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TILBW Bipolar Power Switching Transistor

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The work reports the development of double-interdigitated (two interdigitation level) bipolar power switching transistors with heavily-doped base wells (BW). The novel class of bipolar transistors exhibited the following many-fold advantages in comparison with identical,yet conventional bipolar transistors of the same class(identical area) processed simultaneously: 1) an ~18% increase of $V_{CEO(sus)}$(from 680V to 800V);2) an ~23% increase of V_{CBO}(from 730V to 900V);3) a reduction of of the delay (t_d) and rise (t_r)times by a factor of ~20;4)a two-fold reduction of the fall time t_f;5) an enhanced RBSOA.

1. INTRODUCTION

The work reports the development of a novel bipolar switching device called TILBW transistor (Two interdigitation levels with heavily-doped base wells). The developed transistor exhibits an substantial increase of voltage ratings (V_{CBO}, $V_{CEO(sus)}$) simultaneously with a drastic reduction switching times in comparison with identical, yet conventional devices of the same area processed simultaneously. A distinct advantage of the TO-3-packaged, n-p-n^--n TILBW transistors developed is that their fabrication requires little change in comparison with the standard process flow of similar conventional devices.

2.DEVICE STRUCTURE AND OPERATION

The structure of developed TILBW bipolar n-p-n^--n transistor (Fig.1) comprises the basic double-interdigitated (TIL) base-emitter pattern[1,2], tailored on the alternating deep and shallow n^+-emitter layers. However, in comparison with standard TIL devices, whose main advantages were outlined in Refs.(1,2), the TILBW transistors have additionally a series of heavily-doped p^+-wells, stretching from the shallow n^+-emitter through the thicker p-base into the lightly-doped (n^-) collector. The resulting TILBW configuration do actually control the ultimate device behavior in all modes of operation. A major functional role of p^+-wells is to electrostatically shield the surrounding thin p-base layers, thus increasing the "effective" width of this base under reverse bias conditions of the collector junction. Stated otherwise, the p^+-wells act as a "field stopper", i.e. hinder the expansion of the space charge regions (s.c.r.) boundaries into the thin p-base regions under corresponding metallurgical junction. Thus the p^+- wells "absorb" the high field s.c.r., relaxing its very expansion into the thin p-base,

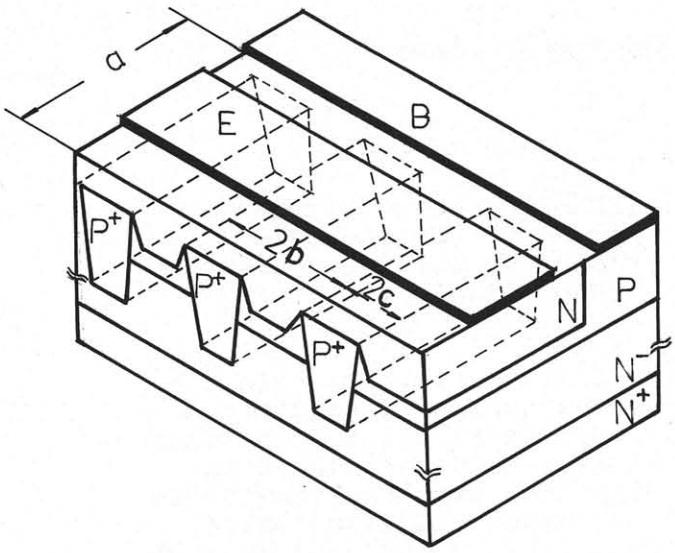

Fig.1. Three-dimensional view of n-p-n⁻-n two interdigitation levels (TIL) bipolar power switching transistor with heavily-doped base-wells (BW) (a is the emitter half-width, b is the length of the elementary TILBW transistor, c is the length of the shallow-diffused n^+-emitter zone of a TILBW minicell).

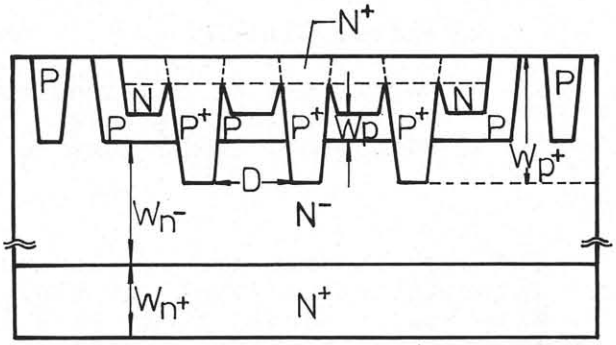

Fig.2. Cross-sectional view of the developed n-p-n⁻-n, TO-3-packaged 0.1 cm^2-emitter area TILBW bipolar power switching transistors. (Structure thickness W=220 μm; p^+-wells depth W_{p^+}=20 μm, distance between the wells D=50 μm; thin p-base width W_p=6 μm; width of the n^- and n^+ collector regions W_{n^-}= 120 μm and W_{n^+}= 80 μm, respectively; surface impurity concentration of the diffused emitter and collector regions is ~2x $10^{20}cm^{-3}$ and ~$10^{19}cm^{-3}$, respectively; the peak impurity concentration in the base under the deep and shallow n^+-emitter zones is ~$10^{16}cm^{-3}$ and ~$10^{18}cm^{-3}$, respectively).

i.e., prevent the early reach-through in the device structure, typical of conventional devices[2,3]. Another major functional role of the p^+-wells is related to the transient modes of device operation. Thus, upon the application of positive signal on the base terminal, hence on the p^+-wells, the thin p-base of TILBW transistors (Fig.1) is flooded with majority carriers (holes). Consequently, the transient turn-on process, occuring along the n-p-n transistor sections with thin p-base (Fig.1), could be substancially speeded-up. Furthermore, the p^+-wells (along with the TIL pattern) lend the opportunity to thoroughly control the main parameters of the transient turn-off and to increase the electrothermal reliability of devices. The latter feature is due to the extremely low p-base sheet resistance associated with both the p^+-wells and shallow n^+-emitter zones. The current extraction toward the base terminal via preferential low base resistance channels (Fig.1) of elementary area [a x (b-c)] (Fig.1) substantially improves the reverse-bias safe operating area (RBSOA) and inhibits the formation of high current density filaments[2,3] as the transient turn-off process goes by.

TABLE I Comparison between the main electrical parameters of TO-3-packaged n-p-n⁻-n TILBW transistors and those of identical yet conventional devices processed on silicon ρ_n=90-100Ω.cm.(Emitter area A_e=0.1 cm^2;T_c=25°C;P_D=150W)

Parameter			Value	
			TILBW	Conventional
Collector-emitter voltage,	$V_{CEO(sus)}$	(V)	800	680
Collector-base voltage,	V_{CBO}	(V)	900	730
Emitter-base voltage,	V_{EBO}	(V)	6	7
Peak continuous collector current	I_C	(A)	5.0	8.0
D.C. current gain h_{FE} at V_{CE}=4V; I_C= 5A			2	3.5
Saturation voltage at h_{FE}=5,I_C=1A,	$V_{CE(sat)}$	(V)	0.95	0.22
Delay time	t_d^x	(ns)	20	900
Rise time	t_r^x	(ns)	40	900
Fall time	t_f^x	(μs)	0.25	0.5
Storage time	t_f^x	(μs)	1.3	1.3

x) Test conditions :I_C=5A; V_{CC}=40 V

TABLE II Comparison between the main electrical parameters of TO-3-packaged n-p-n⁻-n TILBW transistors and those of identical yet conventional devices processed on silicon with ρ_n=40-50Ω.cm.(Emitter area A_e=0.1cm^2; T_C=25°C; P_D=150 W)

Parameter			Value	
			TILBW	Conventional
Collector-emitter voltage,	$V_{CEO(sus)}$	(V)	345	320
Collector-base voltage,	V_{CBO}	(V)	560	510
Peak continuous collector current	I_C	(A)	64	48
D.C. current gain h_{FE} at V_{CE}=4V; I_C=16A			10	12
Saturation voltage at h_{FE}=5,I_C=8A	$V_{CE(sat)}$	(V)	0.31	0.3
Turn-on time,	t_{gt}^x	(ns)	50	50
Sorage time,	t_s^x	(μs)	1.1	1.2
Fall time,	t_f^x	(ns)	70	400

x) Test conditions : V_{CC}= 100 V; I_C=10 A; h_{FE}=5

Since the heavily-doped p^+-wells act as a sink for minority carriers in the base regions, a diminuation of the fall time t_f is also feasible.

3. FABRICATION

The test devices were fabricated on silicon substrates with a resistivity of ρ_n= 90-100Ω.cm. following as closely as possible the standard technological flow for triple-diffused n-p-n⁻-n transistors[3]. The sole distinctive feature of the fabrication process were:a) the p-bases profile (Fig.1) shaping by two diferent steps of boron deposition and drive-in using BN source as out-

lined in detail in Ref.(4);b) the two-step phosphorus diffusion process for the n^+-emitter layers formation as described in Refs.(1,2). Details of the device structure are provided in the Caption of Fig.2. The active emitter area A_e=0.1 cm^2 of TO-3-packaged devices consisted of 1514 mini-cells of elementary area (a x b)=3.2 x $10^{-3}mm^2$(Fig.2). The implemented ratio (b/c)≈2 (Fig.1) ensured an even distribution of deep-diffused n^+-zones and p^+-base wells, respectively, over the emitter area. Conventionally interdigitated transistors with identical area (A_e = 0.1 cm^2) were fabricated through the same process flow as reference for trial devices.

4.RESULTS

From the performed comparative measurements, the following conclusions were drown (Table I):

a. In the developed TILBW devices a typical increase of ~18% and ~23% in the voltages $V_{CEO(sus)}$ and V_{CBO}, respectively, is obtainable in comparison with conventional devices;

b. An actual "collapse" of the turn-on time occurs in TILBW devices :the turn-on delay (t_d) and rise (t_r) times were reduced by a factor of ~20 in comparison with conventional transistors of the same class;

c. A two-fold reduction of fall time (t_f) was also recorded in TILBWs.

The gains outlined at a)-c) were obtained at practically unchanged main electrical parameters of devices (Table I).

Additional experiments were performed with n-p-n^--n TILBWs fabricated on silicon with ρ_n= 40 - 50Ω.cm. The emitter area, the mini-cells geometry and the fabrication process were identical to those outlined for TILBWs with lightly doped collectors (n^-). However in this set of TILBWs, the p^+-wells had barely reached the n^--collector layer. The results of comparative measurements performed on TILBWs and conventional reference devices are summarized in Table II. It is noteworthy that:

a. A slight improvement (~7%) of voltage ratings is still obtainable in TILBWs at practical the same values of the main electrical parameters;

b. An almost six-fold reduction of the fall time t_f is recorded in TILBWs.

5. CONCLUSION

To conclude, it was shown that the TILBW transistors exhibit an substantial improvement in voltage ratings and a drastic reduction of switching times. The recorded reduction of rise (t_r) and fall (t_f) times is all the more important as they control the amount of commutation losses, hence the electrothermal reliability of devices. The refinement of presented concepts could further improve the performance of power switching transistors.

6. REFERENCES

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