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A Double-Barrier-Emitter Triangular Barrier Optoelectronic Switch

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1. Introduction

Devices with N- or S-shaped negative differential resistances (NDR) have potential applications to such areas as high-frequency oscillators, analog-to-digital converters, and microwave circuits. Among the device structures, the double-barrier is one of the most promising candidates for producing the N-shaped NDR [1,2], whereas the triangular-barrier with planar-doped or δ-doped sheets is very suitable for generating the S-shaped one [3,4]. In this work, a triangular-barrier and a double-barrier structure are integrated to form a switch. Owing to the resonant tunneling through the double barrier and avalanche multiplication in the reverse-biased junction, N-shaped and S-shaped negative-differential-resistance (NDR) phenomena occur in the current-voltage (I-V) characteristics under normal and reverse operation modes, respectively. The device characteristics also show variations from dark to illumination conditions. Because the I-V characteristic is associated with incident light, the device can be used as an optical-controlled switch.

3. Results and Discussion

A schematic sketch of the device is shown in figure1. The InGaAs $\delta(p^+)$ quantum well induces a triangular barrier for electron transport and forms a potential well for hole accumulation. A subband is formed in the double-barrier structure. If the positive V_{CE} voltage is large enough to cause the Fermi level of the n^+-GaAs cap layer to be in alignment with the subband in the double barrier, a peak current will be induced by the resonant tunneling effect. An N-shaped NDR phenomenon will be observed in the I-V characteristics. Under reverse operation mode, if a negative V_{CE} voltage is large enough, avalanche multiplication will occur in the reverse-biased E-B junction. The multiplied holes will be accumulated in the InGaAs well or charge the B-C junction to lower the barrier of base, and then the electrons emitted over the barrier from collector to emitter will be increased. This positive feedback process will result in an S-shaped NDR performance in the I-V characteristic.

Figures 2(a) and (b), respectively, show the N-shaped and S-shaped NDR characteristics of the studied device at 300K with superimposed load lines for both the dark (dotted line) and illumination (solid line) conditions. Compared with the dark N-shaped NDR characteristics, the illuminated N-shaped NDR characteristics present a higher peak current I_P, lower valley current I_V, lower peak-current voltage V_p, and lower valley-current voltage V_V, as shown in figure 2(a). The I_V decrement is quite small, nearly unchanged, from dark to illumination conditions. In the studied device, the holes photogenerated by incident light will be accumulated in the InGaAs well to cause a lowering of the triangular barrier, which implies that less voltage is necessary to switch the device. This is meant that a lower V_P and V_V are obtained under illumination. Moreover, the lowered barrier will also produce a higher I_P and I_V. However, the I_V is nearly unchanged from dark to illumination conditions. This is attributed to the lateral current confinement associated with the cap-layer conductivity. As the mesa of the studied device is larger than the metal contact, the lateral current confinement is incomplete. The electrostatic potential in the cap layer is not constant along the cap-layer plane because of the finite conductivity of the layer. Therefore, the potential difference across the device at different points along the cap-layer plane is not the same, and neither is the resonant tunneling effect at each point. Under illumination, the conductivity of the cap layer is increased, i.e., the potential difference at different points on the cap-layer plane is decreased. A larger amount of electrons injected from the cap layer can tunnel through the double barrier with the peak or valley range in the transmission resonance spectra to produce a higher I_P or a lower I_V, respectively. The I_P can be increased by the increasing of the cap-layer conductivity as well as by the lowering of the triangular barrier under illumination. However, the I_V decrement caused by the increasing conductivity neutralizes the I_V increment by the lowing barrier. Thus the I_V is nearly unchanged. From the phenomena mentioned above, it is obtained that the increment of the cap-layer conductivity by input light could raise the peak-to-valley current ratio (PVCR) of the device.

Compared with the dark S-shaped NDR characteristics, the illuminated S-shaped NDR characteristics present a lower switching voltage V_S, lower holding voltage V_H, lower holding current I_H, and a higher switching current I_S, as shown in figure 2(b). Under illumination, because the photogenerated holes accumulated in the InGaAs well lower the barrier of base, a smaller external bias is sufficient to inject electrons over the barrier, and then cause the avalanche multiplication in the E-B junction and initiate the NDR phenomenon. Thus the V_S under illumination is smaller than that under dark. Also because the accumulated holes lower the barrier, the I_S is larger under illumination. The smaller V_H and I_H under illumination are due to the internal gain increased by the accumulated photogenerated holes [5-7].

As the switching characteristics are changeable by the input-light, we could expect the optical switching. In either figure 2(a) or (b), the load line intersects the I-V curves at two different stable points, i.e., A at dark characteristics and B at illuminated characteristics. In the dark, the load line intersects the characteristics at A only. In the illumination case, it is seen that the stable point is at B. The device will make a transition from A to B promptly when light falls on the device. As the light intensity drops, the characteristics will revert to the dark situation and the device will switch back to A. Therefore, the device can be switched with an optical input.

4. Conclusions

A switch, in which a triangular-barrier and a double-barrier structure were integrated, has been fabricated and demonstrated. N-shaped and S-shaped NDR characteristics were obtained due to the resonant tunneling through the double-barrier structure and the avalanche multiplication in the reverse-biased junction, respectively. The increment of the cap-layer conductivity by input light could raise the PVCR of the N-shaped NDR of the device. The I-V characteristics of the device were optically controllable.

Acknowledgements

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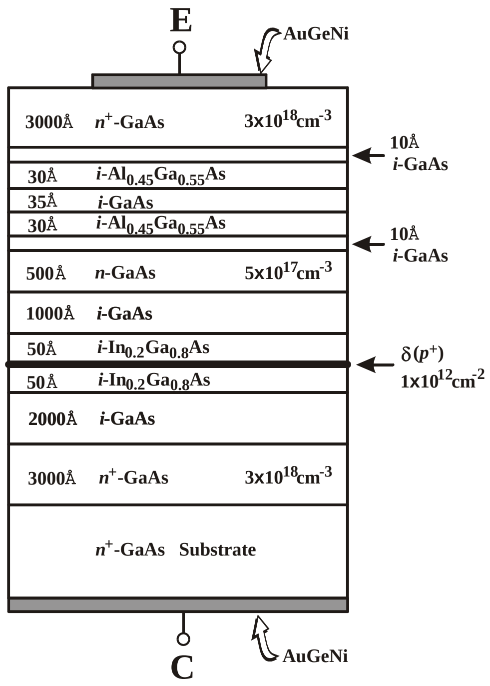

Fig. 1 Schematic sketch of the studied device.

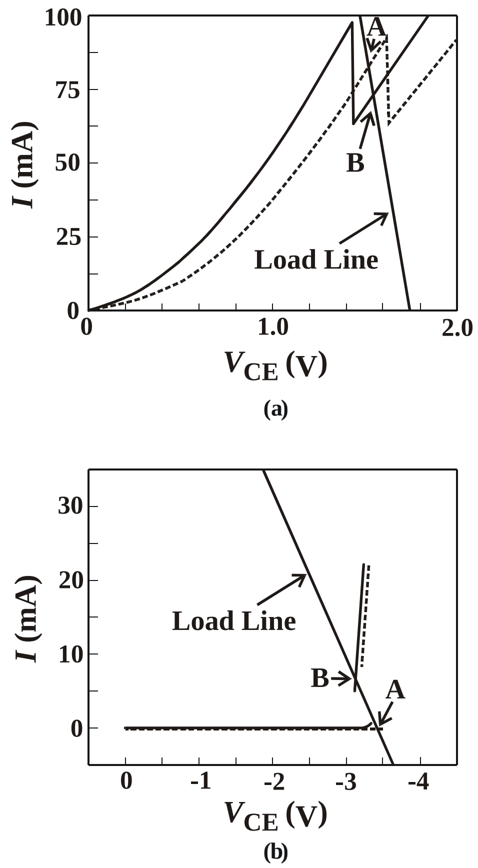

Fig. 2 (a) N-shaped and (b) S-shaped NDR characteristics of the studied device at 300K with superimposed load lines for both the dark (dotted line) and illumination (solid line) conditions.