Materials Science Forum Vols. 389-393 (2002) pp. 1305-1308

A Novel Technology for the Formation of a Very Small Bevel Angle for Edge Termination

F. Yan[1], C. Qin[1], J.H. Zhao[1] and M. Weiner[2]

[1] SiCLAB, ECE Dept., Rutgers University, 94 Brett Road, Piscataway, NJ 08854, USA

[2] New Brunswick Technology Center, United Silicon Carbide, Inc., 100 Jersey Ave., New Brunswick, NJ 08901, USA

Keywords: Avalanche Breakdown, Edge Termination, Inductively Coupled Plasma, Positive Bevel

Abstract. A novel technology toward achieving a bevel edge termination with a very low bevel angle has been developed. 4H-SiC diodes terminated by the positive bevel fabricated with this technology are demonstrated. The reverse current-voltage (I-V) characteristics are reported.

Introduction

A proper edge termination is indispensable for high electric field devices. It is used to spread the edge crowding electric field and prevent early breakdown. For some semiconductors with high critical fields, such as SiC and GaN, a proper edge termination can also be used to reduce the edge surface electric field, relieve the stress on the passivation layer and increase the reliability of devices.

Positive bevel is one of the few edge termination technologies able to completely eliminate the edge electric field crowding effect and realize ideal bulk avalanche breakdown[1]. Moreover, positive bevel can drastically reduce the edge surface electric field. A positive bevel with a bevel angle of 1° can reduce the edge surface electric field to as low as 1% of the bulk field. In this report, we present a technology, which can form a beveled edge with a very low bevel angle. 4H-SiC diodes terminated by 2° positive bevel fabricated with this technology are demonstrated.

Experiments

In this technology, a thick photo-resist (PR) is first spun on a sample. After exposure and development, a short time hot plate baking is conducted. As a result, a beveled edge is formed on the patterned PR. The baking temperature and time are adjusted to control the shape of the PR pattern until the desired bevel angle is achieved. The PR is hardened after baking. Since the etching rate of semiconductor is much slower than that of the baked PR for inductive coupled plasma (ICP) etching, a mesa with a small bevel angle can be achieved by using an edge beveled PR pattern as an etching mask.

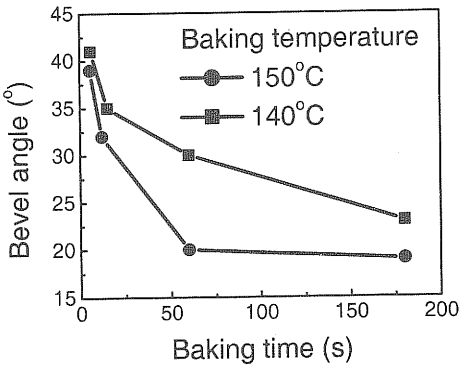

Fig.1 The bevel angle of photo-resist as a function of the baking time at 140°C and 150°C

The shape of a patterned PR changes when post-exposure baking is conducted at a high enough temperature. Depending on the temperature and time of the baking, the bevel angle on the patterned PR can range from 15° to 45°. Figure 1 shows the bevel angle of PR as a function of the baking time at 140°C and 150°C. At 140°C, a 10 second baking results in a bevel angle of 40°. When the baking time increases to 3 minutes, the bevel angle is reduced to 23°. Increasing the baking temperature to 150°C reduces the bevel angle to 19°. Further increasing the baking temperature may result in a lower bevel angle while the pattern of PR may deform.

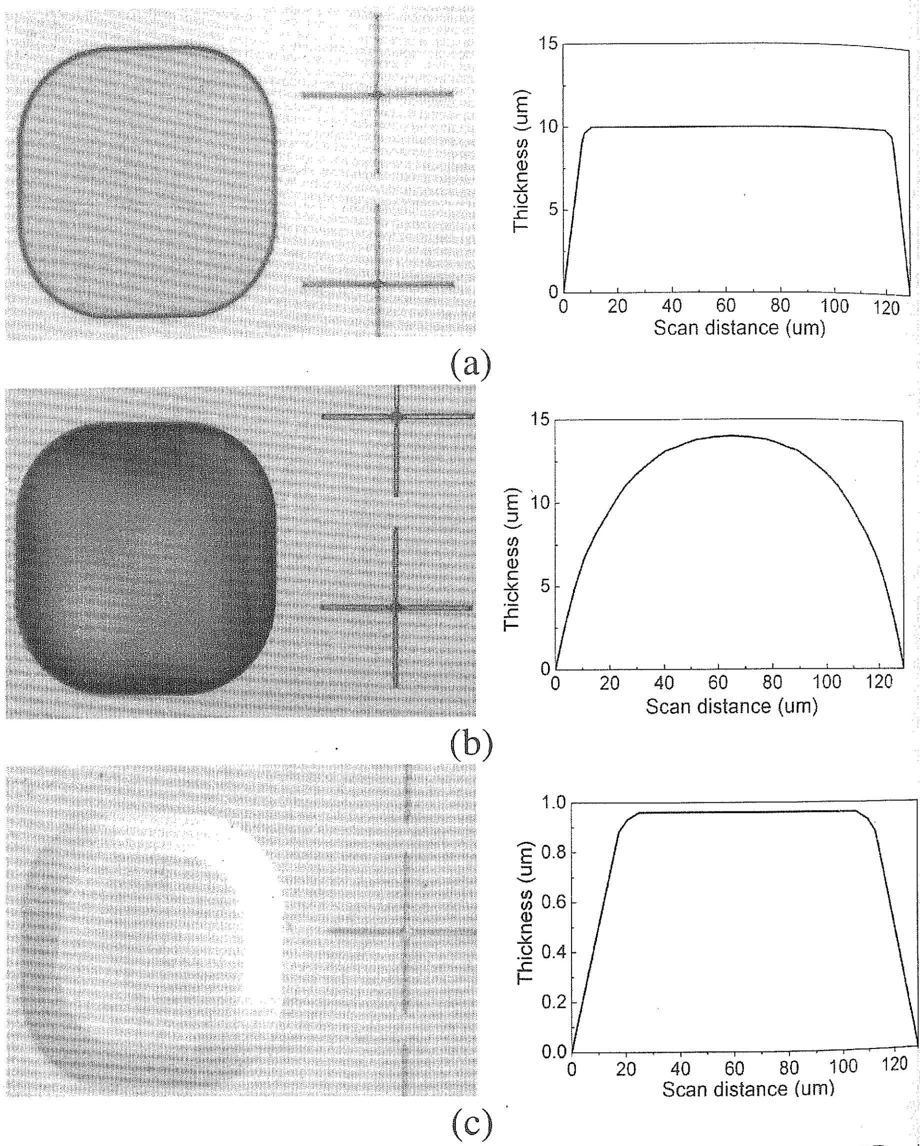

Fig.2 Top view and thickness profiles of (a) thick PR pattern before baking, (b) thick PR pattern after post exposure baking, (c) beveled mesa on 4H-SiC.

Figure 2 (a) shows the top view of the patterned PR before post exposure baking (left). The corresponding cross sectional thickness profile (right) is determined by alpha-step measurement. The size of the square is 130μm x 130μm. The thickness of the PR is 10μm. It should be pointed out that the bevel angle shown in the profile is inaccurate due to the measurement error of a large angle by alpha-step.. After further checking under microscope, the bevel angle of the PR is found to be at least larger than 70° before post exposure baking.

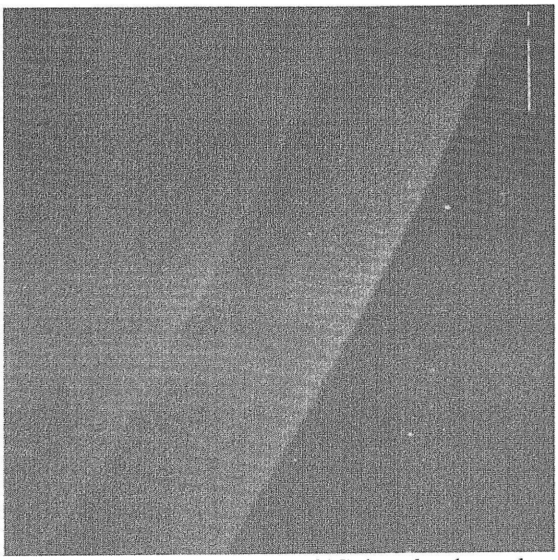

Fig.3 SEM picture of 4H-SiC bevel edge taken with 1000x magnification. Sample was tilted to show the whole bevel

Figure 2 (b) shows the top view of the PR after baking (left) and the corresponding cross sectional profile (right). After post exposure baking, the top view shows that a bevel angle forms at the edge of the PR. The asymmetric bright pattern in Fig. 2(b) is caused by the lighting and shading effect. The actual shape of the PR after baking, as shown in the cross sectional profile, is symmetric. As shown in the thickness profile, the total length of the PR pattern is still 130μm, just as it was before baking. However, the maximum thickness becomes 14μm, indicating that the top part of the PR at the edge shrinks to the center during baking. As a result, the edge is beveled after post exposure baking. The bevel angle shown in Fig 2 (b) is 23°. In our experiments, patterns ranging from 130μm x 130μm to 580μm x 580μm have been studied. There is no obvious dependence between the bevel angle and the pattern size. It is noticed that the bevel angle of original 2μm alignment marks (crosses on the right side of the square) is much bigger than that of large patterns. PR hardening is carried out after the desired bevel angle is formed.

A 4H-SiC wafer covered by the hardened PR is etched by ICP with the O_2/CF_4 mixture under a bias of 50V and a power of 700W for 10 minutes. Figure 2 (c) shows the top view of the resulting beveled mesa on 4H-SiC after removing the remaining PR. A bevel angle of 2° is determined from the cross sectional profile of the beveled mesa, shown in Fig.2 (c) (right). The width of the bevel is about 30μm. The bevel angle of alignment marks is found to be ~45° in this case.

The surface roughness of the bevel edge has been checked under SEM

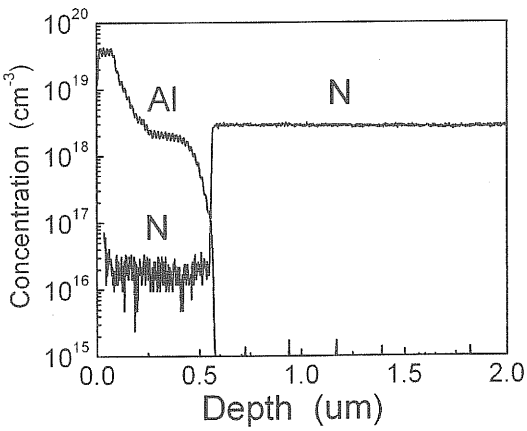

Fig.4 SIMS profile of 4H-SiC structure.

up to 3000X magnification. There is no observable surface roughness. Figure 3 shows SEM pictures taken at a magnification of 1000X. The sample shown in Fig.3 is tilted so that the whole bevel can be seen.

The successful fabrication of the beveled edge with a very small bevel angle has been applied to the fabrication of 4H-SiC diodes. A 4H-SiC wafer with a p^+pn structure grown on n^+ substrate is used. The SIMS profile of the 4H-SiC wafer is shown in Fig.4. The doping concentration and thickness of the p^+, p, and n are $4\times10^{19}/cm^3$ and 0.1μm, $2\times10^{18}/cm^3$ and 0.2μm, and $3\times10^{18}/cm^3$ and 2μm, respectively, with two varied doping density between p^+ and p, and p and n. Considering the varied low doping near the pn junction and the doping of the p layer being lower than the bottom n layer, the resulting diodes have a positive bevel edge termination.

Figure 5 shows the reverse I-V characteristics of a diode with 300μm diameter. Devices have been tested at room temperature (RT), 100°C, and 150°C. The leakage current at 95% breakdown voltage is about 1×10^{-5} A/cm^2 at RT and 1×10^{-4} A/cm^2 at 150°C. 4H-SiC avalanche photodiodes (APDs) terminated by multi-step junction termination extension (MJTE) and passiviated by thermal oxide have shown a leakage current density around 10^{-5} A/cm^2 at 95% breakdown voltage at RT[2]. In this work, even though the edge of diodes is the as-etched 4H-SiC surface without any passivation, the leakage current at 95% of breakdown is still comparable to that of APDs with MJTE and SiO_2 passiviation. The diode runs very stably in deep avalanche at temperatures up to 150°C. The inset is the temperature dependence of the current density-voltage (J-V) curves near the breakdown region. The breakdown voltage increases as temperature increases, showing a positive temperature coefficient of breakdown, a signature of the intrinsic semiconductor avalanche breakdown.

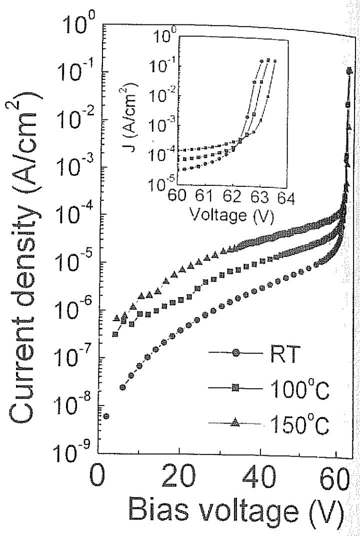

Fig.5 Reverse I-V characteristics of a 300μm diode terminated by a 2° positive bevel. The inset shows the breakdown at different temperatures.

Summary

In summary, a novel technology for the formation of a very small bevel angle for edge termination has been developed. 4H-SiC diodes terminated by a positive bevel have been fabricated with this technology. Low leakage current density and positive temperature dependence of breakdown voltage have been achieved even though no passiviation has been applied to protect the edge. It should be pointed out that this technology is particularly useful for fabrication of reliable APDs and IMPATT diodes where high electric field junctions are normally easier to reach by dry etch process described in this paper.

References

[1]. J. Baliga, *Power Semiconductor Devices*, (PWS Publishing Company, Boston, MA, 1996)

[2]. F.Yan, Y. Luo, J. H. Zhao, M. Bush, G. Olsen, and M. Weiner, Electronics Letters, Vol. 37(2001), p.1080