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SCHOTTKY DIODES WITH HIGH BREAKDOWN VOLTAGES

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Abstract—The methods of increasing the breakdown voltages in silicon Schottky diodes is presented. In addition to a guarding ring, screen-diffusion regions were introduced. In this manner, the electrical field near the Schottky contact was lowered and, as a result, higher breakdown voltages were obtained. By using this method, the breakdown voltage can be increased by a factor of 3–5. However, a large device area is required for the same Schottky contact area and, therefore, the junction parasitic capacitance is greater.

1. INTRODUCTION

The concept of Static Induction Transistor[1] has already been applied to improve the breakdown characteristics of some semiconductor devices. The bipolar Gate Associated Transistor with a very thin base and high breakdown voltage was presented by Kondo and Yukimoto.[2] A similar concept for a different device structure was used by Baliga in his MAJIC–FET[3] and in FCT controlled by the MOS transistor[4]. In this paper, it is shown that the SIT structure can be used to increase the breakdown voltage of a Schottky diode. Figure 1(a) shows an ordinary Schottky diode with field concentration at the peripheries. Standard technique for the fabrication of higher voltage Schottky diodes is to use a guard-ring technique[5]. This method eliminates edge effects Fig. 1(b). Further improvements can be obtained using the structure presented in Fig. 1(c). This structure not only eliminates the edge effect, but also reduces the electrical field near the Schottky contact. In case of the large reverse biasing the thickness of depletion layer is much larger than the spacing between p-type regions. Fig. 1(c). Therefore due to electrostatic interactions in the depletion region, the electrical field near the surface Schottky contacts is reduced and it results in higher breakdown voltage. For the forward biasing the depletion layer is thinner Fig. 1(c), and the additional p-type regions have no effect on the conduction mechanism in Schottky contacts.

2. THEORY

The theoretical relationship for reverse characteristics of Schottky diodes, resulting from the potential barrier lowering by image force was given by Sze[6] and the additional static lowering was described by Andrews and Lepselter.[7] In practice, even if edge effects are eliminated, the breakdown occurs for much smaller voltages than those obtained from theoretical calculations using the one-sided abrupt junction model. This is probably because of a larger electrical field near the Schottky contact caused by the electrical charge of the surface states. The electrical field near the surface determines the breakdown voltage. To obtain a large breakdown voltage, an increase in the reverse voltage on the device must have a little effect on the increase of the electrical field near the surface. One method is to lower the impurity concentration, but this will cause much higher series resistance for forward biasing. The other method, which is applied here, is to use an extra p-regions as a screen to lower the electrical field near the surface during reverse biasing. An equivalent circuit of this device, which is shown in Fig. 2, consists of the Static Induction Transistor and Schottky diode. The gate-to-source voltage of the SIT is equal to the voltage drop on the reverse-biased Schottky diode. If the voltage amplification factor of the SIT is equal to m, then the drain current

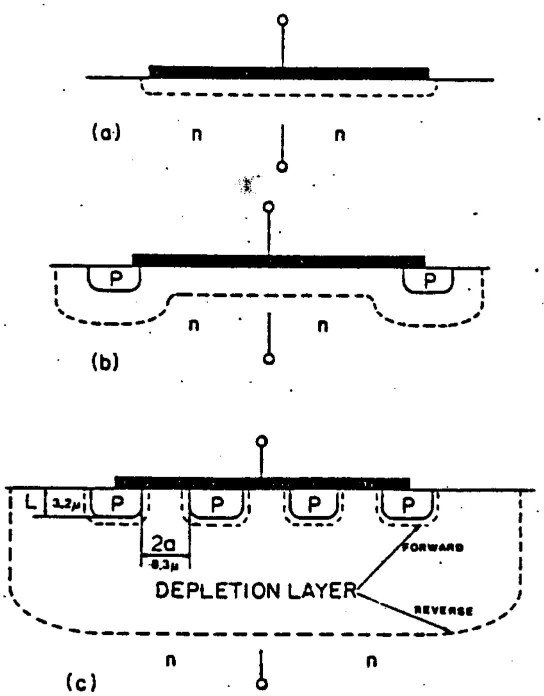

Fig. 1. Cross section of Schottky diodes: (a) Schottky contact only; (b) with guard ring; (c) improved structures.

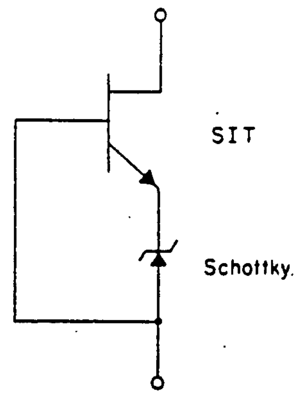

Fig. 2. Equivalent circuit of improved structure of Schottky diode.

will start to flow for voltages which exceed the value:

$$V_{BV} = (m + 1)V_{BVS} \quad (1)$$

where V_{BVS}—breakdown voltage of Schottky junction itself.

The amplification factor m depends on the geometry of the device and can be calculated using empirical relationships given by Ozawa[8]

$$m = 2.5 \exp\left(\frac{\pi L}{4a}\right) - 1, \quad (2)$$

where L and a are structure dimensions shown in Fig. 1(c).

3. EXPERIMENTS

Three structures shown in Fig. 1 with Si–Al Schottky contact were fabricated. The starting material was 20 Ωcm., n-type ⟨111⟩ silicon. The p-type regions were diffused with a sheet resistance of approx. 100 ohms/□ and a junction depth of 3.2 μm. The aluminum layers were evaporated in an electron-beam system and annealed at 420°C in forming gas (15% H_2) for 30 min. The top view of the microstructures is shown in Fig. 3. The typical reverse current voltage characteristics are shown in Fig. 4. The structures shown in Fig. 1(a) have breakdown voltages ranging from 14 to 22 V. The structures with guarded ring Fig. 1(b) have breakdown voltages up to 43 V and the improved structures Fig. 1(c) have breakdown voltages up to 135 V. From theoretical calculations, (eqn 2) the amplification factor for the fabricated structure is equal to 3.6 and the breakdown voltage should reach 190 V or higher. This value was not obtained in the experiment because the effect of avalanche breakdown occurred earlier in p-n junction.

In the case of forward biasing, the p-regions are inactive since forward voltage drop on the Schottky junction is smaller than forward voltage drop on the p-n junction. The high breakdown voltage devices have relatively large series resistances for forward biasing (Fig. 5). It is assumed that the values of series resistances can be significantly reduced if the active structure is fabricated using an n^- epi-layer on n^+ substrate.

4. CONCLUSIONS

The method of increasing the breakdown voltage of the Schottky diode by factor of 3–5 has been demonstrated. Further increase of breakdown voltage is possible with careful design of device geometry. However, this may lead to large series resistance. Also, a three times larger device area is required in order to have the same area of Schottky contact. This, of course, also enlarges the junction parasitic capacitance.

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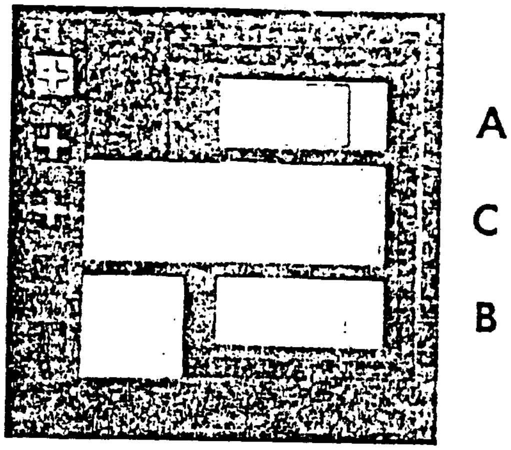

Fig. 3. Fabricated microstructures.

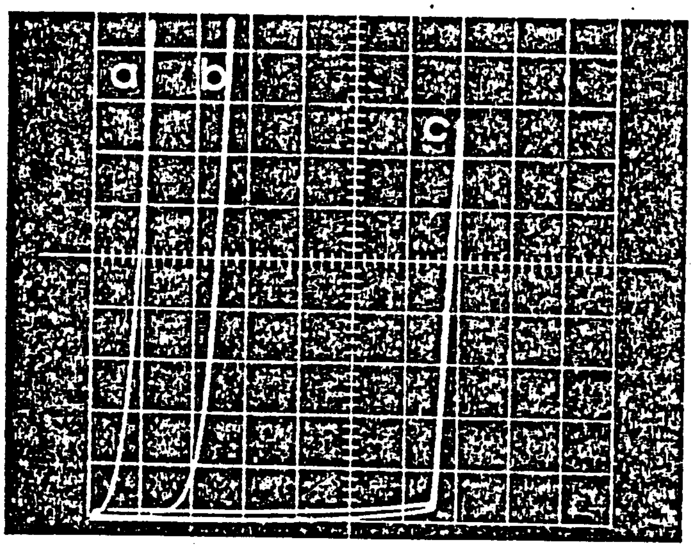

Fig. 4. Reverse characteristics of fabricated Schottky diodes, (a) Schottky contact only; (b) with guard ring; (c) improved structure. (hor. 20V/div., vert. 0.1 mA/div.)

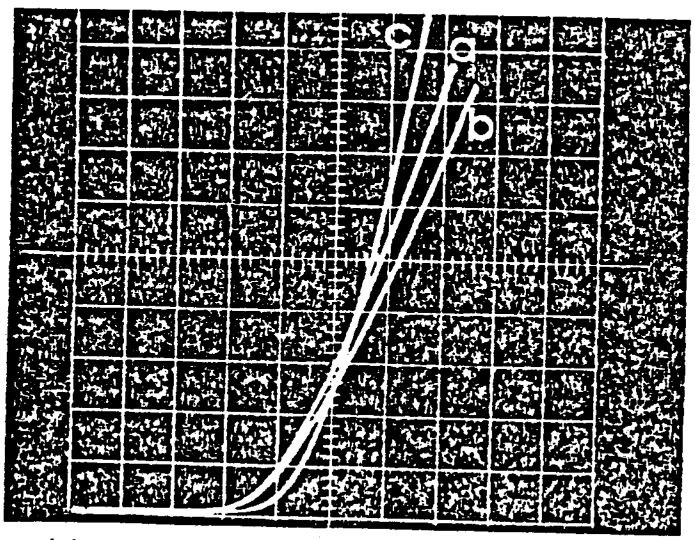

Fig. 5. Forward characteristics of fabricated Schottky diodes, (a) Schottky contact only; (b) with guard ring; (c) improved structure. (hor. 0.2 V./div., vert. 0.1 mA/div.)