Scaling of 4H-SiC p-i-n Photodiodes for High Temperature Applications

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Introduction

Ultraviolet (UV) detection is important in astronomy, combustion detections and medical analysis. Solid-state UV detectors based on wide band gap semiconductors, such as 4H-SiC, are widely studied because of their excellent electrical properties [1]. 4H-SiC based UV detectors are solar blind and can be applied in extremely high temperature environments [2]. However, the state-of-art 4H-SiC photodetectors still have large sizes (>10000 μm^2), which are not suitable to be integrated into high resolution UV photography sensors. To build a full-frame UV imaging sensor containing megapixels, photodiodes smaller than 20 µm by side are necessary. Here, we report the fabrication and characterization of 4H-SiC p-i-n photodiodes with mesa areas scaled from 40000 μm^2 to 400 μm^2. The relationships between the parameters and the areas of the photodiodes are discussed. The photodiodes are fully functional from room temperature (RT) to 500 ºC.

Device Fabrication and Measurements

The photodiodes were fabricated on a 4 inch n-type 4H-SiC wafer with p+(5e18 cm^{-3})/n-(1e16 cm^{-3})/n+(1e19 cm^{-3}) epitaxial layers. The schematic view of the photodiode is shown in Fig.1(a). The photodiodes were square shaped with side lengths of 200 µm, 50 µm, 40 µm and 20 µm (see Fig.1(b)). The mesas were etched by reactive ion etching with $HBr/Cl_2/SF_6$. The cathode contact was Ni with 950 ºC rapid thermal annealing (RTA). The anode contact was Ni/Ti/Al with 815 ºC RTA. Since the cathodes with metal layers (TiW/Al) on top partially blocked the n-type mesas, the actual light detection areas of the photodiodes were slightly smaller. The fabricated photodiodes were tested both in dark and under UV illumination by I-V measurements at RT, 200 ºC, 400 ºC and 500 ºC. The UV illumination source was a UV LED with an emission peak at 365 nm and optical power density of 0.8 mW/cm^2.

Results

The I-V curves of the four photodiodes in dark at different temperatures are shown in Fig.2(a)-(d). The reverse biased current at temperature below 400 ºC is noise because its value is below the detection limit (10 fA) of the parameter analyzer. The forward current has exponential relationship with the forward voltage so that the ideality factor and saturation current of the four photodiodes can be extracted from the Shockley diode equation. The ideality factor (see Fig.3) decreases as the temperature increases (from ~2 at RT to ~1.65 at 500 ºC), however, it remains constant (standard deviation <5%) without size dependence at each temperature. The saturation current (see Fig.4) increases as the temperature increases due to band gap narrowing and the increase of intrinsic carrier concentration. At each temperature, the saturation current decreases as the device area is reduced but not in a directly proportional trend. This scaling effect could be because of the surface recombination of the carriers so that the effective carrier lifetime decreases as the device is scaled down. The measured dark current at reverse bias at 500 ºC in Fig.2(d) shows the same behavior with the extracted saturation current.

The photo current of the four samples under UV illumination at -2.7 V (full depletion voltage of the diode) is shown in Fig.5. For each photodiode, the photo current increases as the temperature is elevated due to band gap narrowing [2]. At each temperature, the photocurrent is directly proportional to the light detection area. The photo to dark current ratio (PDCR) [3] of the devices at -2.7 V at 500 ºC is calculated and shown in Fig. 6. The PDCR of the 40000 μm^2 diode is ~6 times higher than the 400 μm^2 one. The PCDR degrades for smaller photodiodes due to the scaling effect of the saturation current.

Conclusion

Four 4H-SiC based p-i-n photodiodes with mesa areas of 40000 μm^2, 2500 μm^2, 1600 μm^2 and 400 μm^2 have been fabricated. The scaled photodiodes with smaller areas have degradations in PDCR but they still show stable operations within the temperature range from RT to 500 ºC. The reported 400 μm^2 photodiode is a promising candidate to be integrated in high resolution UV photography sensors for high temperature applications.

References

[1] E. Monroy *et al.*, *Semicond. Sci. Technol.*, vol. 18, p. R33, (2003).
[2] S. Hou *et al.*, *IEEE-EDL,* vol. 37, p. 1594, (2016).
[3] W.-C. Lien *et al.*, *IEEE-EDL,* vol. 33, p. 1586, (2012).

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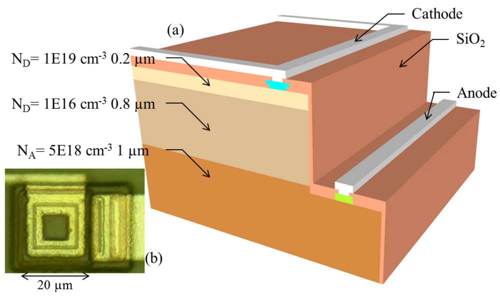

Fig. 1. (a) Schematic view and (b) microscope image of the p-i-n photodiode.

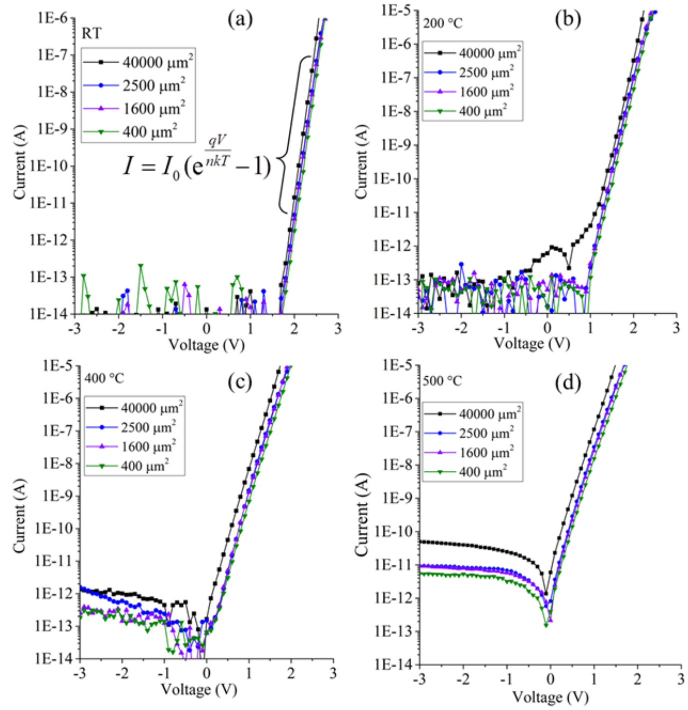

Fig. 2. I-V curves of the photodiodes in dark at (a) RT, (b) 200 ºC, (c) 400 ºC and (d) 500 ºC. The forward current is fitted by Shockley diode equation, where n is ideality factor and I_0 is saturation current.

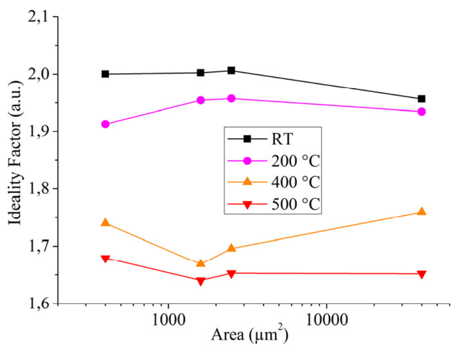

Fig. 3. Ideality factor (extracted from Fig.2 with Shockley diode equation) of the photodiodes at different temperatures.

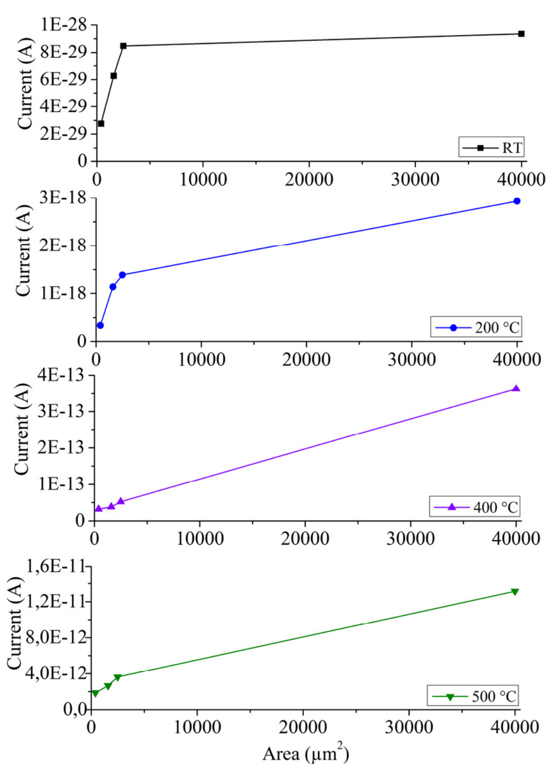

Fig. 4. Saturation current (extracted from Fig.2 with Shockley diode equation) of the photodiodes at RT, 200 ºC, 400 ºC and 500 ºC.

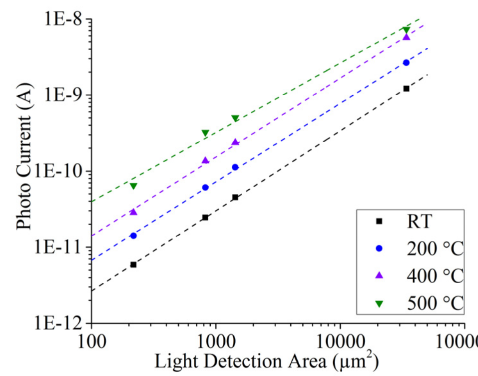

Fig. 5. Photo current of the photodiodes at -2.7 V at different temperatures.

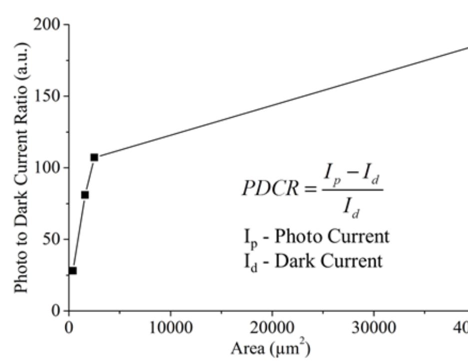

Fig. 6. Photo to dark current ratio (PDCR) of the photodiodes at 500 ºC.

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