A-3-2 V-Bipolar Device Utilizing Built-in Stress Gradient

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New bipolar devices utilizing built-in stress gradient under V-grooves are proposed. V-grooves are formed in the interdigital or stripe type transistors so that the band gap in the base becomes narrower than that in the emitter when compression is applied by bonding the pellets onto Cu headers because of thermal expansion difference. This band gap gradient greatly enhances the downward and/or upward common emitter current gain.

First, we calculate the band gap change under V-grooves. For the strain under V-grooves, the plane strain condition[1] can be used:

$$e_{zz}=0,\ e_{yz}=0,\ e_{zx}=0,\ e_{xy}=0. \qquad \text{(1)}$$

Therefore, Hooke's law for cubic crystals tend to

$$\begin{aligned} e_{xx} &= S_{11}X_x + S_{12}Y_y - S_{12}^2(X_x + Y_y)/S_{11} \\ e_{yy} &= S_{12}X_x + S_{11}Y_y - S_{12}^2(X_x + Y_y)/S_{11} \end{aligned} \qquad \text{(2)}$$

where $e_{\alpha\beta}$ are the strain components, S_{ij} are the elastic compliance constants, and X_α, Y_β, are the stress components. Also, the stress components under the V-groove[2] are given by

$$\begin{aligned} X_x(x) &= P[B/(2x + R)]^{1/2}[1 - R/(2x + R)] \\ Y_y(x) &= P\{[B/(2x + R)]^{1/2}[1 + R/(2x + R)] + R/(2x + R)\} \end{aligned} \qquad \text{(3)}$$

where x is the distance from the bottom of the V-groove, X_x is the stress component in the depth direction, Y_y is the stress component in the width direction of the V-groove, P is the nominal stress, B is the depth of the groove, and R is a radius of the curvature for the bottom of the groove. The band gap change $\Delta E_g(x)$[3] can be calculated by the deformation potential theory and using eqs.(2) and (3). The results are shown in Fig.1. Variables used for calculation are: R = 0.05 μm, the widths A of the grooves are 3, 5, and 10 μm, ($A = B\sqrt{2}$), $P = 2 \times 10^9\,\mathrm{dyn/cm^2}$, this value corresponds to the nominal stress on Si surface when Si chips are bounded onto Cu headers for power IC by Au-Si alloy.

Common emitter current gain β(P) under stress is expressed by

$$\beta(P) = \beta(0)\exp[\ \Delta E_g(e - b)/kT\ ] \qquad \text{(4)}$$

where $\Delta E_g(e - b)$ is the band gap difference between emitter and base with stress, and k is Boltzmann's constant. This equation is applicable to both upward and downward characteristics. If $\Delta E_g(e - b)$ is positive β increases with stress. The V-grooves are formed in the [110] crystal direction in the (100) wafer. Therefore, interdigital or stripe type transistors along the [110] direction are suitable for this V-bipolar device. First, we consider about downward transistors, V-grooves are formed in the emitter region so as to locate the bottom of the grooves at the top of the base region (see Fig.2). While the band gap of the base region under the grooves decreases, that of the emitter region does not. The band gap difference between the emitter and the base $\Delta E_g(e - b)$ is 6.94 kT for A = 3 μm groove. Thus, we can enhance the downward common emitter current gain by three orders of magnitude.

Recently, upward transistors become very popular. In this case, a normal emitter and a collector are inversely used as a collector and an emitter, respectively. Large values of β_u are desirable for various purposes. It is easily deduced that β_u can be enhanced by using V-bipolar technique similar to β_d. Also, new types of integrated circuits can be made by combining V-downward and V-upward transistors. In addition, a sensitive pressure sensor can be made by fabricating a V-bipolar device on an edge-supported thin Si diaphragm.

These V-bipolar devices are so unique that great improvement can be achieved in characteristics by unifying electronics and mechanics. The devices can be batch fabricated using current IC technology.

On the analogy of stress distribution, a preliminary experiment was done in a piezo-transistors.[4] Stress was applied by means of a sapphire stylus. It was obtained that $\beta_u(P) = 1000\ \beta_u(0)$. This result proves the proposal of the V-Bipolar Device.

References

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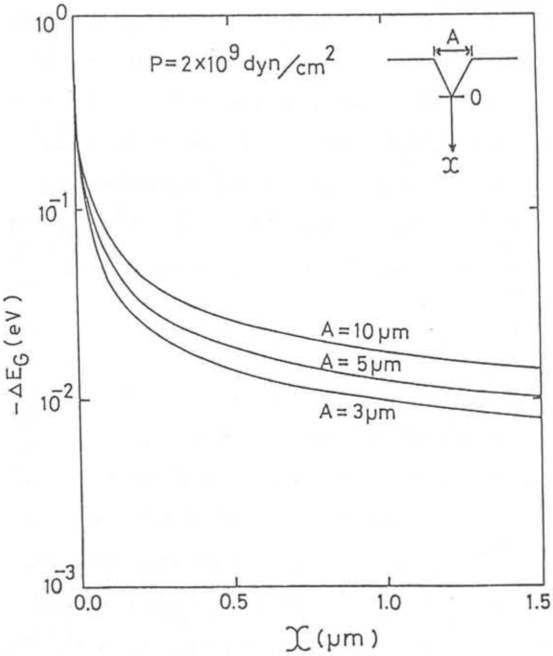

Fig.1. Band gap change under V-groove.

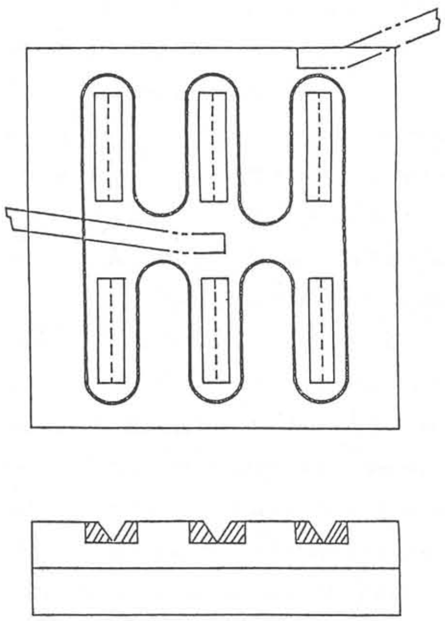

Fig.2. Schematic diagram of V-bipolar device.