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The Cryogenic behaviour of High Power Si and GaAs Schottky Diodes

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I. Introduction

THE potential benefits of operating power devices at cryogenic temperatures are faster switching and lower on-state losses. In the latter case, where the application requires a diode with a breakdown voltages >100V at cryogenic temperatures, a Schottky diode would be the ideal candidate due to the low threshold voltage and increased mobility at low temperatures. Si, GaAs and SiC Schottky diodes are already commercially available and the cryogenic behaviour of 4H-SiC Schottky has been demonstrated by Shanbhag and Chow down to 77K [1]. SiC Schottky diodes can achieve high breakdown voltages up to and above 300V, but they experience incomplete dopant ionisation at room temperatures and therefore would be unsuitable for cryogenic applications. On the other hand, Si and GaAs Schottky diodes experience carrier freeze-out at much lower temperature and therefore could operate in cryogenic environment.

Operating power devices at cryogenic temperatures can have detrimental effects, such as breakdown voltage degradation and increased threshold voltage. In this paper, we will investigate the cryogenic behaviour of Si and GaAs Schottky diodes from ambient temperature down to the temperature of 16K and present their behaviour for the first time.

II. Experimental Results

This paper presents the measurements of SPC Multicomp Si Schottky diode rated at 200V/5A and IXYS GaAs Schottky diode rated at 250V/4A for forward bias (high/low current) and breakdown behaviour. The high current and breakdown measurements were performed a high power curve tracer (Tektronix 371B) and the low current measurements were performed by a semiconductor device analyser (Agilent Techology B1500A). Cryogenic temperatures were induced by placing the device into the cold stage of a closed cycle He-cryocooler (Leybold RDK 10-320).

The measured cryogenic behaviour presented in Fig. 1 suggests that Si Schottky diode behaves as a Merged PiN Schottky (MPS) diode [2]. The MPS structure reduces the on-state resistance of the diode at higher voltage levels. This MPS behaviour is most likely due to the P+ guard rings added to increase the blocking voltage and to reduce reverse leakage current. The MPS behaviour is more apparent at low temperatures (<100K) where the acute transition between conduction through the Schottky region and the P-N junction is clearly observed. The measured reduction in breakdown voltage with decreasing temperature is shown in Fig. 2. It shows a ~23% reduction from 294K to 16K. However, the rate of reduction is much higher at temperatures above 150K and slows down significantly below 100K.

The data presented in Fig. 3 shows the forward bias characteristics of the GaAs Schottky diode. The MPS mechanics due to the P+ guard ring are not observed here. Below the rated current, the current conducts almost entirely through the Schottky regions. However, a different mechanism appears to conduct current at higher voltage. The reason behind this abnormal behaviour is currently uncertain. Fig. 4 shows the low current measurement of the GaAs Schottky diode.

The breakdown behaviour of the GaAs Schottky at 294K, 150K and 16K are presented in Fig. 5. At 294K, the curve shows three different stages of breakdown conduction at ~125V, ~225V and ~270V. The exact breakdown voltage at the temperatures of 150K and 16K are difficult to pinpoint due to the abnormal shape of the breakdown curves; however, it is clear that the decrease in breakdown voltage is much higher than the Si Schottky, around 50-60%.

The conduction loss for both diodes at their rated current is shown in Fig. 6. For the Si diode, the conduction loss increases at low temperatures due to the increased threshold voltage, as well as the reduced conductivity modulation. For the GaAs diode, the increase in threshold voltage is less and, more importantly, the resistance during conduction is much lower due to the large improvement in carrier mobility at low temperature. Therefore, the conduction loss for the GaAs diode improves significantly at cryogenic temperatures.

III. Conclusion

The cryogenic behaviour of high power Si and GaAs Schottky diode has been presented down to the temperature of 16K. The experimental results have indicated the importance of the P+ guard ring in controlling the cryogenic behaviour of the rectifier. The P+ guard ring is required to have a stable breakdown response even at low temperature, on the other hand, it could induce bipolar conduction if not carefully controlled.

References

[1] M. Shanbhag and T.P. Chow, in *ISPSD*, 2002, pp. 129– 132.
[2] B.J. Baliga, *Power Semiconductor Devices*. PWS, 1996.

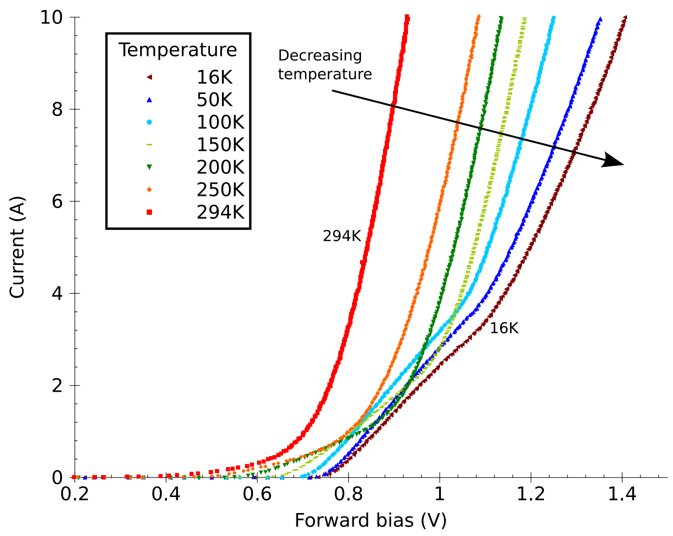

Fig. 1. The forward bias cryogenic behaviour of SPC Multicomp Si Schottky diode rated at 200V/5A.

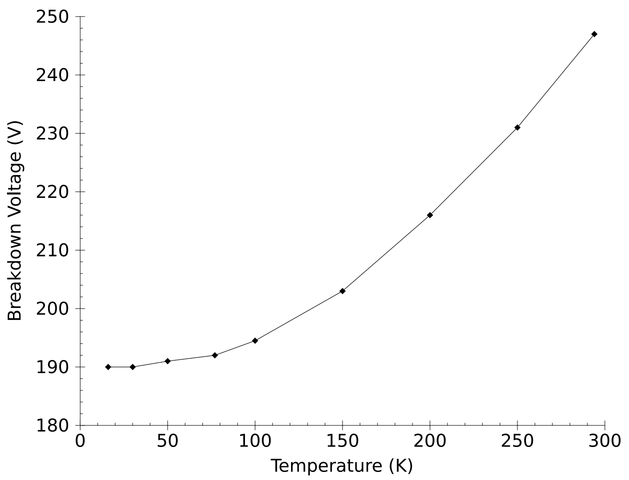

Fig. 2. The reduction in breakdown voltage with decreasing temperature of SPC Multicomp Si Schottky diode rated at 200V/5A.

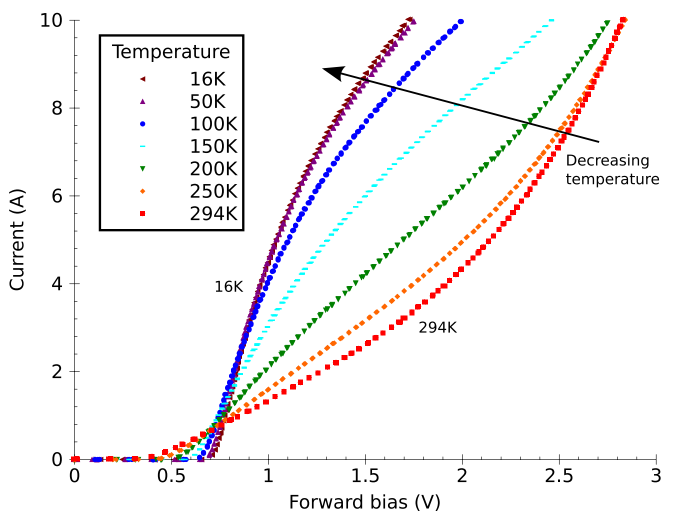

Fig. 3. The forward bias cryogenic behaviour of IXYS GaAs Schottky diode rated at 250V/4A.

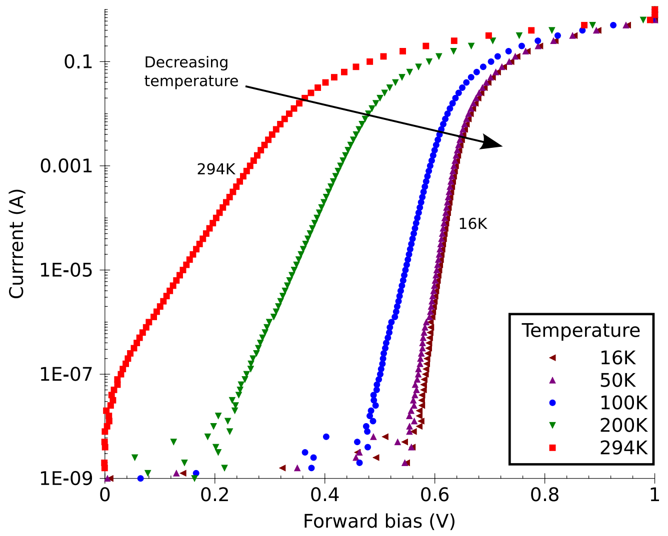

Fig. 4. The forward bias (low current) cryogenic behaviour of the IXYS GaAs Schottky diode.

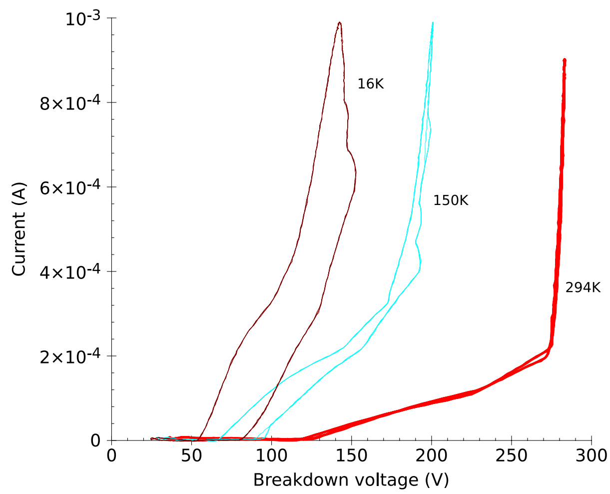

Fig. 5. The measured breakdown curve of the IXYS GaAs Schottky diode at 294K, 150K and 16K.

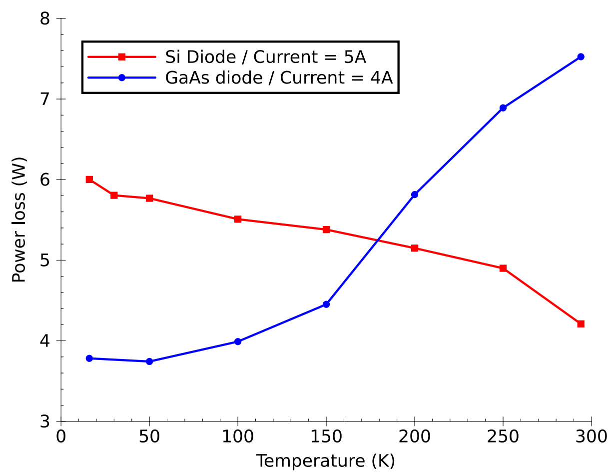

Fig. 6. Conduction loss for the Si and GaAs diode at their rated current with temperature.