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

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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.

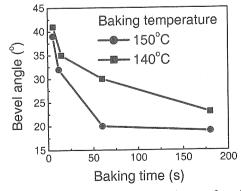


Fig.1 The bevel angle of photo-resist as a function of the baking time at 140°C and 150°C

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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.

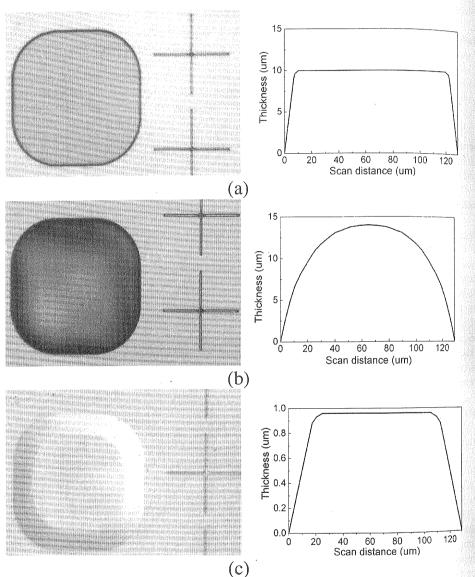


Fig.2 Top view and thickness profiles of (a) thick PR pattern before baking, (b) thick PR pattern after post exposure baking, (c) beveled mesa on 4H-SiC.

Figure 2 (a) shows the patterned PR before baking (left). The consectional thickness patternined by measurement. The size 130 µm. The PR is 10 µm. It shoul that the bevel angle profile is inaccurated measurement error of alpha-step. After a funder microscope, the profile is found to than 70° before post e

Figure 2 (b) shows th PR after baking corresponding cross (right). After post ex op view shows th forms at the edge asymmetric bright p is caused by the ligh he cross sectional r PR pattern is still 13 14µm, indicating th result, the edge is be our experiments, pa There is no obvious bevel angle of orig bigger than that of] hardening is carridesired bevel angle A 4H-SiC wafer hardened PR is etc the O₂/CF₄ mixtur 50V and a power minutes. Figure 2 view of the result on 4H-SiC afte remaining PR. A b determined from 1 profile of the bev in Fig.2 (c) (right) bevel is about angle of alignmen be ~45° in this cas The surface roug edge has been ch ed at a high enough ngle on the patterned on of the baking time 10° . When the baking aking temperature to turn may result in a







) thick PR pattern

ggire 2 (a) shows the top view of the PR before post exposure paking (left). The corresponding cross thickness profile (right) is determined bv alpha-step peasurement. The size of the square is 30μm x 130μm. The thickness of the R is 10μm. It should be pointed out the bevel angle shown in the offle is inaccurate due to the asurement error of a large angle by , oha-step.. After further checking nder microscope, the bevel angle of PR is found to be at least larger 70° before post exposure baking.

figure 2 (b) shows the top view of the property after baking (left) and the corresponding cross sectional profile (left). After post exposure baking, the up view shows that a bevel angle corresponding at the edge of the PR. The symmetric bright pattern in Fig. 2(b)

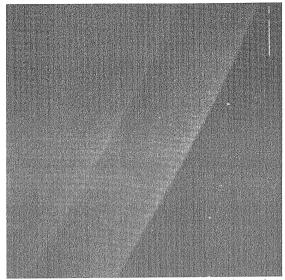


Fig.3 SEM picture of 4H-SiC bevel edge taken with 1000x magnification. Sample was tilted to show the whole bevel

icaused by the lighting and shading effect. The actual shape of the PR after baking, as shown in a cross sectional profile, is symmetric. As shown in the thickness profile, the total length of the pattern is still 130μm, just as it was before baking. However, the maximum thickness becomes that the top part of the PR at the edge shrinks to the center during baking. As a realt, the edge is beveled after post exposure baking. The bevel angle shown in Fig 2 (b) is 23°. In an 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 well angle of original 2μm alignment marks (crosses on the right side of the square) is much

ligger than that of large patterns. PR largering is carried out after the stired bevel angle is formed.

4H-SiC wafer covered by the undered PR is etched by ICP with 10 0/CF₄ mixture under a bias of W and a power of 700W for 10 unutes. Figure 2 (c) shows the top wo f the resulting beveled mesa 4H-SiC after removing the unaining PR. A bevel angle of 2° is the united from the cross sectional unifie of the beveled mesa, shown a Fig.2 (c) (right). The width of the united is about 30μm. The bevel we of a lignment marks is found to 1-45° in this case.

le surface roughness of the bevel the has been checked under SEM

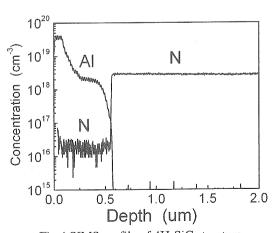


Fig.4 SIMS profile of 4H-SiC structure.

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

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 4×10^{19} /cm³ and 0.1μ m, 2×10^{18} /cm³ and 0.2μ m, and 3×10^{18} /cm³ and 2μ m, 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 $1 \times 10^{-5} \text{ A/cm}^2$ at RT and $1 \times 10^{-4} \text{ A/cm}^2$ at 150°C . 4H-SiC avalanche photodiodes (APDs) terminated by multistep junction termination extension (MJTE) and passiviated by thermal oxide have shown a leakage current density around 10⁻⁵ A/cm² 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 SiO2 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.

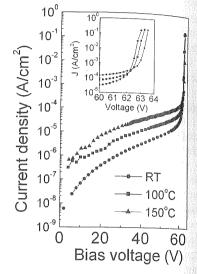


Fig.5 Reverse I-V characteristics of a 300µm diode terminated by a 2° positive bevel. The inset shows the breakdown at different temperatures.

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

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Abstract In boro was found by capa junction at room t of in-diffused borc confirmed the exis peratures showed activation of the either as a deep & electronic nature

Introduction

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