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A Depleted Base Transistor

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Introduction

The idea of I^2L devices using normally-off JFETs has been published by Nishizawa and Wilamowski[1], in which switching npn transistors in I^2L gates were replaced with JFETs operated with a small positive voltage applied to the gate. By operating n-channel normally-off JFETs with positive base current, we have found the same current amplification action as npn bipolar transistors and obtained an interesting result wherein a current amplification factor shows both positive and negative temperature coefficients.

Structure

Figure 1 shows a cross-sectional view of a fabricated normally-off n-channel JFET structure[2]. The starting wafer is a 15 μm, 20$\Omega\cdot$cm epitaxial layer on a < 111>, n^+-type silicon substrate. The first step is to make a base region which serves as a gate in a JFET operation. Boron is so deeply diffused that the depletion layers, spreading in n^- epitaxial layer due to a built-in potential, touch each other. This diffusion composes a depleted intrinsic base in this device, which is essential for the current amplification action. Next, in the middle of the base diffused regions, the emitter region is formed with a phosphorous doped poly-Si. We call this normally-off JFET a depleted base transistor (D. B. T.) from an operating point of view. Since the base and emitter double diffusion is unnecessary in the D. B. T. process, compared with an npn bipolar process, it is possible to have a sufficiently heavy base impurity concentration to make a small base resistance. Actually, the base surface concentration was about 10^{20} cm^{-3}. It is also possible to have a high frequency operation, because the electrons injected from the emitter drift in the depleted base differing from a diffusion in a normal npn bipolar transistor.

Electrical Properties

Current-voltage characteristics of D. B. T. operated in the positive base current mode are shown in Figs. 2(a) and (b). Sample (N-4) in Fig. 2(a) has a rather shallow base diffusion depth so that the depletion layers due to the built-in potential just touch each other, while the base of sample (N-5) in Fig. 2(b) is deeply diffused. Sample (N-4) shows an extremely large h_{FE} of 1500 at $I_C = 5$ mA, $V_{CE} = 5$ V, and sample (N-5) shows h_{FE} of 460 under the same condition. D. B. T. with a shallower base diffusion, namely a narrower depleted base width, brings about a larger current amplification factor. Upside-down operation of these devices shows current amplification factor of 50 and 5 at $I_C = 500\,\mu$A and $V_{CE} = 0.2$ V for the respective samples in

Figs. 2(a) and (b). Therefore, it is possible to use D. B. T. in I^2L circuits. Practically, it is confirmed that an equivalent I^2L gate, composed of a pnp transistor and D. B. T., performs an inverter operation with a sufficient noise margin. An oscillation waveform of a five-gate ring oscillator using these equivalent I^2L gates is shown in Fig. 3. Figure 4 shows a dependence of a current amplification factor upon temperature. From -200°C to -50°C, positive temperature dependence is revealed similar to a bipolar transistor. However, at higher temperature than -50°C, it shows negative temperature dependence. This means that D. B. T. is stable in high temperature operation. Such negative temperature dependence comes from the fact that the injected electrons drift in the depleted base region. Moreover, D. B. T. still keeps a current amplification factor of 100 at low temperature of -200°C, while a usual bipolar transistor loses a current amplifying function. Then, D. B. T. is also useful as a current amplifying device at very low temperature.

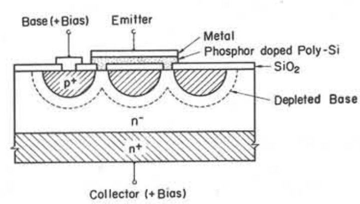
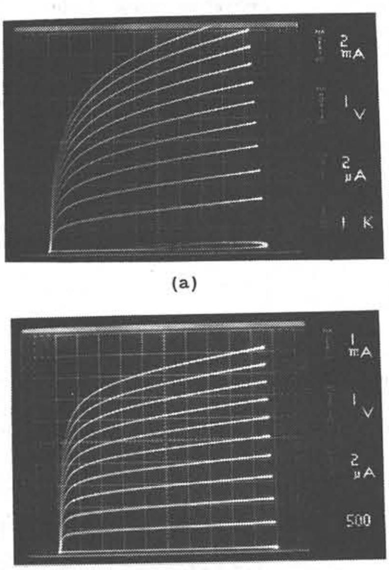


Fig. 1 Cross section of a depleted base transistor (D. B. T.)



(a)

(b)

Fig. 2 I-V characteristics of D. B. T. operated with positive base current, (a) Sample (N-4), (b) Sample (N-5)

References

(1) J. Nishizawa and B. M. Wilamowski, Proc. of 8th Conf. Solid State Devices, suppl. of JJAP, 16, pp. 151-154 (1977)

(2) O. Ozawa H. Iwasaki and K. Muramoto, IEEE J. of Solid-State Circuits, SC-11, pp. 511-518 (1976)

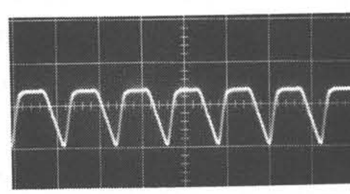


Fig. 3 Oscillation waveform of a five-gate ring oscillator using equivalent I^2L gates.

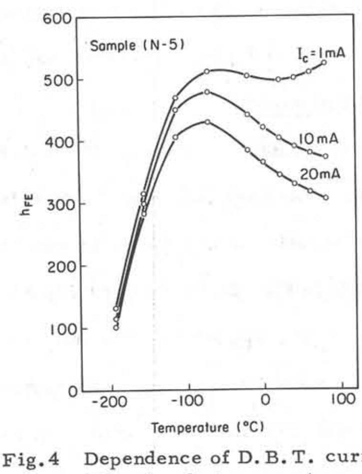


Fig. 4 Dependence of D. B. T. current amplification factor upon temperature.