit is provided and is not provided at the gate drive circuit, with the 50A rating 2MI50S-050 as the specimen.

Fig. 10 *dv/dt* current waveform and gate drive circuit



Since the loss generated by this cannot be ignored at high frequency operation, a reverse bias of 2V or greater is necessary between the gate and source of the MOSFET.

6. CONCLUSION

The technology trend, product series, application technology, etc. of the power MOSFET were introduced above. Backed by the newest design, production, test and evaluation technology, Fuji Electric is promoting the development of new products and fullness of a product series which should meet the needs of users.