Materials Science Forum Vols. 433-436 (2003) pp. 843-846
online at http://www.scientific.net

1kV 4H-SiC JBS Rectifiers Fabricated Using an AlN Capped Anneal

Lin Zhu[1], Mayura Shanbhag[1], T. Paul Chow[1], Kenneth A. Jones[2], Matthew H. Ervin[2], Pankaj B. Shah[2], Michael A. Derenge[2], R.D. Vispute[3], T. Venkatesan[3] and Anant Agarwal[4]

[1]Center for Integrated Electronics, Rensselaer Polytechnic Institute, Troy, NY-12180
Tel: +518-276-6044, Fax: +518-276-8761, e-mail: zhul3@rpi.edu
[2]Army Research Lab - SEDD, Adelphi, MD 20783
[3]Physics Department, University of Maryland, College Park, MD 20742
[4]Cree, Inc., Durham, NC 27703

Keywords: junction barrier Schottky, 4H-SiC, anneal, Schottky rectifier, AlN.

Abstract. 1 kV 4H-SiC JBS rectifiers were fabricated using AlN capped anneal and compared with those annealed conventionally in a furnace. The surface damage during the high temperature activation anneal is significantly reduced using AlN capped anneal. The forward drop of the JBS rectifiers is <2.5 V while the leakage current is about 2 orders of magnitude lower than that of the Schottky rectifier. The blocking voltage >1 kV was achieved.

Introduction

Recently, several Junction Barrier Schottky (JBS) rectifiers have been reported by different groups [1-3]. The JBS rectifier offers Schottky-like on-state and switching characteristics while the off-state characteristics have a low leakage current similar to the PiN rectifier. The conduction loss can be much lower than it is for a PiN diode for devices with a breakdown voltage of less than 3 kV due to high (2.7 V) turn-on voltage of the SiC PN junction. The leakage current of the JBS rectifier is lower than that of a Schottky by shielding the high electric field away from the Schottky contact. Previously, it has been shown that annealing with an AlN cap helps to reduce the surface damage during the high temperature anneal [4].

In this work, 1000 V planar JBS rectifiers with a low forward drop have been fabricated using an AlN capped anneal of the p+ implantation. Al/C/B co-implantation was used to form the p+n junction. Junction termination was achieved by boron implantation. On the same wafer, Schottky and PiN rectifiers have also been fabricated to compare with the JBS rectifiers.

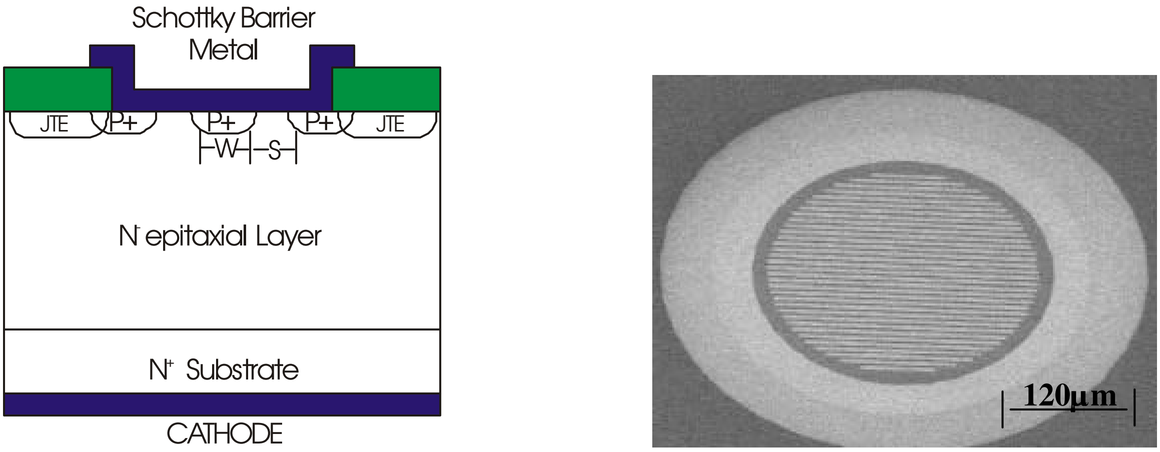

Figure 1. Schematic cross-section (left) and the layout of the JBS rectifier

Device Fabrication

The device schematic cross-section and layout are shown in Fig. 1. The starting material was n epi on n+, (0001), Si face 4H-SiC wafer purchased from Cree Inc. The nominal thickness and the doping level of the N-drift layer are 12 μm and 8×10^{15} cm^{-3}, respectively. The p+ regions were formed using Al/C/B co-implantation. Deep junction was formed by multiple implantation of boron with energy range from 105 to 360 keV. Co-implantation of aluminum and carbon was done to realize the shallow layer. Both implantations were done at 600°C and were optimized using SUPREM to get a box-like profile with depths of ~0.8μm. Junction termination was achieved by low-dose boron implantation. An n-type stopper was formed to reduce field spreading. All the implants were simultaneously annealed at 1600°C. One sample was annealed with an AlN cap at 1600°C for 30 minutes in Ar. Other samples were annealed at 1600°C for 5 minutes in Ar. Tri-layer metalization of Ti/Ni/Al was used to form backside contact, and subsequently annealed at 1000°C in Argon for 2 minutes. Ti was used as the metal to form front Schottky contact.

Activation Anneal

Fig. 2 shows the SEM picture of the sample surface before the activation anneal. After the anneal at 1600°C for 5 min without an AlN cap, there is much surface damage in the p+ region, as is shown in Fig. 3. The sample annealed for 30 min at 1600°C with the AlN cap shows almost no surface damage, as is shown in Fig. 4.

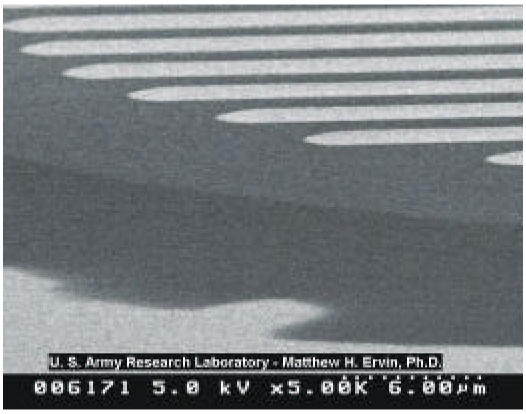

Figure 2. SEM picture of surface before activation anneal

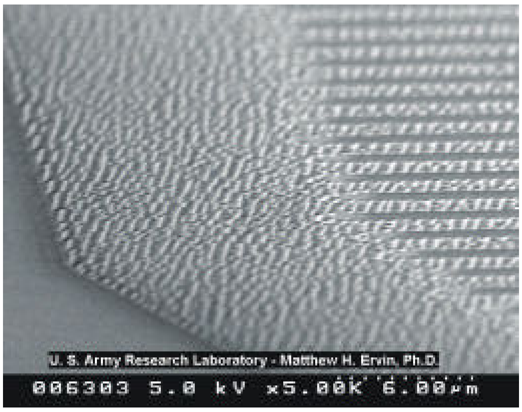

Figure 3. SEM picture of surface after activation anneal without AlN cap

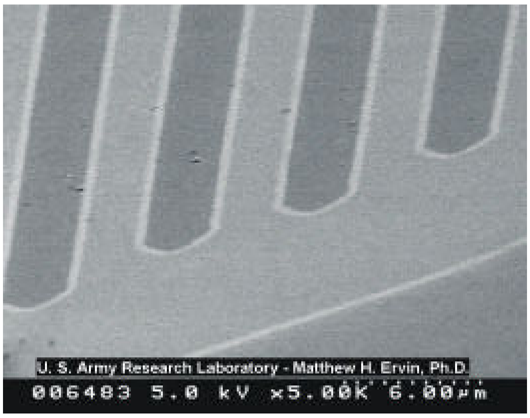

Figure 4. SEM picture of surface after activation anneal with AlN cap

Experimental Results

As shown in Fig. 1, the p+ junction grid is characterized by the width of the p+ implantation window (**W**) and spacing in between (**S**), the width of Schottky area region before the lateral diffusion of Boron and are designated JBS(S,W). These two parameters are important design parameters for the tradeoff in forward drop and leakage current. The forward characteristics of samples with and without AlN capped anneal are shown in Fig. 5. The forward drop of the JBS rectifier for AlN capped sample is <2.5 V at 100 A/cm^2, with an ideality factor of ~1.3. The JBS shown in Fig. 5 is designed with 3μm **S** and 3μm **W**. The forward drop for Schottky diodes are ~1V. The PiN diode shows a large forward drop due to the un-annealed P-contact. There are also some JBS rectifiers with 4μm and 5μm **S**. While the **S** increases, the forward drop will decrease, closer to that of the Schottky diodes. The sample annealed without the AlN cap has a smaller Schottky yield; larger forward drop for Schottky (~1.3 V), but it shows a better activation of the p+ region and P contact. The forward current of the JBS rectifiers can hardly reach 100 A/cm^2 before minority carrier injection commences at V_F>3 V.

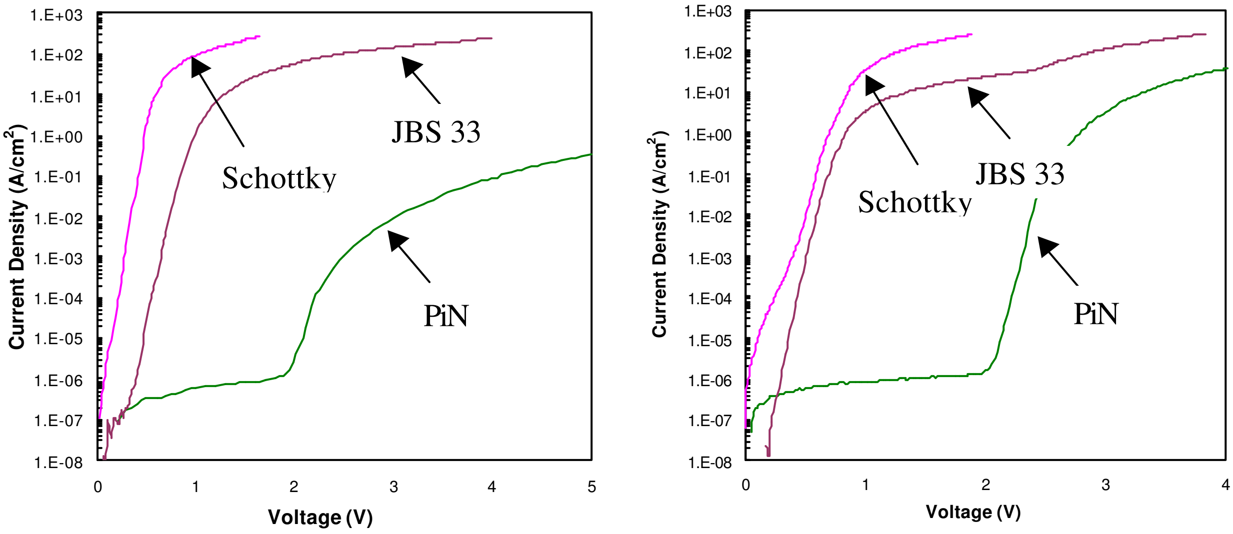

Figure 5. Forward IV characteristics of samples with (left) and without AlN capped annealed

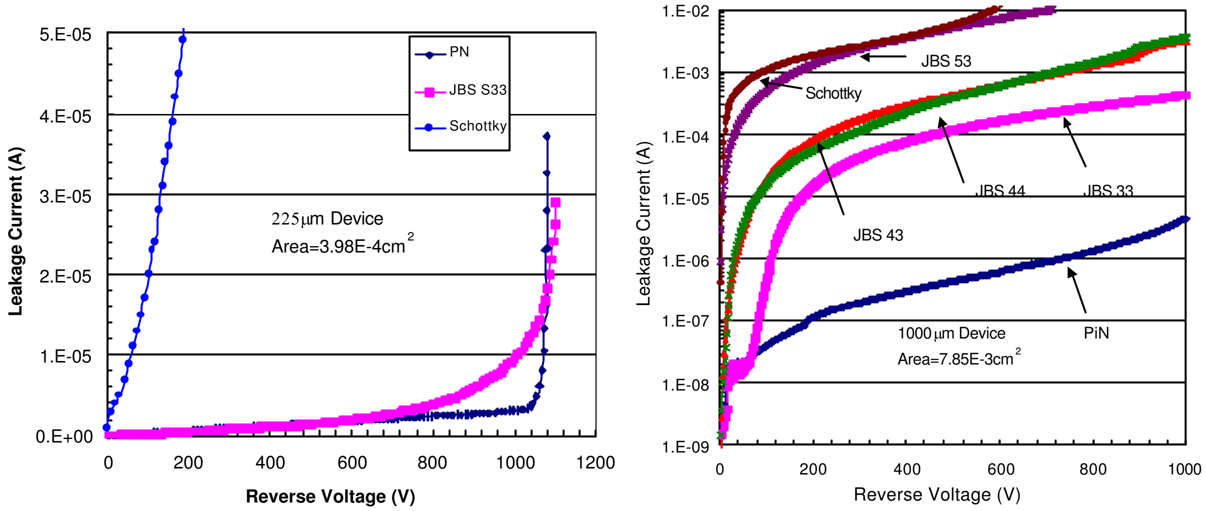

Figure 6. Reverse characteristics of 225μm (left) and 1000μm devices on sample with AlN capped annealed

The blocking voltage of the 225 μm and 1000 μm diameter devices on AlN capped sample is more than 1000 V, as shown in Fig. 6. As the Schottky stripe width (**S**) increases, the leakage current of the JBS rectifier also increases. With a 3 μm Schottky width the leakage current for the JBS rectifier is about two orders of magnitude lower than that of the Schottky rectifier. The devices on samples without an AlN capped anneal can achieve a higher blocking voltage (~1500 V) because of better activation of the JTE implantation. But the samples show much worse yield of 1000 µm devices, shown in Fig. 7.

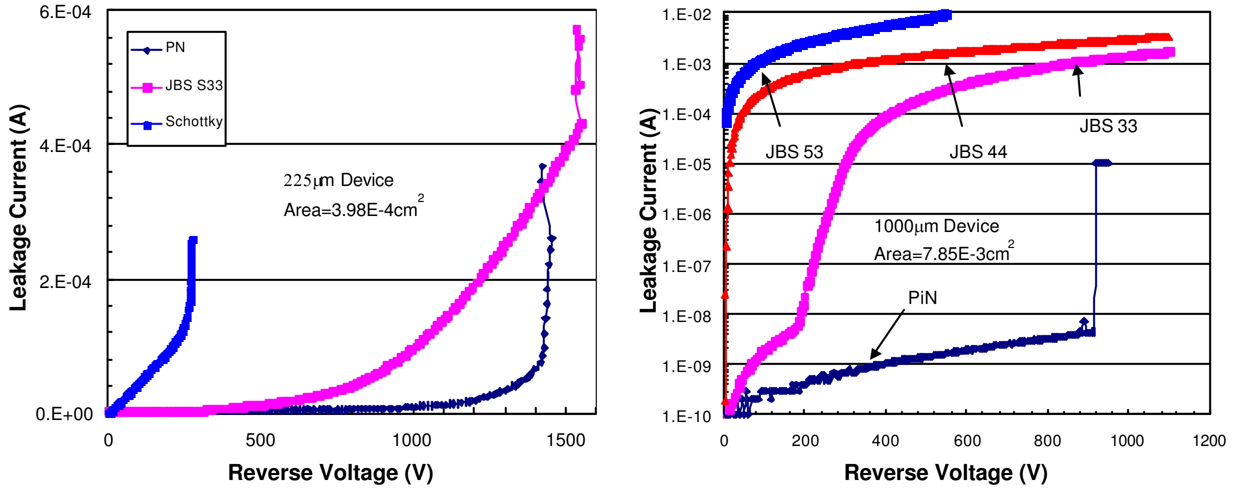

Figure 7. Reverse characteristics of 225µm (left) and 1000µm devices on sample without AlN capped annealed

Summary

In summary, JBS rectifiers with >1 kV blocking capability were fabricated using an AlN capped anneal, which reduced the surface damage during the high temperature anneal. JBS rectifiers with different design parameters were fabricated to determine the tradeoff of forward drop and leakage current. The forward drop of the JBS rectifiers is <2.5 V while the leakage current is about 2 orders of magnitude lower than that of the Schottky rectifier.

Acknowledgement

This work was supported by the ARL Collaborative Technology Alliance in Power and Energy, under Cooperative Agreement No. DAAD19-01-2-0010 and NSF Center for Power Electronic Systems (# EEC-9731677).

References

[1] F. Dahlquist, and H. Lendenmann, Materials Science Forum, Vols. 338-342 (2000), p.1179
[2] K. Asano, and Y. Sugawara, ISPSD, Toulouse, France, May, 2000.
[3] R. Singh, S-H. Ryu, and J.W. Palmour, ISPSD, Toulouse, France, May, 2000.
[4] K.A. Jones, P.B. Shah, K.W. Kirchner, R.T. Lareau, M.C. Wood, M.H. Ervin, R.D. Vispute, R.P. Sharma, T. Venkatesan, and O.W. Holland, Mater. Sci. Eng. **B61-62**, (1999), p.281