TURN OFF CHARACTERISTICS OF THE SUPERCONDUCTING POWER ELECTRONICS DEVICE (S-PED). —IN CASE OF TYPE C AND TYPE D—

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ABSTRACT - The superconducting permanent current switch (PCS) is an important component to build MRI system. This switch uses a thermal and / or magnetic super-to-normal phase transition of the superconductor. Unfortunately, in the past it was not designed for using in line frequency. We made some superconducting power electronics devices operating up to 100 Hz [1]. The results of development and preliminary studying of the heat controlled S-PED up to line frequency are presented .

1. INTRODUCTION

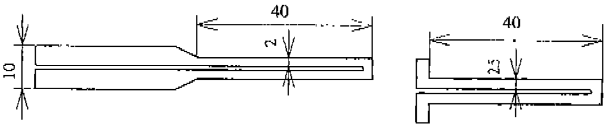
Many efforts have been made to use power semiconductor devices in liquid nitrogen or liquid helium. Due to the large heat dissipation of such devices in cold part, they could not take the place of the current leads and the converter in tie atmosphere. The heat in-leak to cold part with current leads is reduced up to 1 W/kA. This value of heat dissipation is R & D milestone of alternative system, such as flux pump.

As a superconducting switching device, MOS (metal-oxide-superconductor) type superconducting transistors and superconducting base transistors have been studied elsewhere. For the power supply of superconducting magnets, the flux pump can be used. There are two types of flux pump as follows: 1) Superconducting dc dynamos, which contain Volger's type, Atherton's type and the moving flux type. 2) Transformer-rectifier type flux pumps, which contain saturation reactor type, magnetically controlled switch type and thermally controlled switch type. The superconducting transformer for these rectifiers has been also studied. We summarized the history of S-PED in the previous conference (ICPE '95) [2].

S-PED means a superconducting power electronics device. We made some thermally controlled S-PEDs which is normally-on device. They work up to 100 Hz as a full wave rectifier. For the power supply of superconducting magnets, the flux pump can be used as SPEED (Superconducting Power Electronics Excitation Device). In this paper, we describe the turn off characteristics of one of the S-PED (type c and type d). The relations among generated resistance, gate-trigger energy and channel current were obtained.

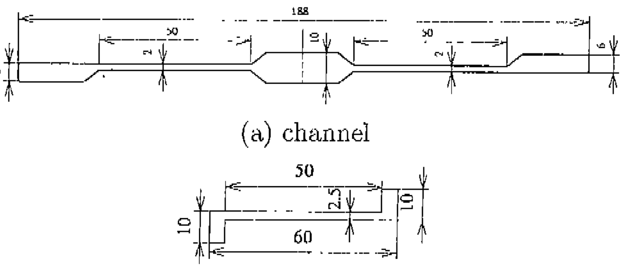
2. DESIGN OF DEVICES

The main ideas in our work are based on developments by L. J. M. van de Klundert et. al. [3], namely:--using as a main channel material - superconducting NbTi foil with thickness less than 20 micrometers and current carrying capacity $\sim$ 100 kA/cm^2;--using planar technology for device. The layers of device (channel, heater, insulator) are glued sequentially between two copper cooling blocks expanded by fins



(a) channel (b) gate

Fig. 1 Sketch of superconducting channel and NiCr heater gate of type c S-PED.



(b) gate

Fig. 2 Sketch of superconducting channel and NiCr heater gate of type d S-PED.

Table 1 Parameters of S-PED

Type (Number)		a(13)	b(13h)	c(12)	d(14/15)	e(16/17)
Superconductor (Channel)	NbTi					
	thickness (μm)	20	20	20	20	20
	active length (mm)	100	100	80	100	300
	width (mm)	2	2	2	2	2
	resistance (Ω)	1.6	1.6	2.2	2.0/2.3	7.62/8.00
Heater (Gate)	Nichrome					
	thickness (μm)	10	10	5	5	5
	active length (mm)	50	50	40	50	50
	width (mm)	2.5 × 2	2.5 × 2	2.5 × 2	2.5	9
	resistance, 4.2K R_g (Ω)	5.34	5.35	3.30	5.00/4.49	1.87/2.45
Heat sink	Copper					
	length of fin (mm)	--	2.5	2.5	3	3
	width of fin (mm)	--	3	3	3	3
Insulator	Kapton					
	thickness between gate and channel (μm)	8	8	8	7.5	7.5
	thickness between channel and heat sink (μm)	8	8	8	12.5	12.5

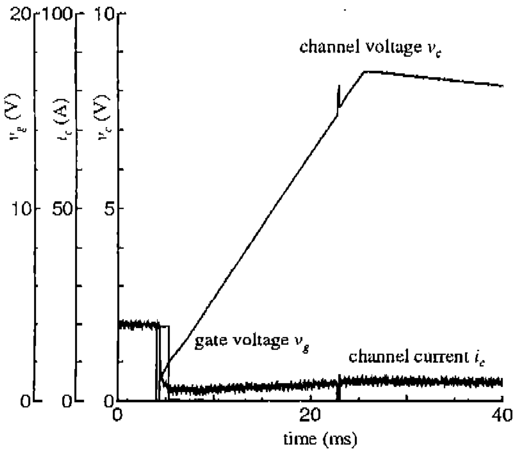


Fig. 3 Turn off transient wave form of channel current and voltage, where $I_0 = 20$ A, $V_g = 2$ V, $T_g = 1$ ms, type d.

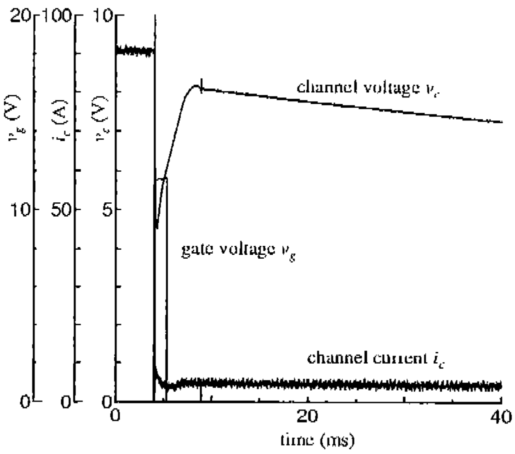


Fig. 5 Turn off transient wave form of channel current and voltage, where $I_0 = 90$ A, $V_g = 11.5$ V, $T_g = 1$ ms, type d.

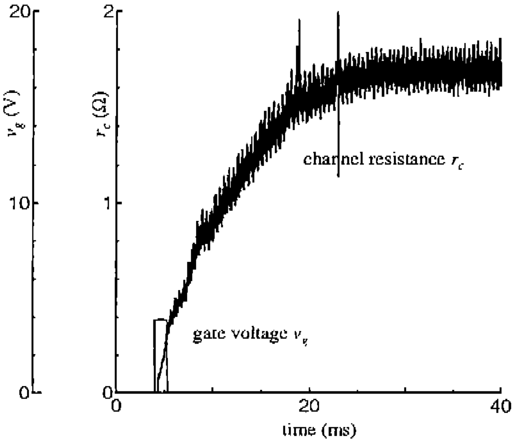


Fig. 4 Turn off transient wave form of channel resistance, where $I_0 = 20$ A, $V_g = 2$ V, $T_g = 1$ ms, type d.

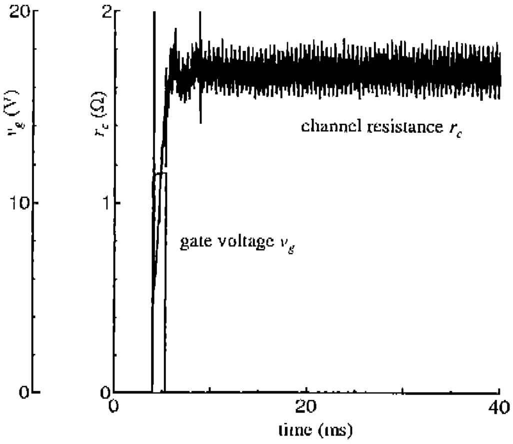


Fig. 6 Turn off transient wave form of channel resistance, where $I_0 = 90$ A, $V_g = 11.5$ V, $T_g = 1$ ms, type d.

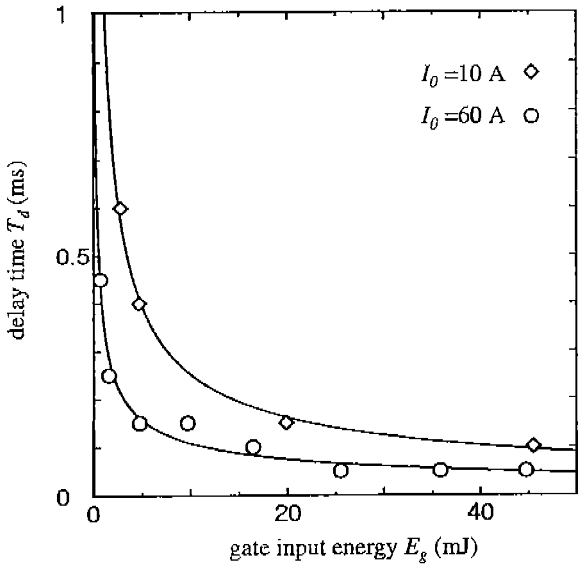


Fig. 7 Relationship between delay time and gate input energy of type c.

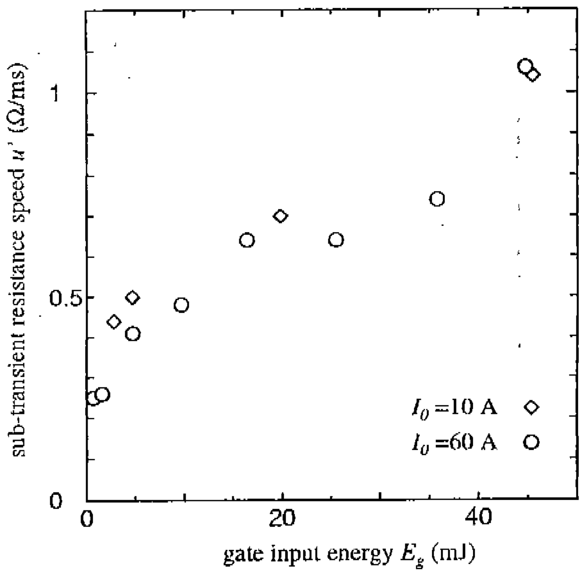


Fig. 9 Relationship between sub-transient resistance speed and gate input energy of type c.

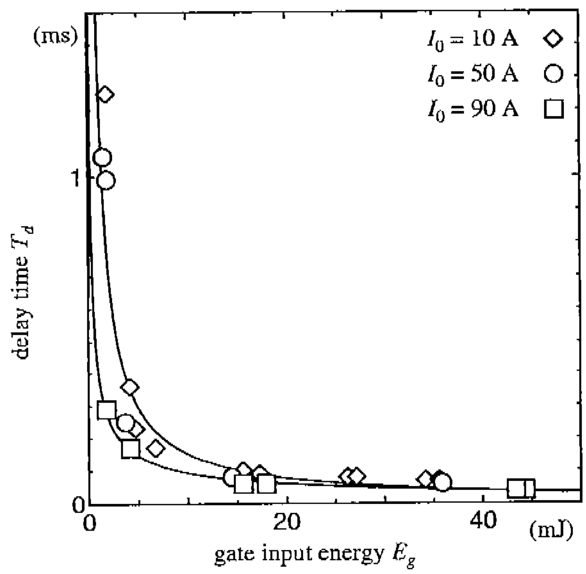


Fig. 8 Relationship between delay time and gate input energy of type d.

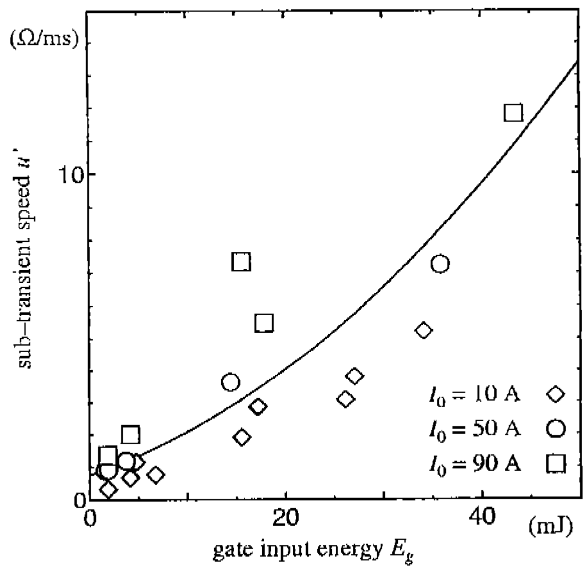


Fig. 10 Relationship between sub-transient resistance speed and gate input energy of type d.

to enlarge the external surface. In Fig. 1 and 2, the shape sketch of superconducting channel and heater gate of type c and d are shown, respectively. The heat generated in heater gate transferred to superconductor channel for super-to-normal phase transition. The parameters of assembled S-PED are shown in Table 1.

3. TURN OFF CHARACTERISTICS

Typical turn off transient wave form of channel current and voltage, where I_0 = 20 A, V_g = 2 V, T_g = 1 ms, are shown in Fig. 3. Because of the relative high impedance of the power source, the channel current decreases steeply after triggered. The channel resistance was calculated with the current-voltage wave form as shown in Fig. 4. The channel resistance appeared after delay time T_d and increased up to sub-transient resistance R' with large gradient (sub-transient resistance speed) u'. Then it reached transient resistance R with little gradient (transient resistance speed) u. R is almost same as the maximum channel resistance R_m. In the case of I_0 = 90 A, V_g = 11.5 V, the responses are shown in Fig. 5 and 6. The spike noise included in the signal causes error in calculated values of subtransient

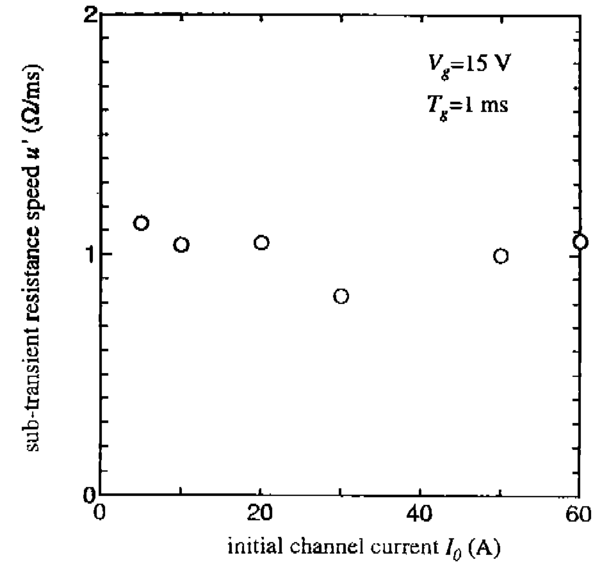


Fig. 11 Relationship between sub-transient resistance speed and initial channel current of type c.

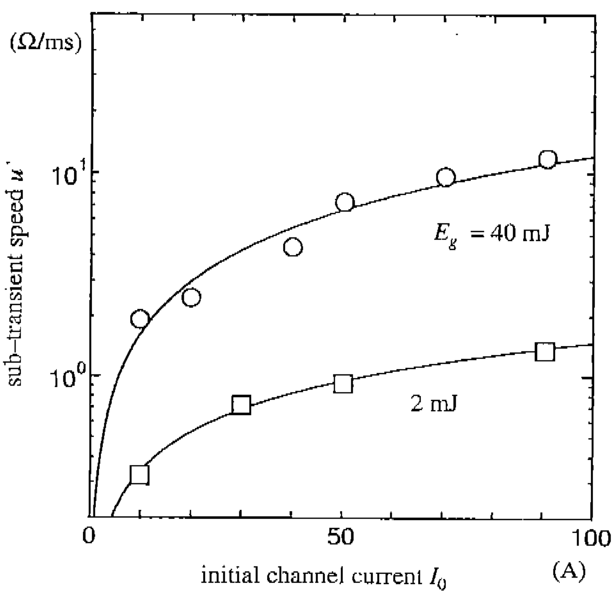


Fig. 12 Relationship between sub-transient resistance speed and initial channel current of type d.

resistance speed etc.

As shown in Fig. 7, the relationship between delay time T_d and gate input energy E_g of type c is defined as $T_d \propto E_g^{-0.53\sim-0.65}$ by curve fitting. As shown in Fig. 8, the relationship between delay time T_d and gate input energy E_g of type d is defined as $T_d \propto E_g^{-0.63\sim-0.97}$ by curve fitting.

The sub-transient resistance speed u' of type c is proportional to the gate input energy E_g as shown in Fig. 9. The sub-transient resistance speed u' of type d is proportional to the square of gate input energy E_g as shown in Fig. 10. But there is no dependence between sub-transient resistance speed and initial channel current I_0 of type c which is the current through channel before turn-off transient as shown in Fig. 11. The dependency between sub-transient resistance speed u' and initial channel current I_0 of type d which is the current through channel before turn-off transient is defined as $u' \propto I_0^{0.64\sim0.87}$ as shown in Fig. 12.

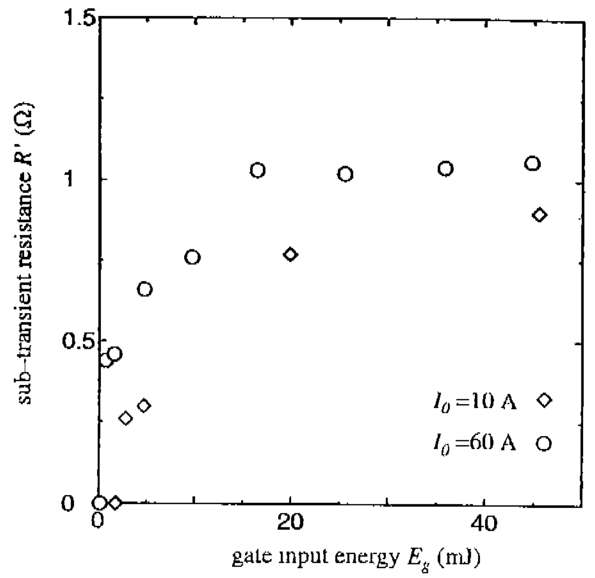


Fig. 13 Relationship between sub-transient resistance and gate input energy of type c.

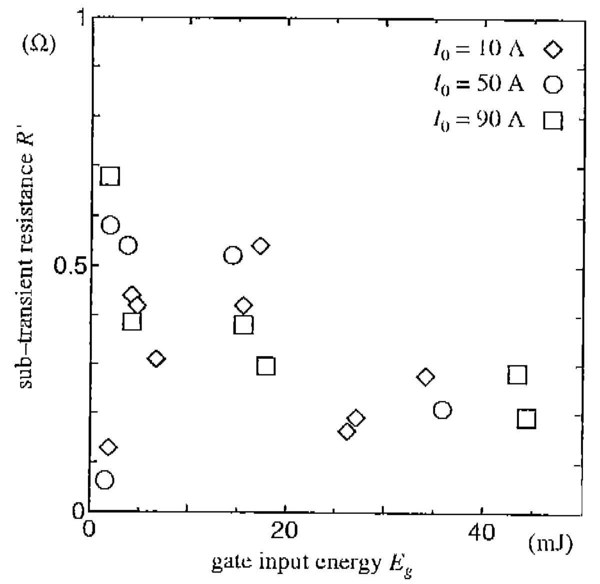


Fig. 14 Relationship between sub-transient resistance and gate input energy of type d.

The relationship between sub-transient resistance R' and gate input energy E_g of type c and d are shown in Fig. 13 and 14, respectively. In the case of type c S-PED, R' is proportional to E_g under the range up to 15 ~ 20 mJ. R' was saturated in the range over

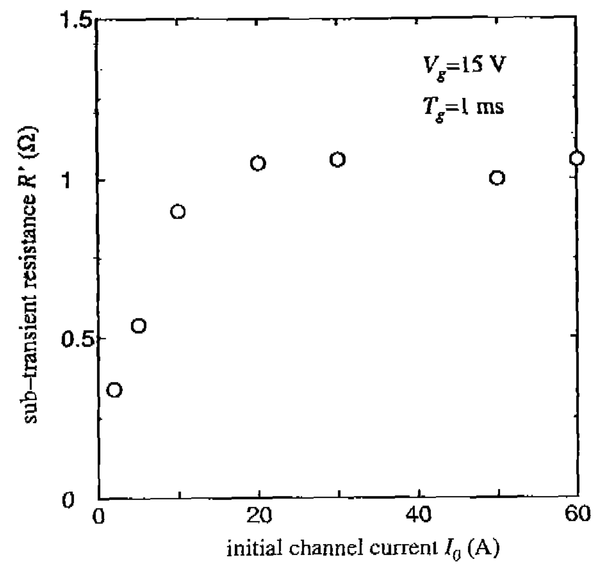


Fig. 15 Relationship between sub-transient resistance and initial channel current of type c.

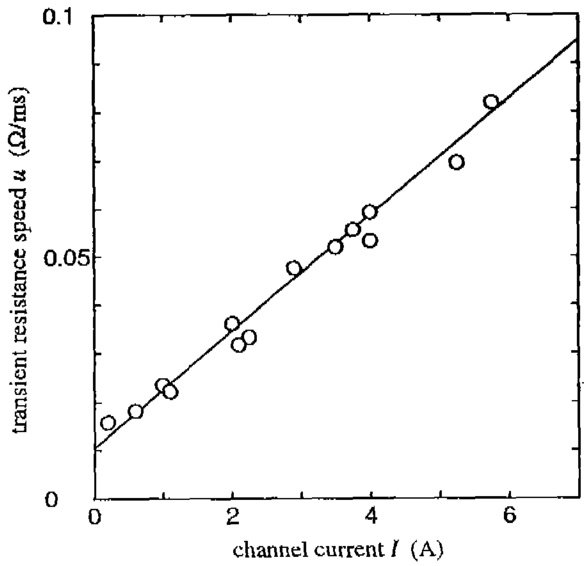


Fig. 17 Relationship between transient resistance speed and channel current of type c.

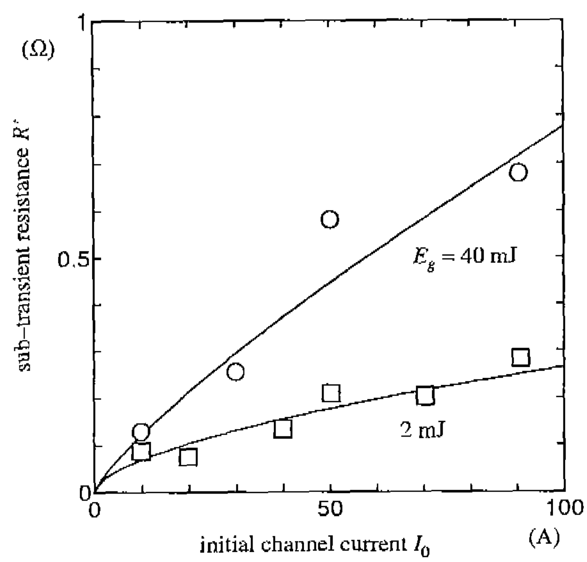


Fig. 16 Relationship between sub-transient resistance and initial channel current of type d.

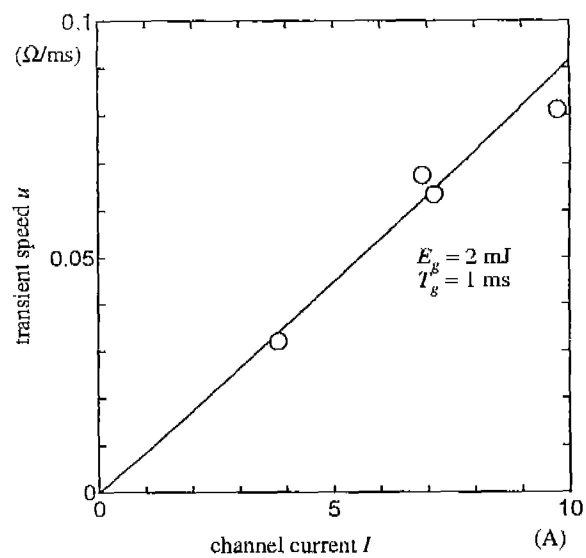


Fig. 18 Relationship between transient resistance speed and channel current of type d.

20 mJ. But one can not find such dependency on type d S-PED, because of the spike noise in the channel voltage signal. The relationship between sub-transient resistance R' and initial channel current I_0 of type c is shown in Fig. 15. R' is proportional to I_0 under the range up to 20 A. R' was saturated in the range over 20 A. The relationship between sub-transient resistance R' and initial channel current I_0 of type d is shown in Fig. 16. Unlike the results of the type c S-PED which is saturated to certain value, R' is proportional to $I_0^{0.58\sim0.81}$.

As shown in Fig. 17, the relationship between transient resistance speed u and channel current I of type c is defined as $u \propto I^{1.2}$ by curve fitting. But there is no dependence with initial channel current I_0. As shown in Fig. 18, the relationship between transient resistance speed u and channel current I of type d is defined as $u \propto I^{1.04}$ by curve fitting. But there is no dependence with initial channel current I_0.

The relationship between minimum turn-off gate energy E_{g0} and initial channel current I_0 of type c is shown in Fig. 19. E_{g0} means minimum gate energy to turn-off the S-PED. E_{g0} decreased with I_0. The relationship between minimum turn-off gate energy E_{g0} and initial channel current I_0 of type d is shown in Fig. 20. E_{g0} decreased with $I_0^{-0.26}$.

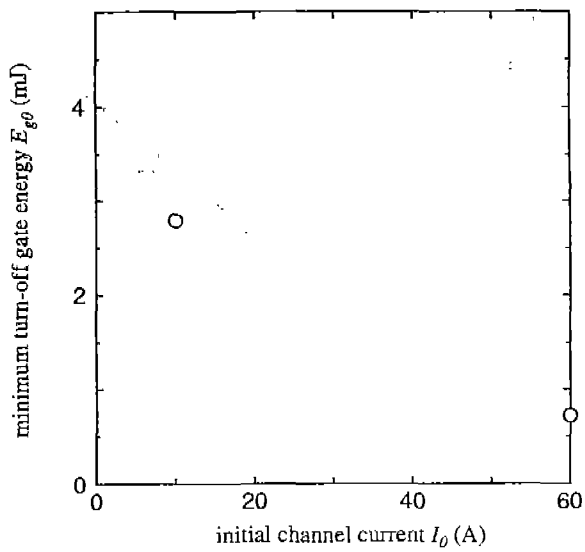


Fig. 19 Relationship between minimum turn-off gate energy and initial channel current of type c.

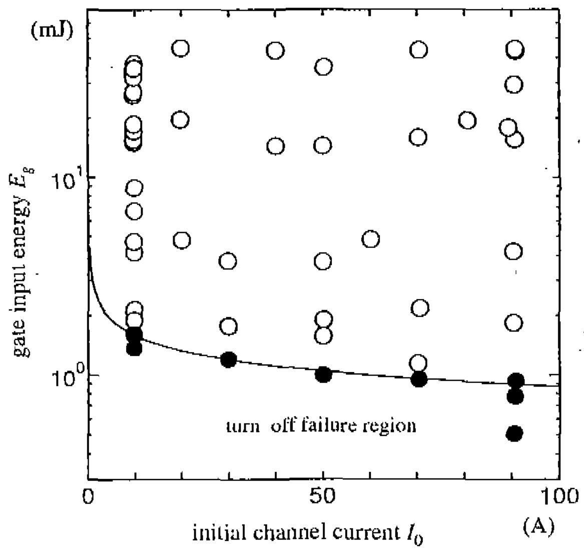


Fig. 20 Relationship between minimum turn-off gate energy and initial channel current of type d.

4. CONCLUSION

The relations among generated resistance, gate-trigger energy and channel current were obtained as follows:

1. Increase of initial-channel current results in decrease of minimum gate-trigger energy.
2. Increase of initial-channel current results in increase of sub-transient resistance.
3. Increase of gate-trigger energy results in increase of sub-transient resistance.
4. Increase of gate-trigger energy results in increase of change speed of sub-transient resistance.
5. The change speed of sub-transient resistance has no correlation with initial-channel current.
6. The sub-transient resistance has no correlation with initial-channel current and gate-trigger energy.
7. Increase of channel current after turn off results in increase of change speed of sub-transient resistance.

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