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FUJI SWITCHING POWER TRANSISTOR

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1 INTRODUCTION

It's been already ten years since Fuji Electric has started mass-producing Fuji power transistors. Thanks to our effort of development and manufacture of transistors of exclusive use for high-withstanding voltage switching through full adoption of triple diffused planar structure, first of the sort among the transistor manufacturers, they just fitted for the needs of the era and they have shown a rapid growth.

Fuji power transistors, starting with power Darlington transistors for automobile ignition of 6-8A, 400V, have progressed to their lateral development into high-speed switching transistors for power supply switching, then to serialization of manufacture of large-capacity mold transistor started by BBT (building block transistor). This BBT is the forerunner, first in the trade, of large-capacity mold type transistor, a link to the later power modules. So that the serialization of their manufacture has been very significant. And now, we are in the era of complexity as repesented by power modules. These types of machines have turned their ignition system from contact to contactless type, and from dropper system to switching system for their general power supplies. It can be said that the moment of their switching to the new system coincided with that of motor control from thyristor and triac systems to transistorization system.

This report describes the progress of the development, and designing policy, as well as characteristics and outline of products in order to offer deeper understanding on Fuji power transistors.

2 FUJI POWER TRANSISTORS, THEIR PROGRESS OF DEVELOPMENT

2.1 Power transistor for automobile ignition

The function of opening and closing of the primary side switch for generating several tens of thousand volts of high voltage on the secondary side of ignition coil has long been contact system. With more strict enforcement of exhaust control law, the use of power transistor in stead of contact for coping with the higher current and with the trend for liberty from maintenance, that has surfaced in the United States around 1975, power Darlington transistors having higher withstanding voltage and higher resistance to rupture have come to be necessary.

Fig. 1 Fundamental circuit of ignition system and its operation

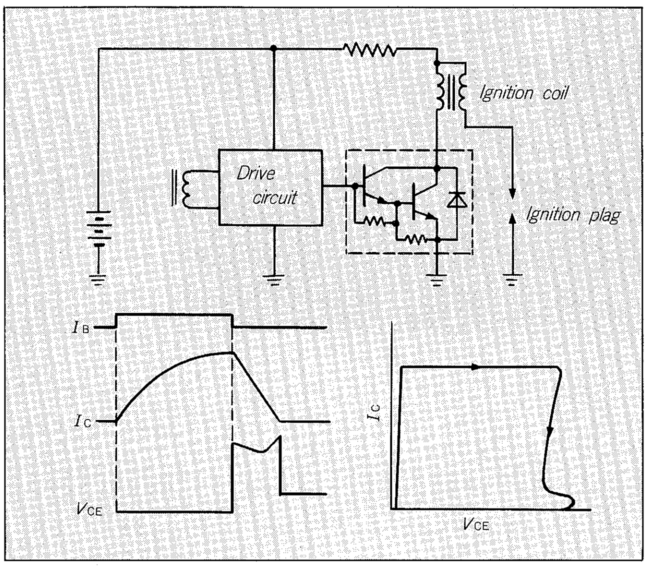


Fig. 1 shows the fundamental circuit of the ignition system and its operation waveform as well as operating trajectory of the transistor. The main operating features of the transistors used here are that, the trajectory in actual operation depends on sustained voltage of the transistor. Before the time of transistor for automobile ignition, there was no practical use that depended on sustained voltage, only such transistors were utilized in a way as they were called "latching method" as means of measuring transistors' sustained voltage.

It is obvious that the operation mode like this in the ignition system, with only conventional forward bias safe operation area (FBSOA), is not proper for defining the resis-tance to rupture of transistor. Generally, the area of safe operation (ASO) will be the larger, when the larger will become the Wi x p value in case other designing parameters are made identical and the specific resistance (p) of high-resistance layer of the collector and thickness (*Wi*) are

Fig. 2 Relationship between p x Wi value and resistance to rupture

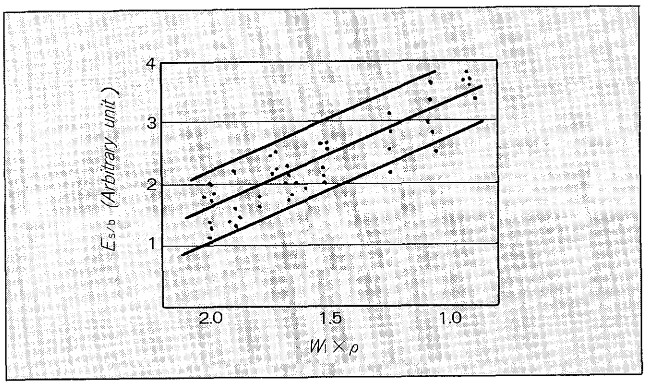


Fig. 4 Avalanche-diode incorporated power transistor

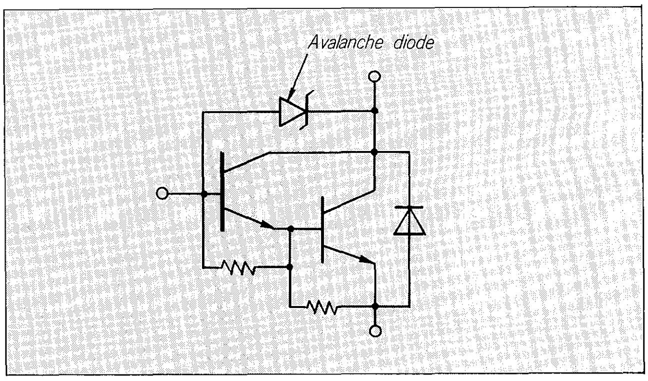
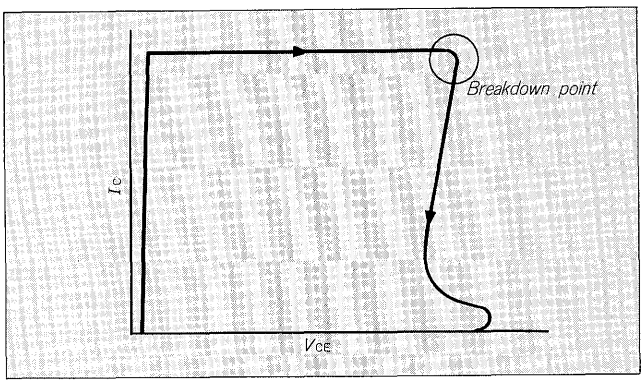


Fig. 3 Peak-point breakdown of ignition transistor



changed. But in the use of this case, as it is shown in *Fig. 2*, the result obtained was different from what we had presumed. In this case, the resistance to rupture can be expressed by the following formula:

$$E_{s/b} = \frac{1}{2} L I^2 \text{ (mJ)},$$

whereas, L (mH): Coil inductance constituting the load,
I (A) : Collector current.

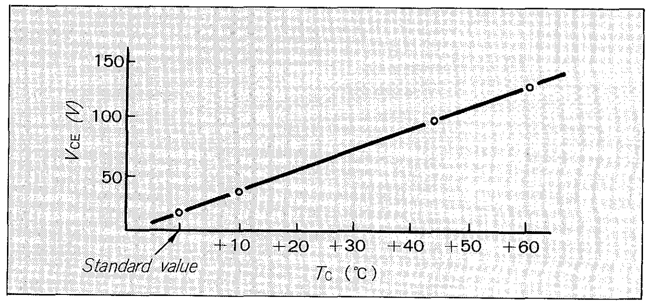
It is that by latching method. By analyzing the operation trajectdories, it has become known that the rupture takes place at the operating point shown in *Fig. 3*, and suppose we call that point, provisionally, peak-point breakdown, the resistance will be as large as $p \times Wi$. That is, it exhibits a tendency that the higher we make the withstanding voltage, the smaller it beocmes. This phenomenon was explained as, by rising of sustained voltage, power (voltage x current) at the peak point will be larger and the influence of this phenomenon enlarges $Wi \times p$, so that it surpasses the effect of enlarging ASOs in general.

One of countermeasures for reinforcing $E_{s/b}$, because of the peak-point breakdown, is not to enlarge *p* but to enlarge *Wi*. However, measures in due consideration of processing capacity at the time of manufacture are, as shown in *Fig. 4*, to insert an avalanche diode between collector and base. Fuji Electric has offered the first one package transistor ETD32 with avalanche diode of this sector of industry, then in succession, 2SD1071 made into one chip and mold type, and these, later, have determined the course of ignition transistors. Now, they are widely used for both two and four-wheeled vehicles in great quantities.

2.2 High-speed switching power transistor

Power transistors for switching power supply also are, as the case of before mentioned ignition transistors, L load ON/OFF transistors. Purpose of development of this series transistor has been to take a good balance of high speed and high resistance to rupture. As the resistance to rupture of the switching transistors, the reverse bias safe operation area (RBSOA) at ON/OFF time is more important, so that we have proposed the method of its evaluation and, at the same time, exhibited the dependency on reverse bias. Also, as a new finding, we have demonstrated that, on the contrary to that of FBSOA, the temperature dependency of RBSOA has a positive coefficient. The resistance to rupture, in other words, is something that defines the level that the transistor junction temperature excedes the critical value, and it was, naturally, expected that the temperature coefficient would have negative value, but as the result of the experiment indicates, and as shown in *Fig. 5*, it has a positive value. It was able to infer that all this is because a carier is being discharged from the part near from the base electrode during transistor's turn off process, and it has to do with the dimensions of the surface area of last continuity region remaining in the central part of the emitter, being the area larger when the temperature gets higher and the current density becoming smaller also. On the basis of these findings, we have serialized the manufacture of high-

Fig. 5 Temperature dependency of RBSOA



speed switching power transistors of 400V, 5-15A aiming at 20-50kHz.

2.3 Making transistor capacity larger

Designing techniques regarding $E_{s/b}$ and switching characteristics accumulated with ignition transistors and high-speed switching transistors were utilized for developing large-capacity transistors for controling motors, which led us to manufacture 500V 30-50A class Darlington transistors.

The features of this series as represented by 2SD1067 and 2SD1056, were realized in the form of, besides the planar type large-surface transistor chips, packaging the large-type TO-3 (MD-18) and high-speed diode as flywheel diode (FWD), as well as the speed up diode (SUD) for improving switching characteristics at the same time.

2.4 Birth of BBT

Going through our experience in application up to 50A by large-type TO-3 package, further enlargement of capacity as well as, from the point of view of easiness of use, another development of a new package were expected, which would take over the place of conventional flat pressure welding type (called flat pack, hockey pack, etc.). As a result of thorough technical studies, it was BBT that we had chosen to develope for the market, and their representative models were 2SD1066, 2SC2770, ET127, etc.

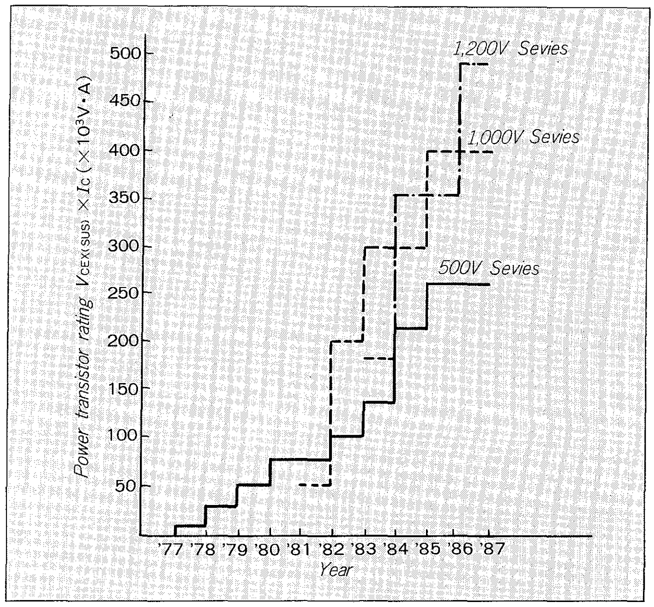
BBTs were the first large-capacity mold transistor of this sector of industry, and they have a capacity of 500V and 100A. However, as they incorporate FWD and SUD, they are better called non-insulated type module rather than unit of transistor. Through development of BBT's, we could raise our technical levels of soldering and molding, and could confirm a high reliability in them in the aspect of damp-proofing and power cycle withstanding capacity.

We have also made a thorough research for parallel operation performance, constituting one of the objects of the BBT development, and brought about an improvement of characterisitics themselves of the transistor and, at the same time, various concrete problems emerged from parallel operation through a positive communications with application engineers. In particular, the direct parallel system that we have propelled strongly, we have a feeling that it has become the standard practice later, that is now.

2.5 Insulation type power transistor module

The above-mentioned BBTs are non-insulation type power transistor modules, and they are advantageous for their heat dissipating properties and enlargement of their capacity through parallel connection, but in case of housing many active chips in one package for making the system more complex, there will be a restriction in functional aspect. The emergence of power modules insulating collector from heat dissipating substrates brought designers of equipment and machineries, a compact designing and cost reduction in instrumentation. *Fig. 6* shows a progress of serialization of power transistor module manufactures. Among the products, the most available from the point of

Fig. 6 Process of development of power transistor modules



vew of quantity are those of 2-transistor and 2-diode constructions called commonly as duos, however, for those used for comparatively low current and low load as inverters for air conditioners, the mainstream is the sextet (also called six-in-one). In Fuji Electric, they are designated as 1D1, 2D1, and 6D1, for a single set, duo and sextet, respectively, and these designations are adopted as model name. D signifies Darling composition, while I, insulated type.

Power transistor modules are in constant development, and their field of application includes as many as motor control for machine tools, versatile type transistor inverter, inverter for exclusive use for air conditioner, uninterrupted power supply (UPS), chopper, welding machines and power supply for rolling stocks.

3 DESIGNING OF FUJI POWER TRANSISTOR

The outlines of electrical characteristics of Fuji power transistor and designing policy common to group of machines in chip designing are the following.

3.1 Electrical characteristics

Being a transistor, it is only natural that it has predetermined current amplification (h_{EF}) and withstanding voltage (V_{CBO}, V_{CEO}), but in case of Fuji power transistor, it emphasizes the importance of $E_{s/b}$, resistance to rupture as defined by RBSOA, reduction of turn-off loss, withstanding voltage between emitter and base (V_{EBO}), and parallel operation performance.

The resistance to rupture depends greatly on chip pattern (mask) designing and diffusion profile, and $E_{s/b}$ value is guaranteed by $1/2LI^2$ (mJ) value adapted to adaption circuit and RBSOA, as shown in *Fig. 7*, by withstanding voltage at the time of reverse bias (V_{CEX}) in two times more value of DC current rating ($2I_C$). This represents the

Fig. 7 Switching transistor RBSOA

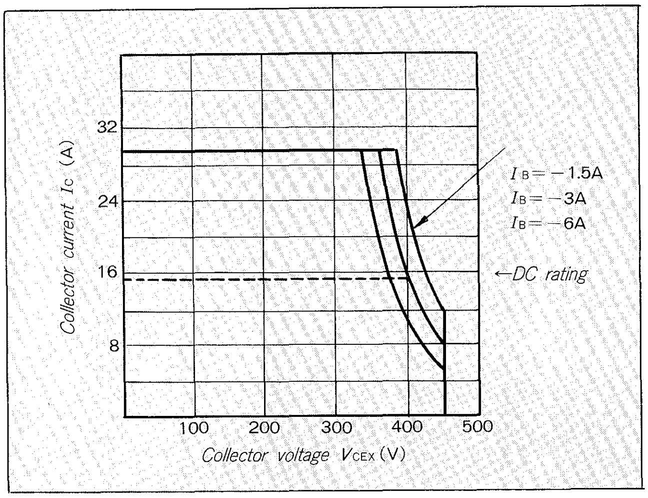
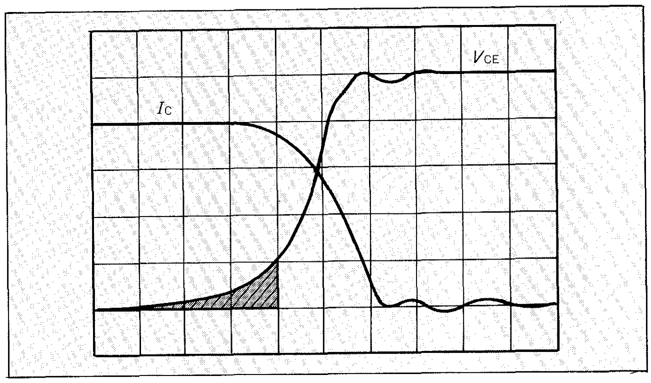


Fig. 8 Voltage "lifting" at the turn-off time



spike voltage (V_{CEP}) generated at the turn-off time, or permissive value against the overcurrent. Also, representation of short-circuit ASO is advantageous for designing the protective circuit.

The turn-off time playing an important role in switching characteristics has a part that can fairly be represented quantitatively by t_{stg} and t_f, and a part that cannot be quantified so easily as "lifting" of collector voltage shown in *Fig. 8*. As the collector current in this region retains more or less the maximum value, generated loss will be greater. And the greater will be the with-standing voltage, the more remarkable this "lifting" will become, and in extreme cases, thermal runaways are induced. This phenomenon can be explained in a qualitative from that it takes place on account of increase in collector resistance due to the attenuation of the conductivity modulation during turn-off process and progressing of carrier extinction from emitter periphery (the part nearer to base electrode) making effectively the emitter electrode surface smaller. Though it may be a question of degree, this is a transistory characteristic that essentially exists. Fuji power transistor is designed by taking into consideration of this point also and for the optimum pattern design and diffusion profile.

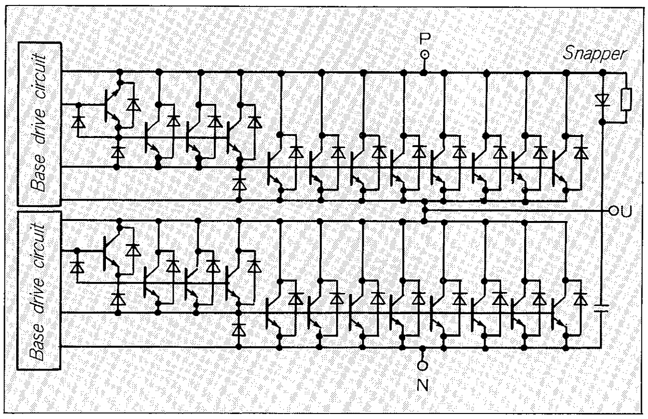
In order to shorten turn-off time, a reverse bias is impressed between base and emitter and the transistor is operated. It is necessary that emitter-base withstanding voltage should have a value larger than a predetermined value. Also, the larger the reverse bias is, the shorter the turn-off time would become. Usually, a voltage of 5 to 6V is impressed, but sometimes, a voltage about 10V may be required. Also, in some cases, avalanche withstanding voltage is required between emitter and base. In either case, stable emitter-base characteristics are important, and when they are instable, this would cause directly a deterioration of V_{EB} characteristics, as well as deterioration of h_{FE} may be induced as the secondary effect. Fuji power transistors are coping with this problem by improving the precision of junction working between emitter and base, and stabilization through a better planar junction surface technology.

Large-capacity transistors, beginning with BBTs, are

Table 1 Main series of Fuji mold type switching transistors

	Model	V_{CBO} (V)	V_{CEO} (V)	$V_{CE(SUS)}$ (V)	I_C (A)	P_C (W)	h_{FE}			t_{on} (μs)	t_{stg} (μs)	t_f (μs)	Package
								I_C(A)	V_{CE}(V)				
Darlington	2SD1071	450	300	300	6	40	500	4	2	–	–	–	TO-220AB
	ETE41	450	300	300	8	80	500	7	2	–	–	–	TO-3P
Super high-speed switching	2SC3317	500	400	400	5	40	10	2	5	0.5	1.5	0.75	TO-220AB
	2SC3318	500	400	400	10	80	10	5	5	0.5	1.5	0.75	TO-3P
	2SC3319	500	400	400	10	100	10	5	5	0.5	1.5	0.75	TO-3
	2SC3320	500	400	400	15	80	10	6	5	0.5	1.5	0.75	TO-3P
	2SC3321	500	400	400	15	100	10	6	5	0.5	1.5	0.75	TO-3
High withstanding voltage	2SC3549	900	800	800	3	40	10	1	5	1.0	4.0	0.8	TO-220AB
	2SC3550	900	800	800	3	80	10	1	5	1.0	4.0	0.8	TO-3P
	2SC3551	900	800	800	5	80	10	2	5	1.0	4.0	0.8	TO-3P
High speed	2SC3723	450	400	400	5	40	10	2	5	1.0	2.5	0.5	TO-220AB
	2SC3724	450	400	400	10	80	10	4	5	1.0	2.5	0.5	TO-3P
	2SC3725	450	400	400	15	80	10	6	5	1.0	2.5	0.5	TO-3P

Fig. 9 Parallel connection by direct parallel system

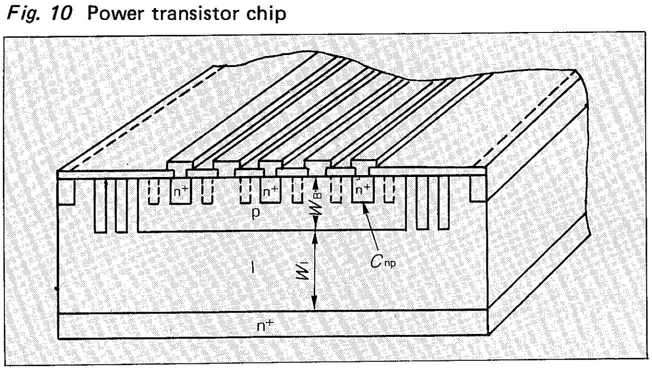


parallel operated aiming at their application to large-capacity machines and equipment. For transistor parallel operation, it is necessary to consider both static and dynamic balances. In order to cope with the problem, the conventional way was to insert each saeturable reactor in series, and to insert emitter resistance to emitter side and base resistance to base side, however, as the result of thorough studies on performance of parallel operation through experience with transistors for power swtiching and BBT, it was made clear that it was input-between-base-emitter characteristic (V_{BE} (SAT)) that determined the performance of parallel operation and in order to obtain the bset effect, the best way was to make the dispersion as small as possible. And as the result, we have come to propose a simple and clear system, what we call the direct parallel system as shown in *Fig. 9*. This system can, if the V_{BE} (SAT) dispersion is within certain predetermined limit, contain the dynamic as well as static balances within a permissible value. So that parallel operation of Fuji power transistor is comparatively easy.

3.2 Chip designing

The means of bringing the above-mentioned electrical characteristics into reality is, mainly, in designing of transistor chips. *Fig. 10* shows a structural model of Fuji lpower transistor chip. The high-resistance i-layer thickness (W_i) and specific resistance are determined by withstanding voltage class, and p+ guard-rings are made in dual or triple structures with an aim of obtaining higher resistance to rupter, and are made in the same process as that of base diffusion. In emitter diffusion, doping concentration itself is important, constituting one of the factors that determine the current dependency of h_{FE}. The concentration of emitter-base junction (C_{np}) after the emitter diffusion is controlled by the diffusion time, and that will determine the h_{FE} level.

Fig. 10 Power transistor chip

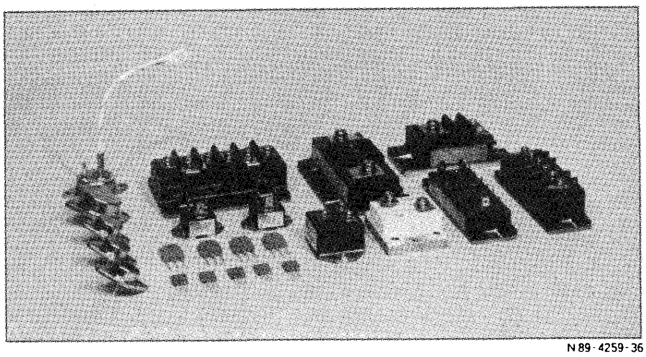


Fundamentally, by changing the mask and crystal, characteristics of each machine type are realized and the

Table 2 Main series of Fuji power transistor modules

	Model	V_{CBO} (V)	V_{CEO} (V)	V_{CE} (SUS) (V)	I_C (A)	P_C (W)	h_{FE}	I_C(A)	V_{CE}(V)
BBT	2SC2770	600	600	450	100	770	8	60	5
	ET127	600	600	450	100	770	100	100	5
500V module	EVG31-050	600	600	450	30	200	100	30	5
	EVK31-050	600	600	450	50	300	100	50	5
	EVK71-050	600	600	450	75	350	70	75	5
	EVL31-050	600	600	450	100	500	100	100	5
	EVM31-050A	600	600	450	150	600	70	150	5
	ETN85-050	600	600	450	300	1,200	70	300	5
550V module	2DI50D-055A	600	600	550	50	300	70	50	5
	2DI75D-055A	600	600	550	75	350	70	75	5
	EVL31-055	600	600	550	100	500	70	100	5
	EVL32-055	600	600	550	120	500	70	120	5
	ETN81-055	600	600	550	200	1,000	70	200	5
	1DI240A-055	600	600	550	240	1,000	70	240	5
	1DI480A-055	600	600	550	480	2,000	70	480	5
1,000V module	2DI30D-100	1,000	1,000	1,000	30	200	100	30	5
	2DI50D-100	1,000	1,000	1,000	50	300	100	50	5
	2DI75D-100	1,000	1,000	1,000	75	400	100	75	5
	2DI100D-100	1,000	1,000	1,000	100	500	100	100	5
	2DI150D-100	1,000	1,000	1,000	150	800	100	150	5
	2DI200D-100	1,000	1,000	1,000	200	1,000	100	200	5
	1DI300D-100	1,000	1,000	1,000	300	1,600	100	300	5
	1DI400D-100	1,000	1,000	1,000	400	2,000	70	400	5
1,200V module	2DI30A-120	1,200	1,220	1,200	30	200	70	30	5
	2DI50A-120	1,200	1,220	1,200	50	400	70	50	5
	2DI75A-120	1,200	1,220	1,200	75	500	70	75	5
	2DI100A-120	1,200	1,220	1,200	100	800	70	100	5
	2DI150A-120	1,200	1,220	1,200	150	1,000	70	150	5
	1DI200A-120	1,200	1,220	1,200	200	1,600	70	200	5
	1DI300A-120	1,200	1,220	1,200	300	2,000	70	300	5
	1DI400A-120	1,200	1,200	1,200	400	3,120	100	400	5
Sextet-unit module	6DI10A-050	600	600	450	10	80	100	10	5
	6DI15A-050	600	600	450	15	80	100	15	5
	6DI20C-050	600	600	450	20	120	100	20	5
	6DI30A-050	600	600	450	30	150	100	30	5
	6DI30B-050	600	600	450	30	150	100	30	5
	6DI50C-050	600	600	450	50	230	100	50	5
	6DI75A-050	600	600	450	75	350	100	75	5
	6DI100A-050	600	600	450	100	400	80	100	5
	6DI10A-120	1,200	1,200	1,200	10	100	70	10	5
	6DI15A-120	1,200	1,200	1,200	15	150	70	15	5
	6DI30A-120	1,200	1,200	1,200	30	230	70	30	5

Fig. 11 Outer view of Fuji power transistors



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manufacturing process is the same even though the machine types are different. Though the length of circumference, if the chip size is the same, can be made longer by narrowing the emitter lattice width, which in turn, is determined by mask designing, the length of circumference is determined in function of the emitter lattice length. The so-called mesh emitter structure forming emitter region in form of island, in stead of emitter lattice, is also effective for lengthening the circumference. After forming passivation film, electrodes are formed by aluminum deposition.

4 SERIES OF FUJI SWITCHING POWER TRANSISTORS

Table 1 shows representative machine types of Fuji switching power transistors and their characteristics. Transistors for automobile ignition are mold package products, but the chips contained in these products are widely used for power hybrid IC's. For high-speed switching, there are, besides 2SC3300 series, the speediest, corresponding to 100 kHz; 2SC3700 series and 800V-withstanding 2SC35 series.

For modules, there are single units, dual units and sextet units, complete up to 1,200V, 400A. *Fig. 11* shows the outer view of these products.

5 CONCLUSION

We have, in this report, described the progress of development, features and present situation of Fuji power transistors. Switching power transistors are now in phase, as in case of power transistor modules, of a rapid expansion. It is believed that they will, as one of actuators taking a position opposite to IC's that had made a remarkable progress, take up continuously an important position. For aiming also at intelligent power modules in which it is said to exist future trends, the key to further development is how to grasp effectively the users' needs.

By taking up a balance between differenciation and standardazation, we are determined to propel our orderly development. What we aim at is the development also of our field of industries, and we would appreciate very much to have the comments and guidance from all sectors of our users.