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PROGRESS IN POWER MOSFETS FOR SWITCHING SUPPLIES

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1. FOREWORD

Power MOSFETs with high-speed switching performance are growing in the market and it has been a long time since they were first used. Fuji Electric performs design, manufacture, quality assurance, and marketing consistently with Fuji Electronic Components, Ltd. and has commercialized power MOSFET for switching power supplies, inverters, UPS, automobiles, electric tools, and other market needs.

Fuji Electric is pouring its efforts into low drain-source on-state resistance and high-speed switching to make the power MOSFET easier to use and into improve of pattern deisgn technology, simulation technology, microfabrication technology, and process technology to achieve hith ruggedness strong against overload at abnormal operation in the circuit. What must not be forgotten is the appearance of various packages which mount these excellent power MOSFET chips. The development of power MOSFETs for switching supplies is described from the standpoints of technology and product series.

2. INTRODUCTION OF POWER MOSFET PRODUCT SERIES

The product series of Fuji Electric power MOSFETs which has its own features, is shown in *Table 1* and *Table 2.*

3. DEVELOPMENT OF POWER MOSFET CHARACTERISTICS

It is no exaggeration to say that full scale use of power MOSFETs in switching supplies was due first to a substantial reduction of the drain-source on-state resistance per unit area and second to commercialization of high-speed switching elements with a lower input capacitance. The third reason is said to be commercialization of elements strong against the surge voltage generated by overload, abnormal circuit operation, etc. (*Fig. 1*)

Table 1 Standard series (F — I series)

Rating		Package				
V_{DSS} (V)	I_D (A)	T pack	TO-220	TO-220F	TO-3P	TO-3PF
500	7		2SK950	2SK949	2SK723	
	10				2SK724	2SK1099
	15				2SK725	
	18				2SK899	
550	4			2SK897		
	15				2SK725A	
600	4			2SK1550		
650	3			2SK1554		
	5			2SK1553		
800	3	2SK1663	2SK904	2SK903	2SK954	2SK1105
	5				2SK955	2SK1384
900	3	2SK1659	2SK961	2SK960	2SK726	
	5				2SK727	2SK1212

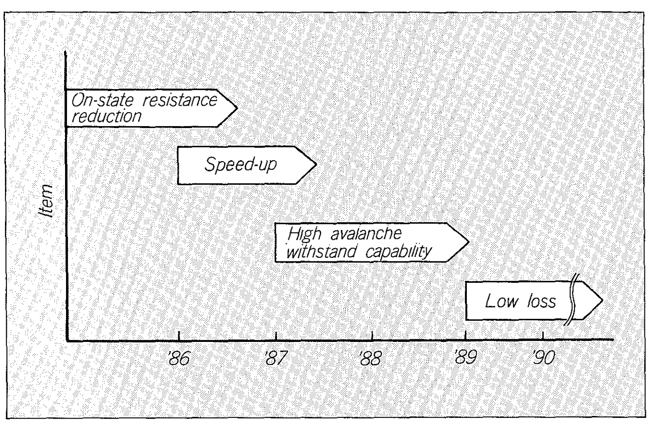
▭ : High avalanche withstand capability product

Table 2 High-speed switching series (F — II series)

Rating		Package					
V_{DSS} (V)	I_D (A)	T pack	TO-220	TO-220F	TO-3P	TO-3PF	TO-3PL
450	6		2SK1007	2SK1006			
	7		2SK1009		2SK1386		
	10			2SK1101	2SK1011	2SK1660	
	13				2SK1013		
	18				2SK1015		
	20				2SK1017		
	35						2SK1019
500	4.5		2SK1008				
	6		2SK1010				
	10	2SK1504	2SK1503	2SK1102	2SK1012		
	12				2SK1014		
	15				2SK1016		
	18				2SK1018		
	30						2SK1020
600	9			2SK1507			
700	3			2SK1662			
800	2.5		2SK952	2SK951	2SK953	2SK1211	
	3		2SK1021	2SK1545			
	4	2SK1552	2SK1023	2SK1547	2SK1171	2SK1224	
	7				2SK1081		
	9				2SK956	2SK1385	
900	2		2SK958	2SK957	2SK959		
	2.5		2SK1022	2SK1546			
	3.5	2SK1510	2SK1024	2SK1548	2SK1172		
	6				2SK1082		
	8				2SK962	2SK1217	
	10				2SK1512		
1000	5				2SK1511		

▭ : High avalanche withstand capability product and standard product

Fig. 1 Transition of power MOSFET characteristics improvement



3.1 Reduction of drain-source on-state resistance

The drain-source on-state resistance components of an MOSFET is shown in *Fig. 2.* That is, it is expressed by the following equation:

$$R_{on} = R_S + R_{ch} + R_{ACC} + R_{JFET} + R_{epi} + R_{SUB}$$

R_S : Source region resistance
R_{ch} : Channel resistance
R_{ACC} : Accumulation layer resistance
R_{JFET} : JFET part resistance
R_{epi} : High resistance drain region resistance
R_{SUB} : Silicon substrate resistance

These resistance components depend on the cell pattern dimensions and there are an optimum value for each MOSFET drain-sourcer voltage. The F – I and F – II series were developed in '86 – '87 by improvement of fine cell pattern technology. These series a cell density of about four times and the on-state resistance is approximately 70% compared with previous MOSFETS. (*Fig. 4*)

Fig. 2 Power MOSFET resistance components

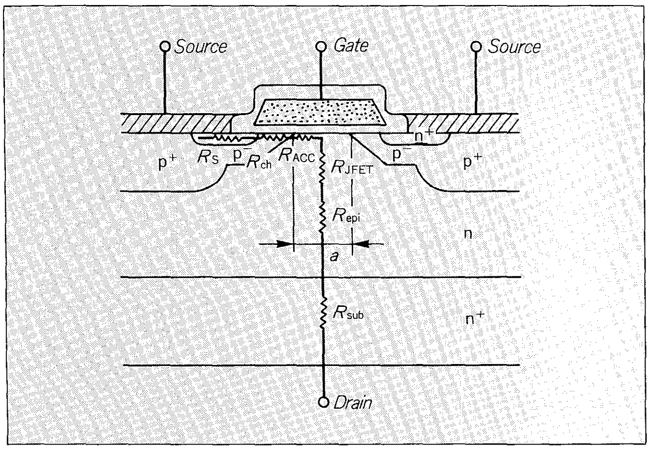


Fig. 3 Cell spacing and on-state resistance

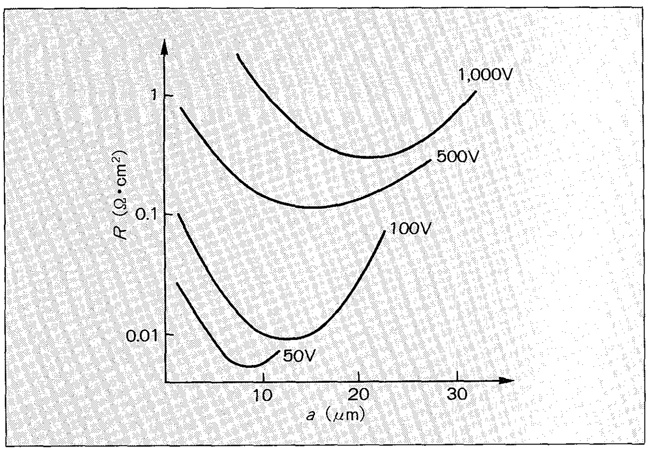
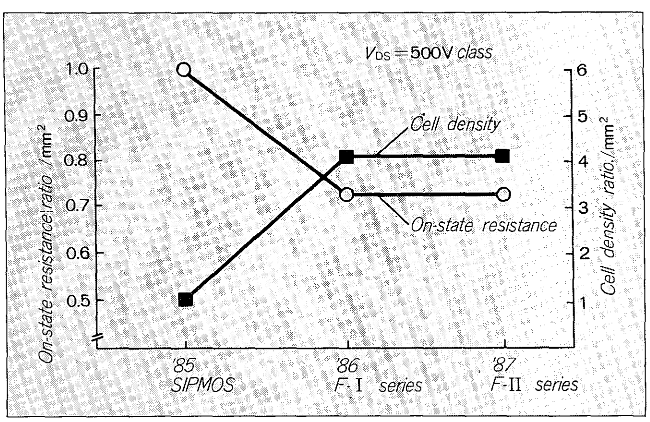


Fig. 4 Transition of on-state resistance reduction



3.2 Reduction of input capacitance (C_{iss})

For MOSFETs of switching supplies use which are applied at high frequency, C_{GD} (gate-drain capacitance) in the input capacitance (C_{iss}), has large effect on the switching operation.

Figure 5 shows transition of the typical input capacitance reduction of a 500 V device. That of the high-speed switching series (F – II) reaches approximately 70% of the standard series (F – I). To realize this, the gate oxide was optimized and the pattern was optimized by simulation. (*Fig. 6*) *Figures* 7 and *8* shows the typical turn-off operating waveform of the standard series (F – I) and high speed switching series (F – II). It can be seen that high speed switching characteristics by input capacitance reduction effect is good.

Fig. 5 Transition of input capacitance reduction

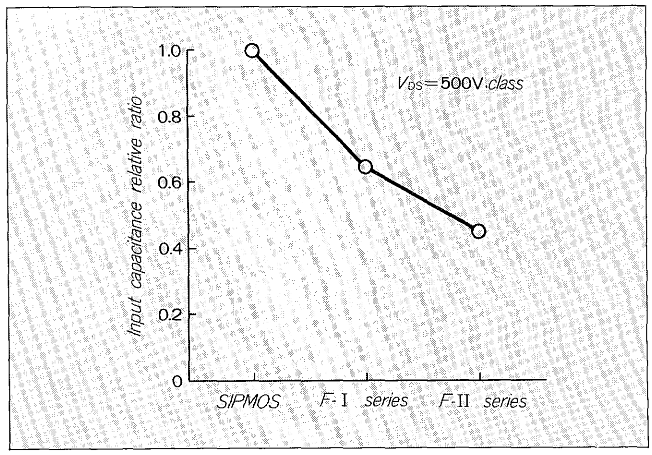
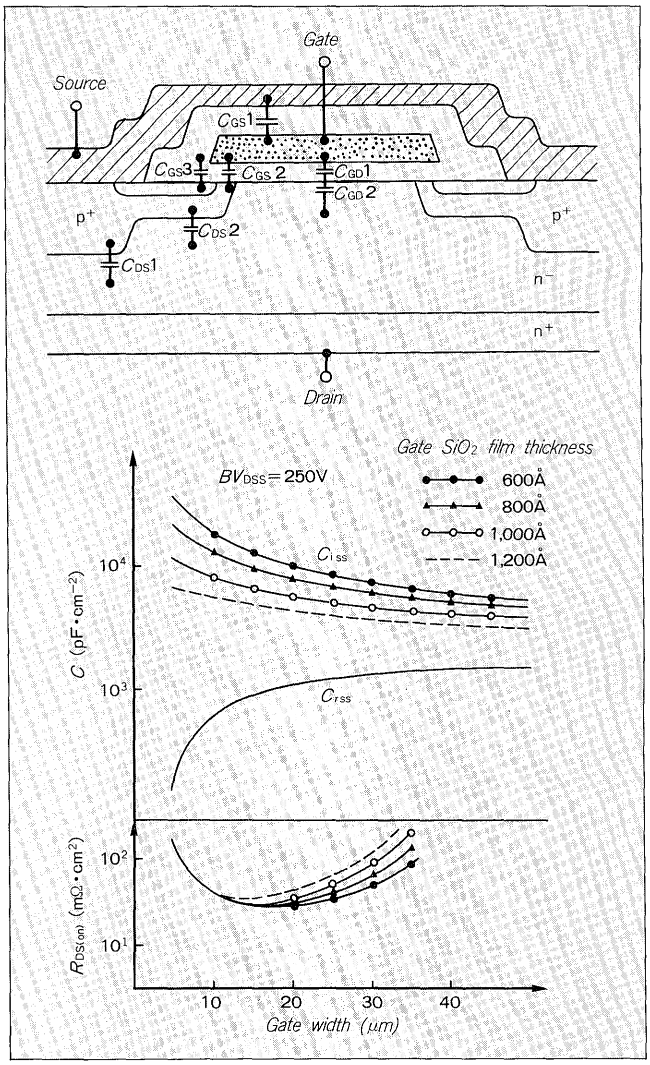


Fig. 6 Gate width and capacitance and $R_{DS(on)}$ (calculated value)



3.3 Improvement of avalanche withstand capability

Generally, when a switching power device is applied

Fig. 7 Standard series (F — I) turn-off waveforms

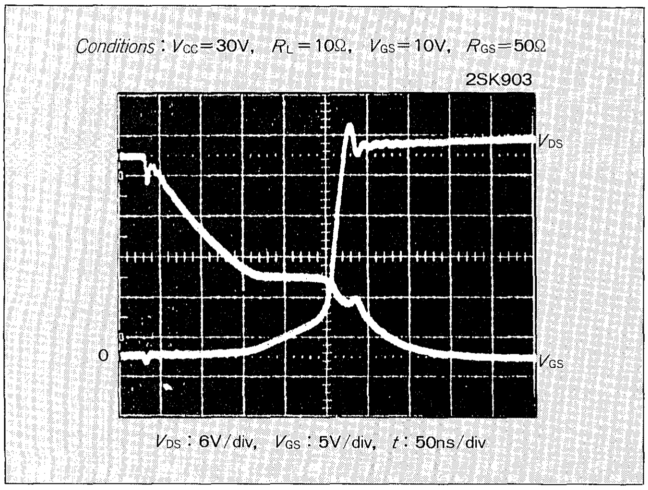


Fig. 8 High-speed switching series (F — II) turn-off waveforms

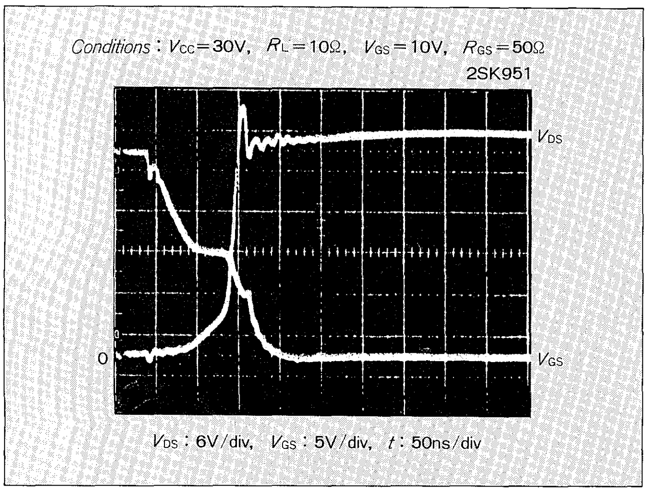


Fig. 9 Avalanche withstand capability measurement circuit and operating waveforms

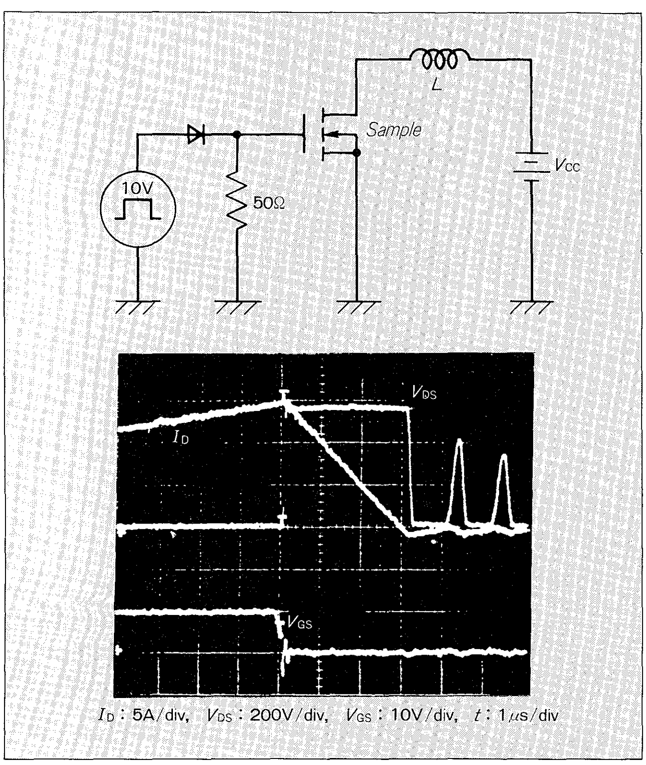


Fig. 10 Avalanche withstand capability measured value

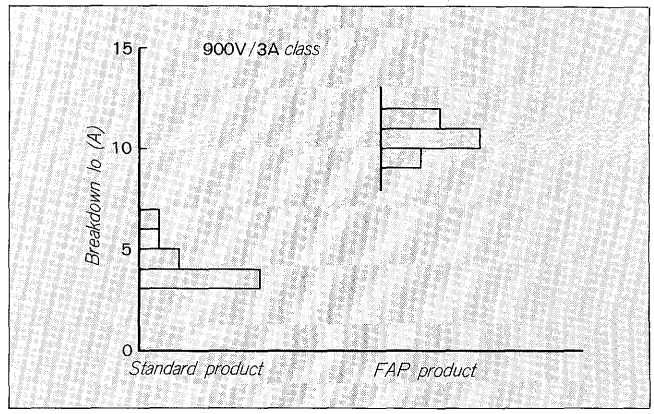


Fig. 11 Avalanche pulse width and avalanche current (breakdown value)

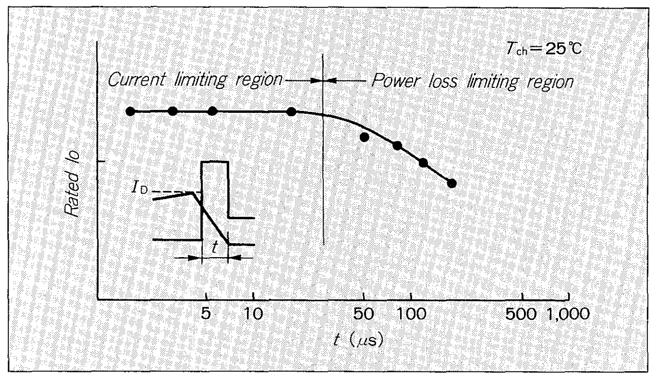
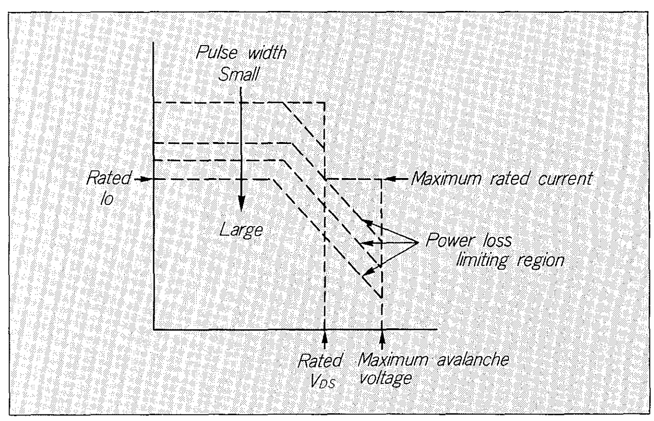


Fig. 12 New avalanche withstand capability assurance method



in a circuit, a design such that the countervoltage generated by the wiring and transformer inductance component at turn-off operation is held within the voltage rating of the device is natural. However, because of unexpected load changes, an overvoltage exceeded the device voltage rating is sometimes applied to the main elements (drain-source) and the device is sometimes broken. A power MOSFET which can avoid such situation is demanded, and the high avalanche withstand capability series [FAP (Fuji Avalanche Proof) series] shown in *Table 2* was developed between 1988 and 1989.

(1) Avalanche withstand capability measurement circuit

The avalanche withstand capability measurement circuit is shown in *Fig. 9.* This circuit measures the capability of the device to transaction all the energy stored in the inductance (L) in the avalanche mode by MOSFET turn-off operation. The avalanche capability is specified by L value and circuit current and channel temperature.

(2) FAP series characteristics and avalanche withstand capability

The avalanche withstand capability of the FAP series was substantially improved without any loss of the MOSFET characteristics of the basic F – I and F – II series by optimization of wafer process technology. The avalanche withstand capability of the typical 900V class standard products and FAP products is compared in *Fig. 10.*

(3) FAP series application method

Evaluation method for avalanche withstand capability is not standardized yet. A method proposed in the past specifies the avalanche withstand capability by drain current and energy value. It is difficult to evaluate a precise withstand capability by this conventional method, because this ignores the time function.

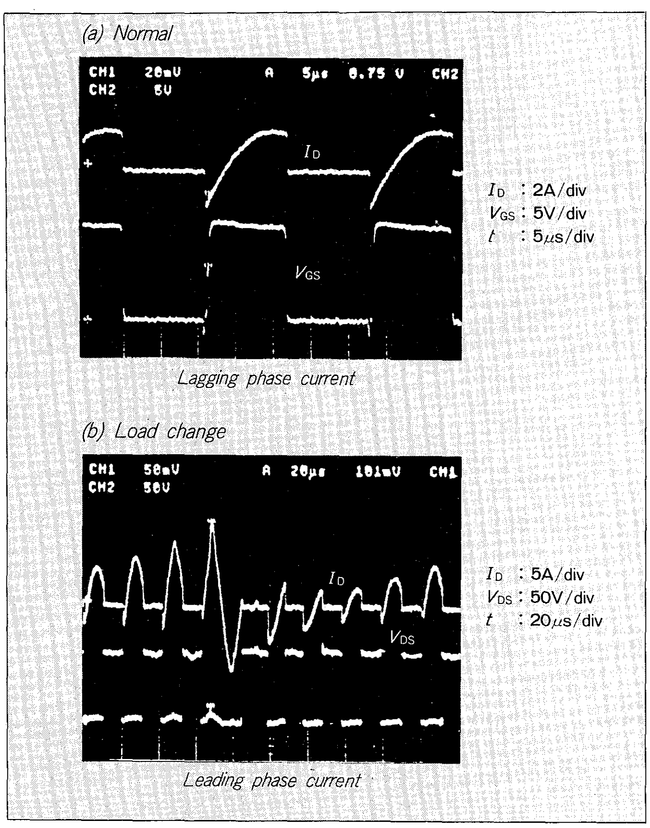
At the beginning of 1990, Fuji Electric advocated that consideration on extension the conventional forward bias SOA characteristics after clarifying the relationship between the avalanche pulse width and breakdown current is desirable from the standpoint of MOSFET application. (*Fig. 12*)

3.4 Improvement of built-in diode for reverse recovery operation mode withstand capability

With ordinary switching supplies, there are very few cases in which a built-in diode of the power MOSFET is used. However, in cases such as resonant type power supplies, the current phase is changed by load changes, etc. (*Fig. 13*) In this operation mode, built-in diode reverse recovery operation occurs and the parasitic transistor in the MOSFET is operated by the high dv/dt at reverse recovery operation and breakdown is sometimes occur.

The improved avalanche withstand capability FAP series has a higher dv/dt withstand capability than the standard series. This series is can also be used built-in diode in reverse recovery operation mode.

Fig. 13 Current phase change at resonant power supply



4. PACKAGE SERIES

The bipolar transistor and diode and power MOSFET package was developed for

(1) higher capacity
(2) full plastic mold
(3) surface mounting.

Generally, higher capacity was aimed at realization of 500V 30A class devices from the appearance and alleviation

Fig. 14 Molded package series

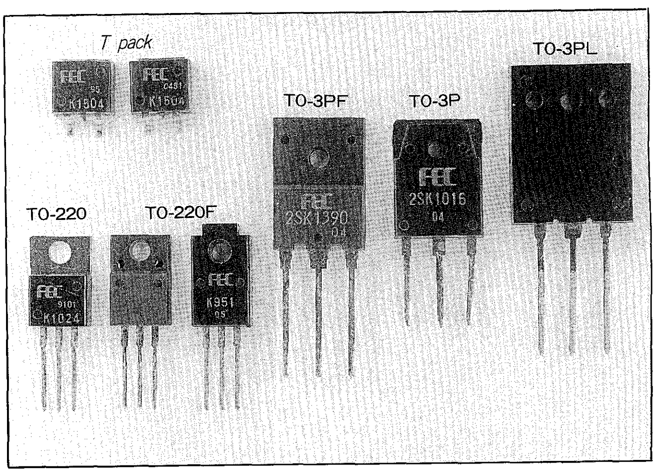


Fig. 15 Comparison of junction construction

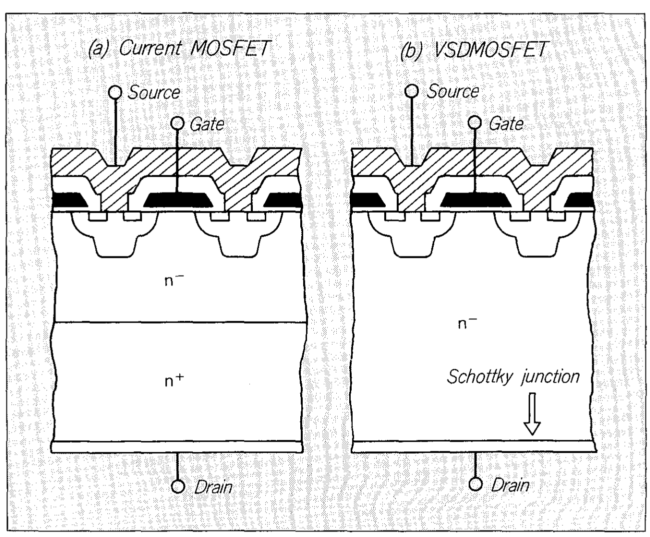
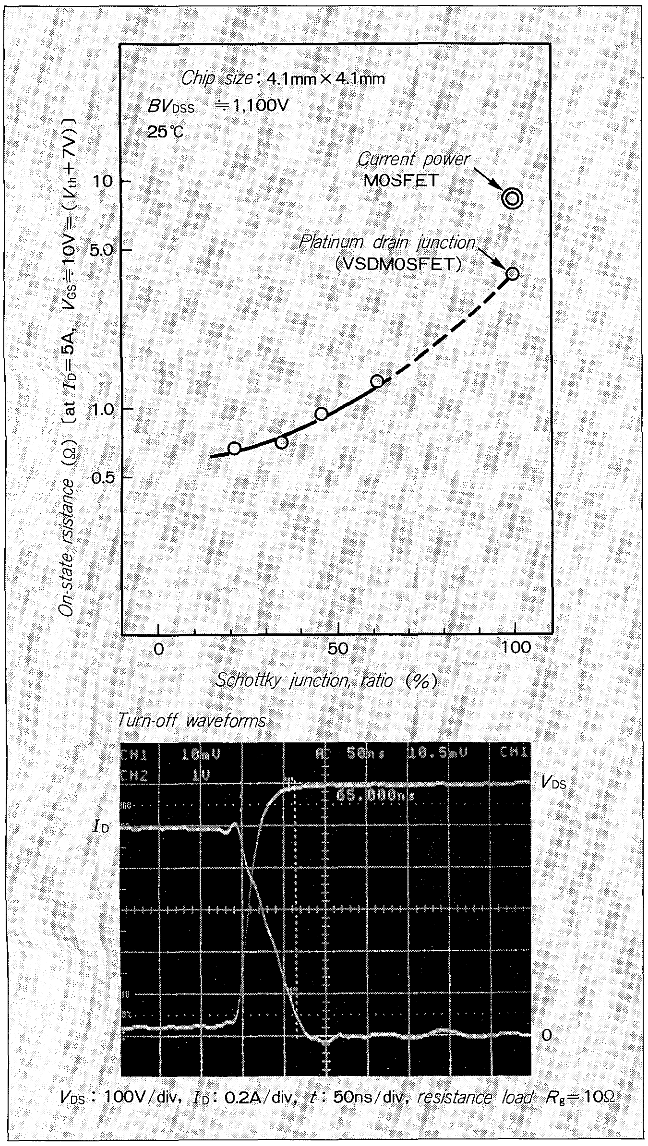


Fig. 16 VSDMOSFET turn-off waveforms and on-state resistance



of parallel connection trouble. Full plastic mold was aimed at simplification of the insulation with the cooling fin, and surface mounting was aimed at power supply noise reduction and reduction of the size of apparatus. The Fuji Electric molded package series is shown in *Fig. 14*. In the future, expansion of the surface mounting series is planned and commercialization of easier application for switching supplies is considered.

5. FUTURE TREND

Improvement of the drain-source on-state resistance and switching time of MOSFETs and commercialization of lower loss and lower gate driving power products are considered.

The new type MOSFET is introduced here.

5.1 VSDMOSFET

The junction construction of the VSDMOSFET (Vertical Schottky Barrier Drain Contact MOSFET) is shown in *Fig. 15*. The difference from the conventional construction is that a Schottky junction was added at the drain electrode side.

5.2 VSDMOSFET characteristics

Because the VSDMOSFET has a better low drain-source on-state resistance than conventional MOSFETs, high speed performance of approximately 100ns fall time is maintained. (*Fig. 16*) An MOSFET with a low drain-source on-state resistance that could not be realized with conventional MOSFETs is realized by optimizing the element cross section construction and amount of holes injected from the Schottky junction.

6. CONCLUSION

The progress of switching supplies use power MOSFET technology and the MOSFET product series at Fuji Electric were introduced. More efforts will be made to develop power MOSFETs products to meet customer's requirements further.