6-5

Ultra-High Voltage Semiconductor Devices

Takeshi Matsushita and Hisao Hayashi
SONY CORPORATION Atsugi Plant
Atsugi, Kanagawa

1. Introduction

Mesa pn-junctions can withstand a high reverse bias voltage, but often exhibit surface leakage and long-term instability for many applications. Planar junctions were thought difficult to achieve high breakdown voltages because of the uncontrolled surface charge and the finite radius of junction curvature. Concentric ring junction structures, however, have been devised to prevent the surface breakdown of planar junctions, but not the bulk breakdown. We have succeeded in preventing not only the surface breakdown but also bulk breakdown of the main junction by introducing a new structure of the field limiting rings. Employing this concept, we have fabricated ultra-high voltage silicon transistors of about 8kV by using the relatively low resistivity (60-70 Ω-cm) N type Si substrate.

2. Theory

In the concentric ring junction structure (Fig.1), the potential difference between the ring is given approximately by the expression,

$$(V_{n-1})-(V_n)=\frac{qN}{4\varepsilon}\left[\frac{W-2X_j}{W-X_j}(X_j+d)^2+(W-2X_j)X_j\right]\cdot\ln\frac{X_j}{W-X_j}\quad , \qquad (1)$$

where (V_{n-1}) is the potential of the ring (n-1), (V_n) is the potential of the ring (n), N is the donor density of the N region, ε is the permittivity of the semiconductor, W is the distance between the rings in the mask pattern, X_j is the junction depth and d is the distance from the ring junction (n-1) to the end of its space charge region modified by that of the ring (n).

When (V_{n-1}) increases, d also increases and hence $(V_{n-1})-(V_n)$ increases according to Eq. (1). Because the ring (n-1) and the ring (n) are fixed in the space, the increase of $(V_{n-1})-(V_n)$ results in the increase of the electric field between the rings and then breakdown takes place between the ring junctions. If d could be suppressed in the space by arranging some field limiting rings, the electric field would not exceed a critical value and eventually breakdown can be avoided.

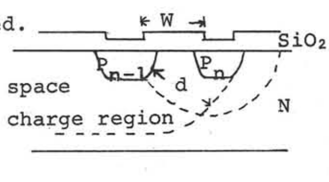

Fig. 1 A structure of concentric ring junctions.

3. A structure of the ultra-high voltage transistor

A structure of the ultra-high voltage transistor is shown in Fig.2. As the reverse bias voltage of the collector increases, the space charge region from the base P_o spreads into the N region and first reaches to the ring P_1 and next to the ring P_2. At the same time the space charge region extends downward and reaches to the ring $P_{1'}$, and then to the ring $P_{2'}$. Therefore N region becomes narrower by the spreading of the space charge regions from the top and bottom ring junctions. Then d is suppressed by the bottom ring junctions. Finally breakdown occurs at the most exterior ring junction. V_{CBO} of the transistor is given,

$$V_{CBO} = (m+1) \times V_p \quad , \tag{2}$$

where m is the total number of the rings of the top surface and V_p is the potential difference between the ring (n-1) and ring (n).

Therefore, V_{CBO} of the transistor can be made infinite in principle.

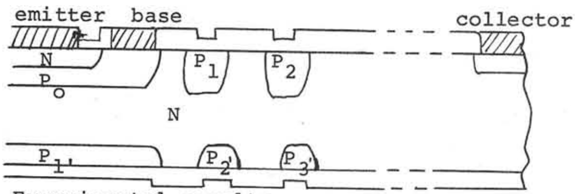

Fig. 2 A structure of an ultra-high voltage transistor

4. Experimental results

The potentials of each ring are examined and the experimental results are shown in Fig.3 including the theoretical curves. Fig.3(a) is the case of the conventional concentric ring junctions without the extention of the space charge from the bottom rings. Fig.3(b) is the case of this investigation. The potentials, as shown in Fig.3(b), increase with the base potential V_o and the potential differences become constant when V_o becomes higher than about 1.2kV. Therefore breakdown does not occur between the rings.

Characteristics of an ultra-high voltage transistor are shown in Figs.4 and 5, where the pellet size, pellet thickness, base width, emitter depth, resistivity of collector N region, and total number of top field limiting rings are 5.5 X 5.5mm², 200μ, 25μ, 10μ, 60-70Ω-cm and 15, respectively. The other characteristics are as follows; V_{CEO} = 7.5kV and f_t = 3 MHz.

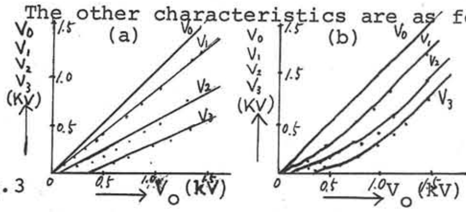

Fig.3

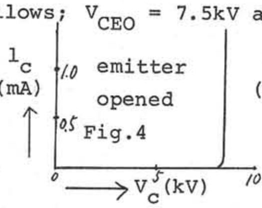

Fig.4

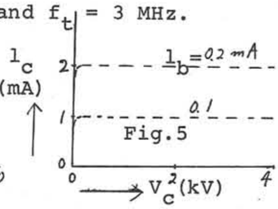

Fig.5