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Fabrication of high breakdown voltage silicon Schottky barrier diodes using various edge termination structures

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ABSTRACT

In this work, the design and fabrication of Au/n-Si Schottky barrier diodes (SBDs) with various edge termination schemes, including a reduced-surface-field-type lateral super-junction, a polycrystalline silicon (poly-Si) floating ring, and a p^+-poly-Si guard ring, are presented. Experimental results show that the reverse leakage current of the proposed SBDs was reduced and the breakdown voltage increased with an increase of the poly-Si width of the guard ring.

It was found that the device and fabrication technology developed in the present study is applicable to the realization of SBDs with a high breakdown voltage (≥160 V), a low reverse current density (≤5.6 μA/cm^2), a low forward voltage drop (≤5.6 V @ 1 A/cm^2), and an adjustable Schottky barrier height of 0.764 to 0.784 eV.

1. Introduction

The Schottky barrier diode (SBD) is formed by a metal is contact with a semiconductor. It is a majority carrier device with applications in the high frequency area. However, it is difficult to apply SBDs to high power devices due to their low breakdown voltage, which is caused by the edge effect [1–5]. SBDs differ from *p–n* injection devices in that rectification occurs as a result of the potential barrier between the metal and semiconductor, rather than a doping profile. SBDs are majority-carrier devices which offer the advantage of faster reverse recovery without the minority-carrier stored charge that is observed in *p–n* rectifiers and *p–i–n* rectifiers. SBDs with low a forward voltage drop (V_F), low reverse leakage current density (J_R), and high breakdown voltage (V_{BD}), are required in the electronics industry [2,4,5]. V_F and J_R of SBDs are key factors in determining the power loss of SBDs for power applications, which strongly depend on the Schottky barrier height (SBH). In general, a large SBH results in a low J_R but a large V_F, and vice versa [6,7]. Furthermore, V_{BD} strongly depends on the distribution of the surface electric field of the devices under reverse bias. How to suppress J_R to achieve SBDs with minimum power loss and how to improve the breakdown voltage of SBDs so that it approaches the theoretical value are still problems in device fabrication.

In this work, SBDs with sophisticated edge termination (ET) structures, including p^+-poly-Si guard ring and floating ring, field plate, and RESURF (REduced SURface Field)-type [8–11] lateral super-junction (LSJ), are proposed and fabricated. The various edge termination schemes employed in this work are aimed at reducing the surface electric field to obtain a breakdown voltage that approaches the ideal value. The influence of the geometric parameters of the ET structure, including the widths of the guard ring, floating ring, and field plate, as well as the space between the guard ring and the floating ring, on the electric properties of devices is investigated. To avoid possible damage to the semiconductor surface used for the metal/semiconductor Schottky contact, a fabrication process for the guard ring that employs boron ion implantation into a poly-Si overlayer and then thermal diffusion into the substrate is employed. The effects of the proposed fabrication process on J_R reduction as well as V_{BD} enhancement are also discussed. Technology related to the design and fabrication processes for silicon SBDs with a high breakdown voltage (V_{BD}≥160 V) and a low leakage current density (J_R≤5.6 μA/cm^2) is also presented.

2. Experimental procedure

To study effects of various ET designs on the breakdown characteristics of SBDs, three different types of SBD as shown in Fig. 1, were fabricated. Fig. 1(a) shows the type A device, which has a p^+-poly-Si guard ring and a field plate ET design. The type B device (Fig. 1(b)) is based on the structure of type A but it has an additional floating ring at the periphery of the device. Fig. 1(c) shows the structure of the type C device, in which a RESURF-type LSJ ET scheme is incorporated with the type B SBDs structure [10]. A portion of the top view of the type C device is shown in Fig. 1(d). The details of the RESURF-type LSJ structure are clearly defined. In the type C device (Fig. 1(d)), the length and width of the p^-region of the

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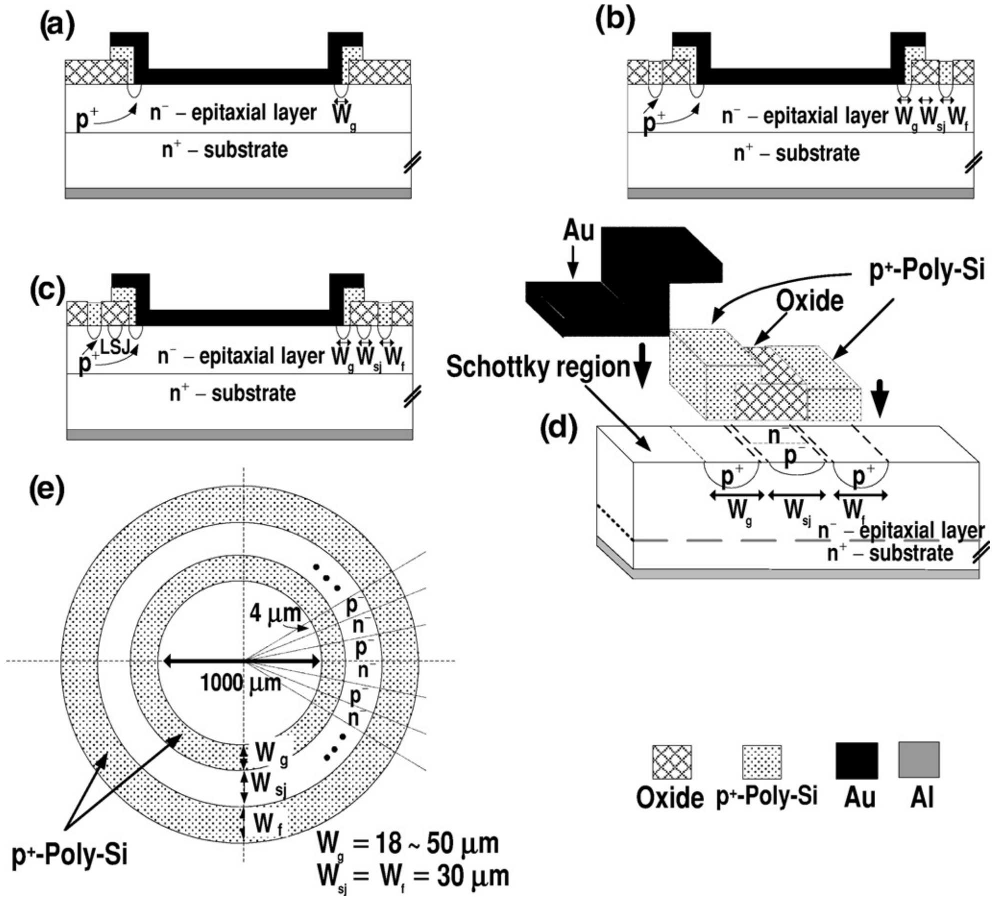

Fig. 1. Cross-section schematic diagram of the proposed SBDs: (a) using p$^+$-poly-Si guard ring structure (type A), (b) using both the p$^+$-poly-Si guard ring and p$^+$-floating ring structure (type B), (c) using a RESURF-type lateral super-junction, p$^+$-poly-Si guard ring, and p$^+$-floating ring structure (type C), (d) portion of top view of device (type C) with an emphasis on RESURF-type LSJ structure, and (e) top view of the type C SBD with applied the radial 3D RESURF-type LSJ termination, p$^+$-poly-Si guard ring, and p$^+$ floating rings.

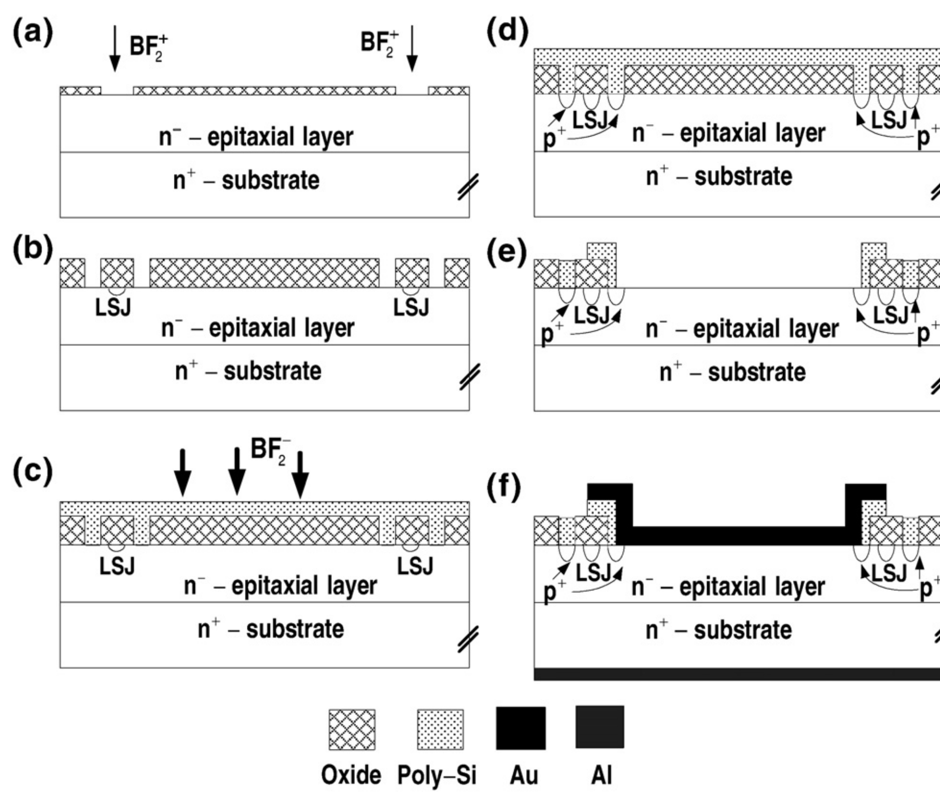

Fig. 2. The basic fabrication process for the proposed SBDs.