A New High-Power Voltage-Controlled Differential Negative Resistance Device—The Lambda Bipolar Power Transistor

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Abstract—**A new high power voltage-controlled differential negative resistance device using the LAMBDA bipolar transistor structure, called the LAMBDA bipolar power transistor, is proposed and studied. The basic structure of this new device consists of the simultaneous integration of an interdigitated bipolar junction transistor and a merged metal–oxide–semiconductor field effect transistor. Two basic interconnection configurations of the integrated devices are also discussed. Several interesting applications based on the fabricated devices are also demonstrated. It is shown that the proposed device can be used as power signal generator and amplitude modulator using very simple circuits.**

A NEW voltage-controlled differential negative resistance device using the simultaneous integration of a bipolar junction transistor and a merged metal–semiconductor field effect transistor has been proposed and studied by Wu *et al.* [1]. Several important applications of this new device in photo-sensitive detector [2], high-density static RAM [3] had been demonstrated. The *I–V* characteristics and important device parameters of this new device had also been analyzed in details [1].

In this letter, a new high-power voltage-controlled differential negative resistance device, called the LAMBDA bipolar power transistor, is presented. The basic configuration of this new device is similar to that of the LAMBDA bipolar transistor proposed previously except that the structure of integration is different. In order to handle higher power, the npn bipolar junction transistor with interdigitated structure is used, which is the same as that of the conventional bipolar junction power transistor. However, the n-channel MOSFET, which is used to take out the base current of the bipolar transistor, is fabricated around the bipolar transistor in a separate p-well in order to have higher aspect ratio (W/L; W is channel width, L is channel length). The basic schematic structure of the LAMBDA bipolar power transistor is shown in Fig. 1. There are two basic configurations for interconnection as shown in Fig. 2. One is that the p-well of the n-channel MOSFET is connected to the base region of the bipolar junction transistor as shown in Fig. 2(a); the other is that the p-well of the n-channel MOSFET is connected to the emitter electrode of the bipolar junction transistor as shown in Fig. 2(b). In the first connecting configuration, the substrate of the n-channel MOSFET is reversely biased with emitter-base voltage of the bipolar junction transistor, so the peak voltage in the *I–V* characteristic is always located in the low-voltage range due to the substrate bias effect. However, in the second connecting configuration, there is no substrate bias for the n-channel MOSFET, so the differential negative resistance characteristic can be extended to a higher voltage, depending on the doping concentration in the p-well.

In order to fabricate the LAMBDA bipolar transistor as described, three testing patterns were designed and the metallization pattern of the fabrication mask is shown in Fig. 3, in which the smallest pattern is designed with the p-well of the n-MOSFET connected to the base electrode; the other two

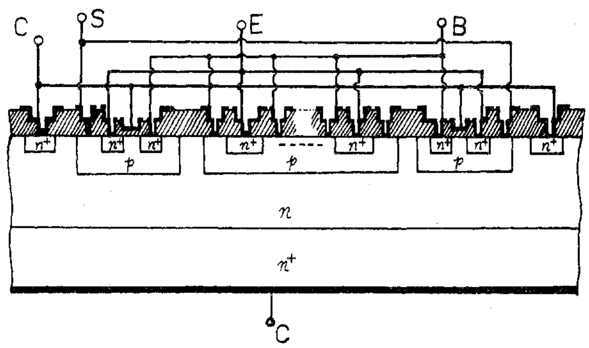

Fig. 1. The schematic structure of the LAMBDA bipolar power transistor.

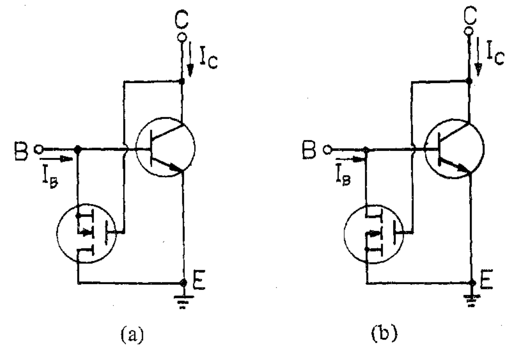

Fig. 2. (a) The *p-well* of the n-channel MOSFET is connected to the base electrode of the bipolar junction transistor. (b) The *p-well* of the n-channel MOSFET is connected to the emitter electrode of the bipolar junction transistor.

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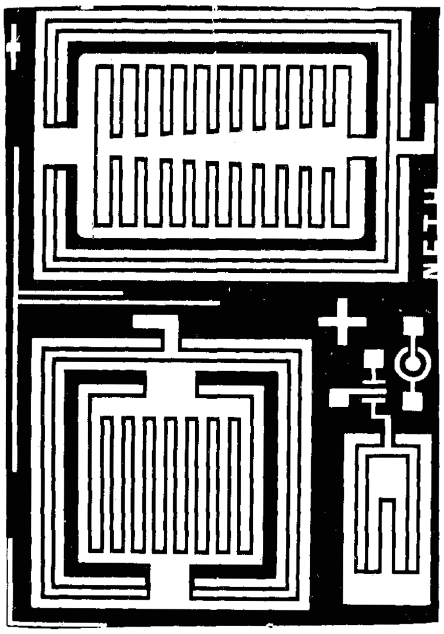
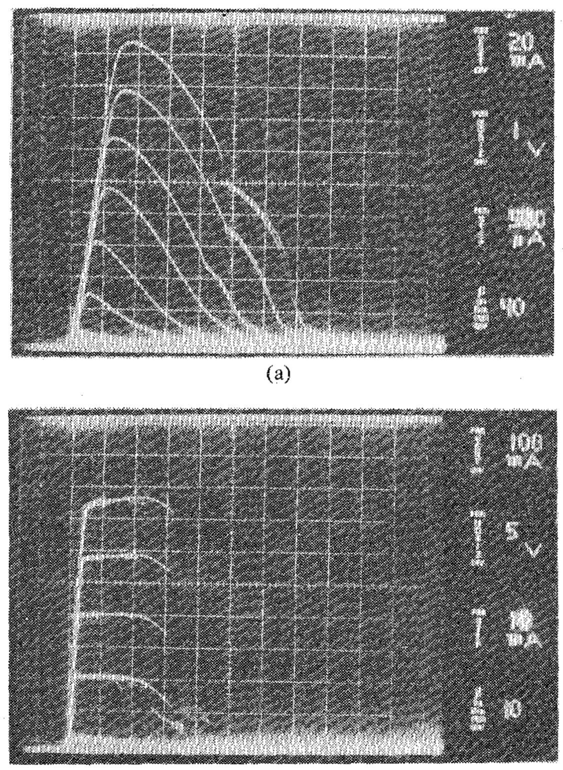


Fig. 3. Metallization pattern of the fabrication mask, in which the dimensions of each pattern are shown in Table I.

TABLE I

Pattern No.	1	2	3
Channel Length (μm)	15	15	15
Channel Width (μm)	6000	4500	1520
Base area (cm^2)	1.5×10^{-2}	1×10^{-2}	4.5×10^{-3}
Emitter area (cm^2)	9.5×10^{-2}	3.78×10^{-3}	1.32×10^{-3}
Emitter periphery (μm)	15400	13200	1540
Base corner radius (μm)	50	50	50
Emitter finger Width (μm)	70	60	85
Emitter finger Length (μm)	350	700	380
No. of fingers	22	8	2

patterns are designed with the p-well of the n-MOSFET connected to the emitter electrode. The fabrication sequences are similar to those of the LAMBDA bipolar transistor described in [1], but the junction depth is slightly deeper (4-7 μm) for power device fabrication. Typical I-V characteristics of the fabricated LAMBDA bipolar power transistors are shown in Fig. 4, in which Fig. 4(a) was measured from the smallest pattern. It is clearly seen from Fig. 4(a) that the substrate bias effect seriously moves the peak voltage to the lower voltage range due to connecting configuration as described before. In the case of Fig. 4(b), the differential negative resistance is located in higher voltage range due to no substrate bias effect and the maximum operating current is also higher due to a larger pattern. The basic circuit connection of a sinusoidal oscillator is shown in Fig. 5(a), where R_B is a biasing resistor and an LC tank circuit is used to adjust the oscillation frequency of the sinusoidal signal. For the present case, $V_{cc} = 25$ V, $R_B = 5$ kΩ, $I_B = 5$ mA, $\beta = 72$, $I_c = 360$ mA, the peak to peak sinusoidal signal is 50 V (2 times of V_{cc}) as shown in Fig. 5(b), in which ten times attenuator was used between the output of the circuit and oscilloscope. The output oscillation frequency is about 3.4 MHz determined by the tank circuit. Using simple calculation, the output power of this sinusoidal signal is about 6.3 W. If an audio signal is coupled to the base terminal of the LAMBDA bipolar power transistor as shown in Fig. 5(a), then the action of amplitude modulation can be obtained. Fig. 5(c) shows the amplitude-modulated signal with the carrier frequency of 3.4 MHz and the audio signal frequency of 10 kHz. Note that the peak magnitude of input audio signal is 56 mV. It is verified that the LAMBDA bipolar transistor not only acts as a carrier signal generator, but also acts as a modulator and a amplifier for the audio signal. It is quite apparent that a slight distorsion of the modulated signal can be observed from Fig. 5(c) due to voltage signal input. If the signal is coupled from the emitter or the current signal is applied to the base, the distortion problem can be eliminated. Other interesting applications of the LAMBDA bipolar power transistor are in pulse generation and relaxation oscillation, which will be described elsewhere.

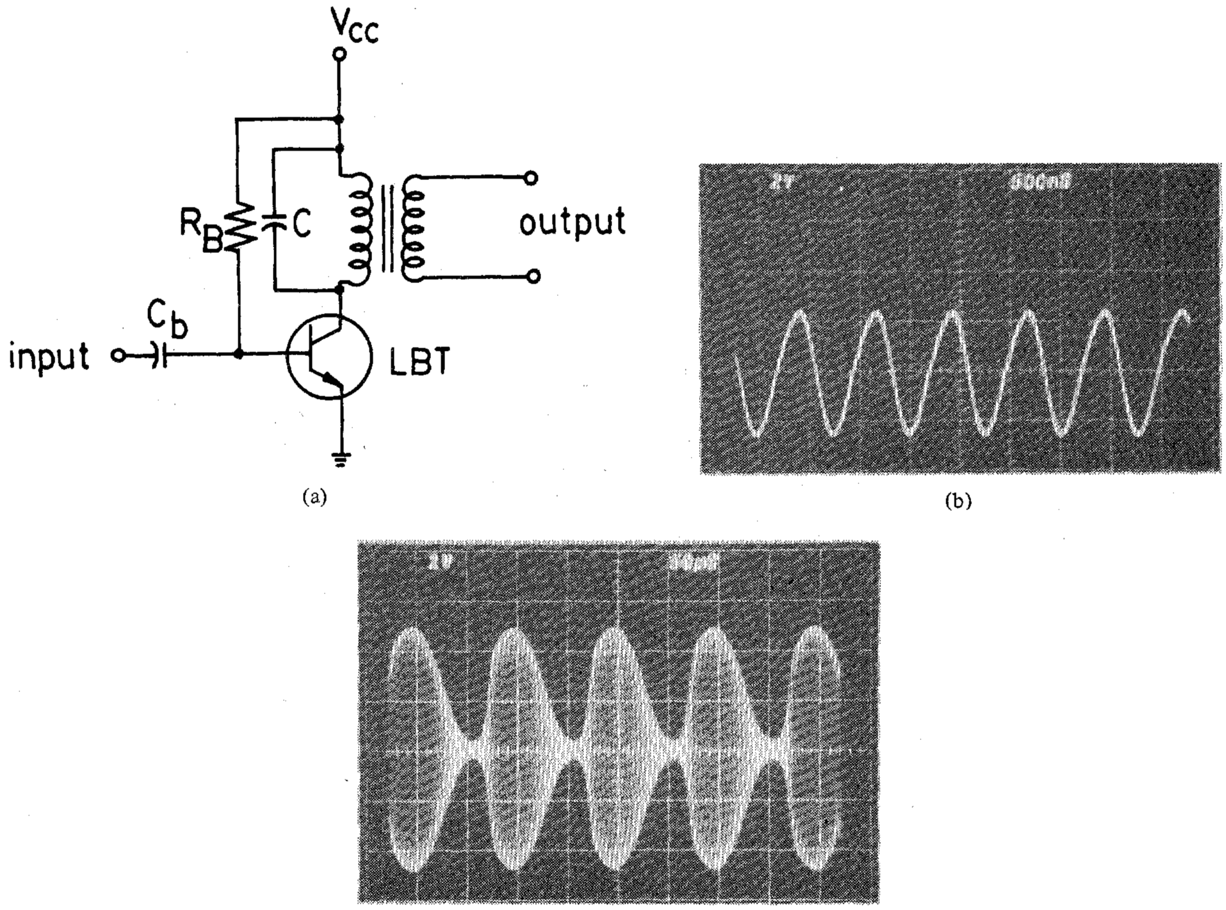


(a)

(b)

Fig. 4. The I-V characteristic of the fabricated LAMBDA bipolar power devices, (a) measured from the smallest pattern (pattern no. 1, device LBT-511); (b) measured from the largest pattern (pattern no. 3, device LBT-411).

In conclusion, a new high-power differential negative resistance device—the LAMBDA bipolar power transistor has been proposed and fabricated. Several interesting applications in signal generation and modulation have been demonstrated. The main feature of the proposed device is that higher power handling capability can be easily obtained by existing tech-



(c)

Fig. 5. (a) Basic circuit connection for the LAMBDA bipolar power transistor to be used as a sinusoidal oscillator (without input signal at the base) or an amplitude modulator (with input signal at the base); (b) output waveform of a sinusoidal oscillator using LBT-621; (c) output waveform of an amplitude modulator using LBT-411. Both devices were fabricated using pattern no. 3, but the junction depths were slightly different.

nology, which enables the LAMBDA bipolar transistor (LPT) to be used as power signal generator using very simple circuits.

References

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