UDC 621. 382. 333

FUJI HIGH POWER TRANSISTORS

Tsuneto Sekiya
Shoichi Furuhata
Shin'ichi Itoh
Hiromu Haruki

I. FOREWORD

Single and Darlington transistors from 4A to 15A were previously developed and have been used and highly acclaimed in the ignition system of automobiles and another engines, in low power motor control, power supplies and other inductive loads.

Four kinds of high power 600V 30A, 600V 50A Darlington transistors 2SD805, 2SD806 and single transistors 2SC2442, 2SC2443, have now been developed. These transistors are for motor applications, and power supplies for computers and other industrial equipment, and employ the triple diffused planar structure as their fablication method, and their stable quality and high speed switching ability have been confirmed. The device design and fabrication method of high power transistors will be outlined and their features of characteristics introduced below.

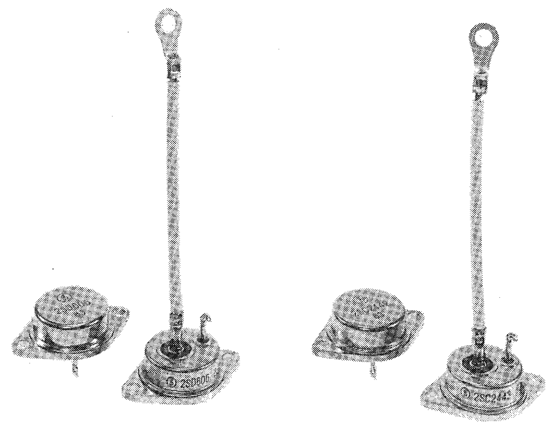


Fig. 1 Fuji high power transistors

II. OUTLINE OF DEVICE DESIGN AND PRODUCTION METHOD

The following points were given special consideration in the design of the Fuji high power transistors:

(1) Wide area of safe operation (ASO).
(2) Short switching time.
(3) High DC current gain h_{FE} (2SD805, 2SD806).
(4) High reliability.

Exterior views of the 2SC2442, 2SD805 (30A class large TO-3 package) and 2SC2443, 2SD806 (50A class large TO-3 flat base package) are given in *Fig. 1*, and the equivalent circuit of the 2SD805, 2SD806 is shown in *Fig. 2*. The features of 2SD805, 2SD806 are no anti-parallel paracitically connected diode between collector-emitter and added diode between the base-emitter of the driving transistor. The former prevents destruction at the period of turn-off and the latter improves the switching time (especially the turn-off time).

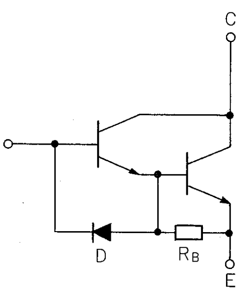


Fig. 2 Equivalent circuit of Fuji high power darlington transitors 2SD805, 2SD806

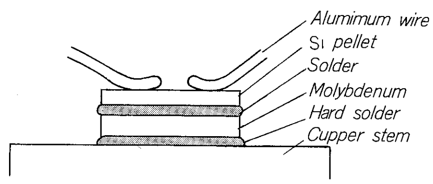


Fig. 3 Inner structure of high power transistors

The interior construction of this series is shown in *Fig. 3*. To prevent thermal fatigue between the Si pellet and metal stem, a molybdenum plate is hard soldered to the copper disc and the transistor pellet is soft soldered to molybdenum plate. Since the quality of solder and soldering conditions have a large effect on the ASO and power cycle performance of the device, they have been given special consideration.

The Darlington transistors 2SD805, 2SD806 employ a 2 pellet construction from the following standpoints:

(1) In the case of the one pellet construction, a anti-parallel parasitic diode is usually added between the col-

lector-emitter, resulting in an adverse effect on the transistor at turn-off.

(2) In device design, the drive stage and output stage can be designed separately, and the drive stage can be easily applied high-speed transistor to shorten the total switching time.

III. RATINGS AND CHARACTERISTICS

The ratings and characteristics of the Fuji high power transistors 2SC2442, 2SC2443, 2SD805, and 2SD806 are given in *Table 1*, and their h_{FE}–I_C characteristics are given in *Fig. 4*.

1. Switching Time

One of the special features of this series is their short switching time, especially their turn-off time t_{off} (sum of storage time t_{stg} and fall time t_f). The turn-off time dis-

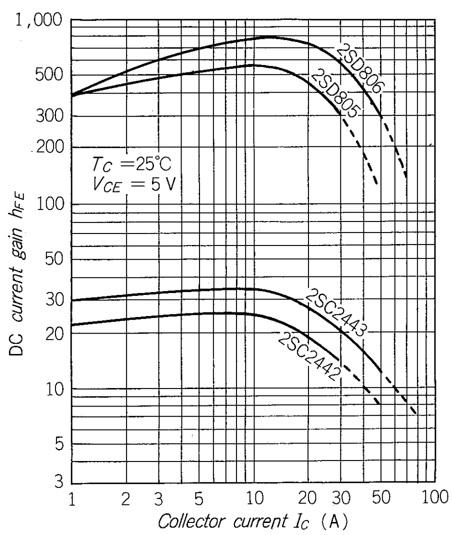


Fig. 4 h_{FE}-I_C characteristics of high power transistors

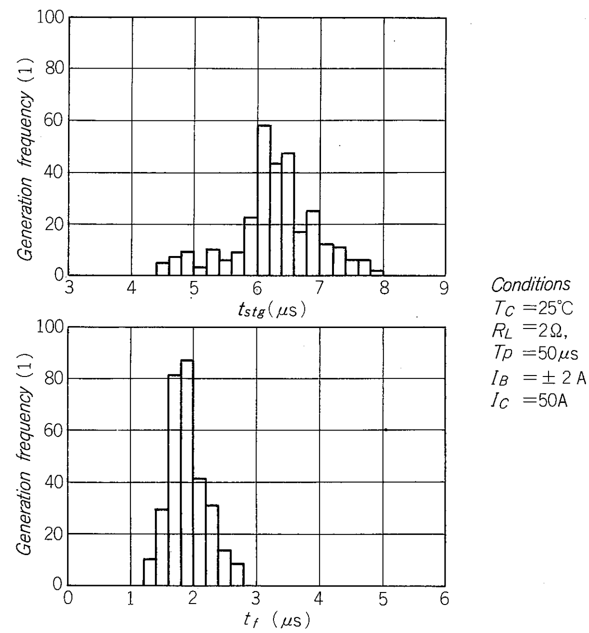


Fig. 5 Distributions of turn off time (2SD806)

Table 1 Ratings and characteristics of Fuji high power transistors

Note) *1: R_{BE} = 200Ω, *2: R_{BE} = 50Ω

Type		2SD805	2SD806	2SC2442	2SC2443
Construction		Darlington	Darlington	Single	Single
Maximum ratings	V_{CBO} (V)	600	600	600	600
	V_{CER} (V)	*1 450	*1 450	*2 450	*2 450
	V_{EBO} (V)	6	6	6	6
	I_C (A)	30	50	30	50
	P_C (W)	200	400	200	400
	T_j (°C)	+150	+150	+150	+150
Electrical characteristics (Tc = 25°C)	I_{CBO} max (mA) [V_{CBO}]	1 [600V]	1 [600V]	1 [600V]	1 [600V]
		min typ max	min typ max	min typ max	min typ max
	h_{FE} [V_{CE}, I_C]	100 – – [5V, 30A]	100 – – [5V, 50A]	8 – – [5V, 25A]	8 – – [5V, 40A]
	V_{CE}(sat) (V) [I_C, I_B]	2.0 [30A, 0.6A]	2.0 [50A, 1A]	1.0 [25A, 5A]	1.0 [40A, 8A]
	V_{BE}(sat) (V) [I_C, I_B]	2.5 [30A, 0.6A]	2.5 [50A, 1A]	1.5 [25A, 5A]	1.5 [40A, 8A]
	t_{on} (μs) [I_C, I_{B1}]	3 [30A, 0.6A]	3 [50A, 1A]	2 [25A, 5A]	2 30A, 6A]
	t_{stg} (μs) [I_C, $I_{B1,2}$]	12 [30A, 0.6A, 0.6A]	12 [50A, 1A, 1A]	7 [25A, 5A, 5A]	7 [30A, 6A, 6A]
	t_f (μs) [I_C, $I_{B1,2}$]	4 [30A, 0.6A, 0.6A]	4 [50A, 1A, 1A]	1 [25A, 5A, 5A]	1 [30A, 6A, 6A]

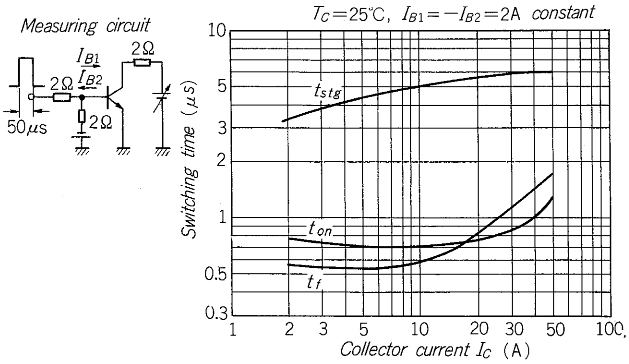
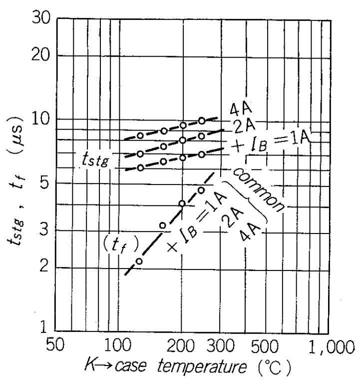


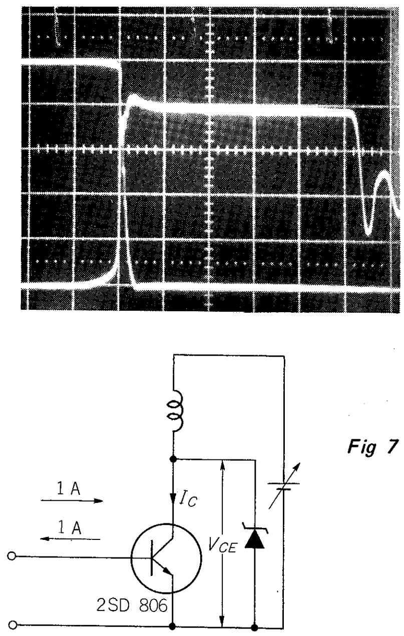
Fig. 6 **Relationship between switching time and collector current**



Conditions
T_P = 50μs
R_L = 2Ω
Reverse base current
2A constant

Note) (K−100)°C represents the actual temperature.

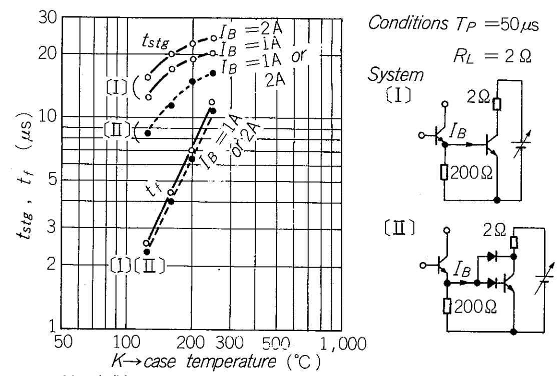
Fig. 8 **Temperature dependence of switching time (2SD806, reverse biased)**



t: 5μs/div
I_C: 10A/div
V_{CE}: 100V/div
T_C: 25°C

← V_{CE}, I_C = 0

Fig 7 **Operation waveforms and testing circuit of inductive load**



Note) (K−100)°C represents the actual temperature.

Fig. 9 **Temperature dependence of switching time (2SD806, not reverse biased)**

tribution of the 2SD806 at room temperature is given in *Fig. 5* as an example, and its collector current I_C dependence characteristic is given in *Fig. 6.*

The switching loss at turn-off is larger in the case of inductive load. *Fig. 7* shows an example of the operation waveforms and testing circuit of inductive load of the 2SD806. The turn-off loss of 2SD806 when switched at 2kHz, $V_{CE(max)}$ = 400V, I_C = 40A, is approximately 20W, and is smaller than that of conventional devices, From the standpoint of practical use, the switching loss can be reduced further by adding a snubber circuit, etc.

The switching time is governed by the drive condition and junction temperature. The relationship between the case temperature and switching time when the reverse current between the base-emitter is made 2A constant and the forward base current is made a parameter is shown in *Fig. 8.* t_f has a large temperature dependence and becomes approximately 2.5 times larger at 25°C than at T_C = 150°C. Compared to this, t_{stg} changes very little. On the other hand, the change of t_f relative to the forward base current is extremely small.

Fig. 9 is the temperature dependence when the 2SD806 base drive system is changed and the case when the base junction is not reverse biased and the case when an overdrive prevention diode (so-called collector-catcher diode) has been added are shown. Especially, the point that is different from the switching time when the base is reverse biased is that the temperature dependence characteristic of t_f is higher, and is a difference of about 4 times at T_C = 150°C and 25°C. However, the simple base circuit is the greatest advantage of this system.

2. Area of Safe Operation (ASO)

In a chopper or inverter circuit, at a shorted circuit or other abnormality, the transistor plunges into the active region and the ASO is exceeded and then the device is often destroyed before the protection circuit is operated. The 2SC2442, 2SD805 are 30A transistors, but have a pulse current capability of double, or 60A, and the 2SC2443, 2SD806 are 50A transistors, but have pulse current capability of 100A. Moreover, the power limit line at the region of 1ms or less that is a problem in practical use is widened considerably. The non-repetitive ASO of the 2SD806 is shown in *Fig. 10* and its repetitive ASO characteristic is shown in

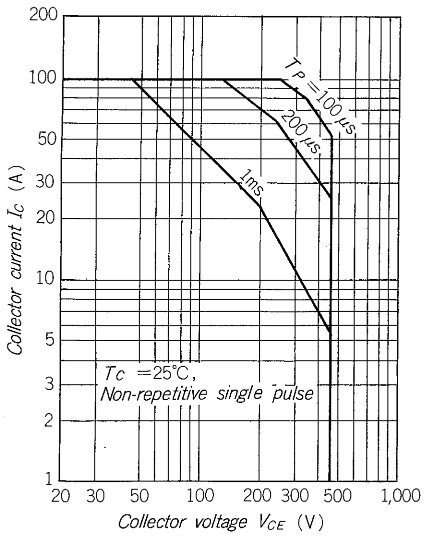


Fig. 10 Non-repetitive ASO of 2SD806

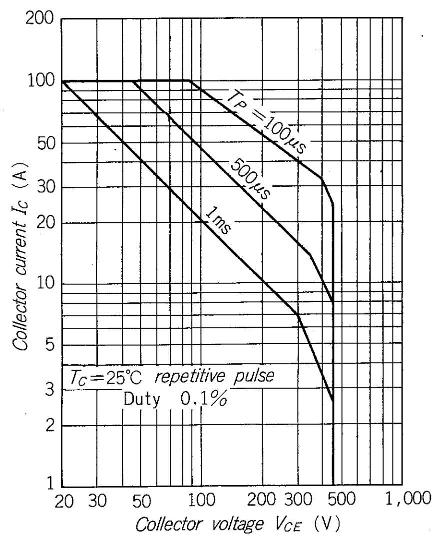


Fig. 11 Repetitive ASO of 2SD806

Fig. 11 as examples.

3. Anti-parallel Connected Diode Between Collector-emitter (for Darlington Transistor)

When TR_1 and TR_2 are in the ON state at the inductive load inverter circuit shown in *Fig. 12*, energy is stored in the load by the current route $TR_1 \rightarrow L \rightarrow TR_2$. TR_1 and TR_2 are then placed into the OFF state, the energy stored in the load is discharged through the route $L \rightarrow D_3 \rightarrow$power supply$\rightarrow D_4$.

On the other hand, the Darlington transistor has a stabilization resistor R_{BE} between the base-emitter of the output transistor. This resistor is formed by shorted hole between the base-emitter (*Fig. 13*). As a result, when the collector-emitter is viewed from the reverse direction, the anti-parallel connected diode is built-in and discharge of the accumulated energy of the load is performed by branching

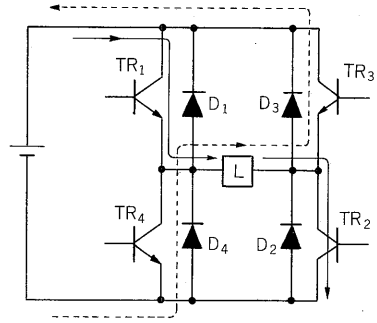


Fig. 12 Inverter circuit with inductive load

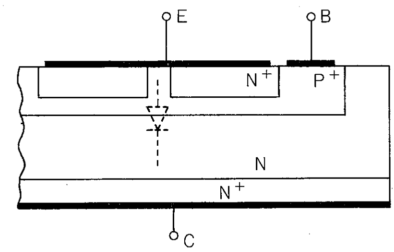


Fig. 13 Formation of parasitic diode by shorted hole

to an externally connected diode and this parasitic diode, but since the current capacity of the parasitic diode is not very large, it may be destroyed.

Moreover, since this parasitic diode is a so-called low-speed diode and its reverse recovery time t_{rr} is about several µs even though it is not destroyed, after a certain time has elapsed after TR_1 and TR_2 at the circuit of *Fig. 12* have been placed in the OFF state, TR_3 and TR_4 are placed into the ON state, but the reverse current of the parasitic diode at t_{rr} increases the turn-on loss of TR_3 and TR_4.

Ample consideration has also been given to this point in the Fuji high power transistors 2SD805, 2SD806, and their circuit design can be flexible.

4. *dv/dt* Characteristic

In the case of Darlingtom transistor especially, consideration may have to be given to the sudden rise voltage that is such a large problem with thyristors. If the output capacitance of the driving transistor is made C_{ob}, the output stage transistor is driven by the displacement current caused by $C_{ob} \times dv/dt$, and a fairly large transient current flows. Against this, the dv/dt capability is improved by appropriate setting of R_{BE} and considering the output capacitance of the output transistor. The change of the current value caused by dv/dt when R_{BE} has been changed at the 2SD806 is shown in *Fig. 14*.

IV. RELIABILITY

The Fuji high power transistors were developed as an extension of the I_C = 4~15A one pellet Darlington transistors and high-speed switching transistors up to 400V,

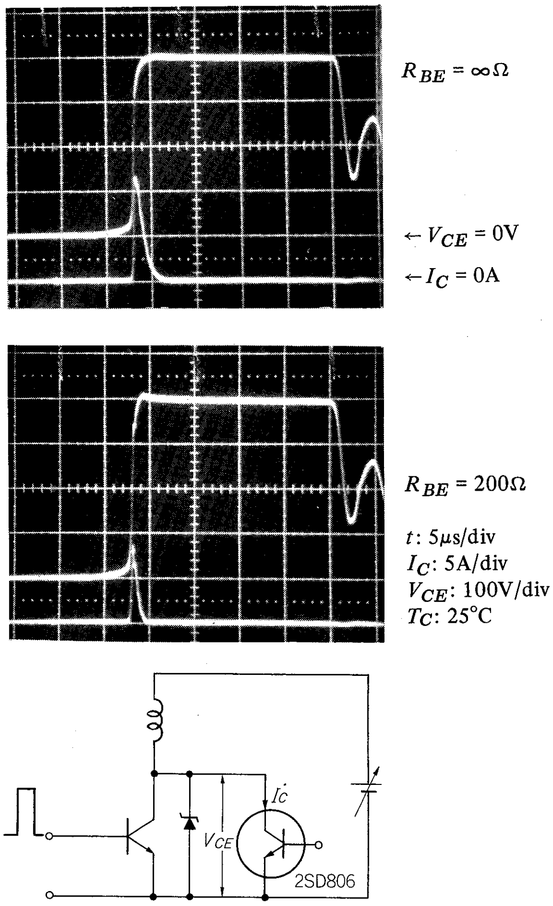


Fig. 14 *dv/dt–I_C* characteristics with respect to R_{BE}

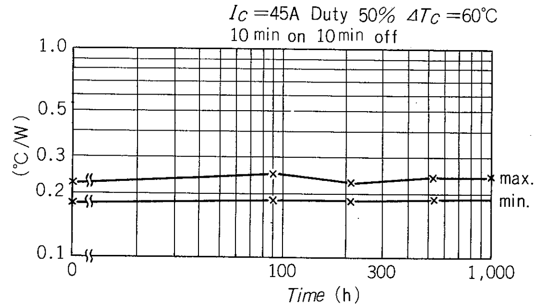


Fig. 15 Results of power cycle test

30A, and utilize the same production technology. Excellent results are obtained in the voltage impression (BT) test, heat cycle test, and other common reliability tests. Since a molybdenum plate is hard soldered as described in section **II**, it has ample reliability against thermal fatigue that poses a trouble when the pellet size is large, even in the power cycle test (intermittent powering) shown in *Fig. 15.*

V. CONCLUSION

This series was developed with user requirements in mind, and they were designed along this line as much as possible. First, we feel that elimination of trouble, small variation of characteristics, short switching time, etc. are almost completely satisfied. The further popularization of high power transistors is dependent on progress in reducing the cost of devices further, and we will be happy for your assistance from all standpoints in the future.