Design, Fabrication and Characterization of Deep Ultraviolet Silicon Carbide Avalanche Photodiodes

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Silicon Carbide (SiC) is an ideal semiconductor for fabricating ultraviolet sensors due to its wide bandgap. The large bandgap of Silicon Carbide (SiC) also provides the benefit of being transparent to visible light, thereby obviating the need to utilize expensive, sometimes bulky and imperfect optical filters. SiC photon detectors additionally offer natural immunity to visible light leakage into the detector system. Thanks to its wide bandgap, SiC devices have the potential to provide more than fifteen orders of magnitude improvement in dark current background noise than their silicon analogues. These low dark currents, as well as further SiC material properties, also allow operation at elevated temperatures. This may favor SiC photodiode use over their Si and Photo Multiplier Tube (PMT) counterparts in NASA's future Heliophysics and Planetary instruments like The Solar Dynamics Observatory (SDO) Extreme ultraviolet Spectro-Photometer (ESP), which is a part of the Extreme ultraviolet Variability Experiment (EVE) suite of instruments.

SiC Avalanche Photo Diodes (APDs) have relatively lower breakdown voltages than photo multiplier tubes, which are used for their low noise and high multiplication factors. In addition to offering similar multiplication and noise performance, SiC APDs also offer a low weight option due to the lower weight of the diode itself, its electrical peripherals (due to their relatively low voltage levels), and minimal shielding requirements. SiC low voltages, compared to PMT operation, also greatly simplify electrical requirements for the rest of the system.

We have designed, simulated, fabricated and tested SiC APDs for the detection of deep-UV photons with wavelengths in the 175nm-250nm range. One of the problems associated with deep-UV light detection is that the absorption coefficient of this wavelength in SiC is large. Therefore the electron-hole creation occurs near the surface, where there is minimal electric field to drift newly generated carriers. To increase efficiency and responsivity, we need to reduce surface recombination. This can be achieved by either passivating recombination centers at the surface or increasing the field at the surface, which result in electron-hole separation before any possible recombination. We note that recombination rate within the bulk SiC is significantly less than that at the surface**.**

We have used newly developed simulators [1] for the SiC APDs in conjunction with special fabrication techniques to achieve detection of the deep-UV photons. **Figure 1** shows simulation results of some of our earlier designs as a function of doping. As expected breakdown voltage increases as doping decreases. Based on the initial designs, and limitations of the fabrication methods, we developed a recipe for APD fabrications. One of the fabricated APD chips is shown in **Figure 2** along with the DC breakdown measurements of its devices. The APDs breakdown roughly at 195 V, which is significantly less than those used to bias PMTs. **Figure 3** shows the responsivity curves of one of this chip's APDs as a function of bias and wavelength. As can be seen, we have achieved high responsivity for photons with 200 nm wavelengths, compared to commercial deep-UV detectors such as GaP photodiodes with responsivities <0.1A/W for the same wavelength.

In summation, SiC APDs offer a great potential for highly sensitive deep-UV imaging systems. Our work has shown that fabrication of these devices with increased UV sensitivity can be achieved with high yields for these devices, in conjunction with good design and careful fabrication techniques.

[1] M. Dandin, A. Akturk, A. Vert, S. Soloviev, P. Sandvik, S. Potbhare, N. Goldsman, P. Abshire, K. P. Cheung, "Optoelectronic characterization of 4H-SiC avalanche photodiodes operated in DC and in geiger mode," Proceedings of Int. Semiconductor Device Research Symposium (ISDRS), 1-2 (7-9 Dec. 2011).

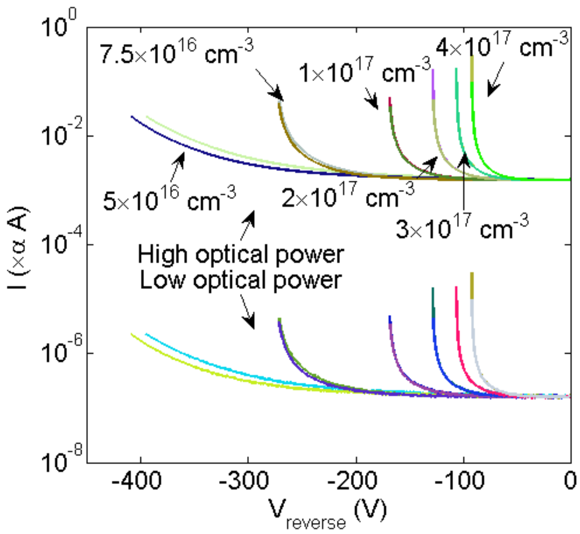

Figure 1: SiC APD I-V calculations for APDs with varying concentrations of n- layer: 5×10^{16}, 7.5×10^{16}, 1×10^{17}, 2×10^{17}, 3×10^{17}, 4×10^{17} cm^{-3}.

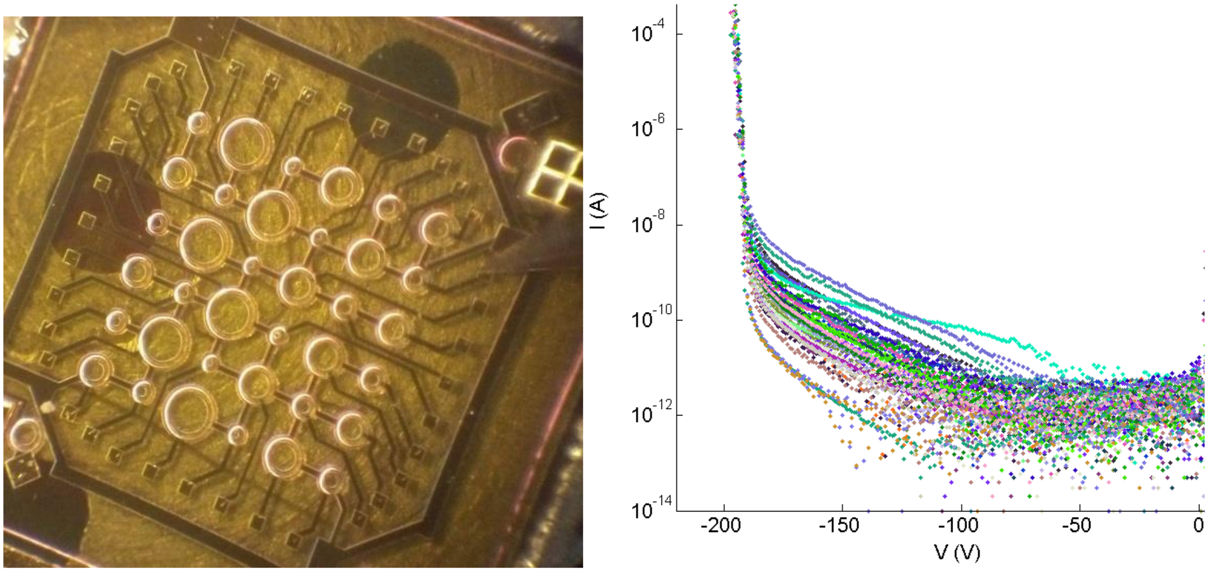

Figure 2: A fabricated APD array chip along with measured APD breakdown characteristics.

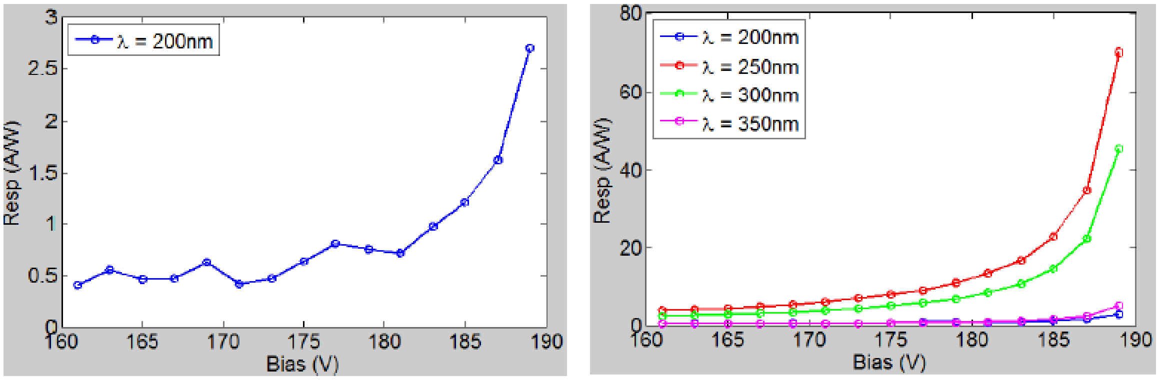

Figure 3: Measured responsivity of typical fabricated small diameter APDs.