Temperature coefficient
of SiC based UV photodiodes

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INTRODUCTION

This report assigns the temperature coefficient (TC) of sglux SiC-photodiodes in relation to the incident wavelength. It is known that the temperature dependence of the photocurrent changes notably over the spectral sensitivity range because different physical processes are involved at different wavelengths (1). To take a closer look at this behaviour measurement results taken at several UV wavelengths between 260 nm and 367 nm are presented and discussed. Widely used standard UVA/UVB/UVC incandescent lamps are hardly stable enough to reliably detect signal changes in the anticipated range of ±0.1%/K. Therefore temperature stabilized UV LEDs with varying centre wavelengths have been used for the measurements.

EXPERIMENTAL SETUP

UV LEDs (UV TOP produced by SET Inc.) with centre wavelengths of 260 nm, 276 nm, 310 nm, 342 nm and 367 nm respectively each with a FWHM rating of ~10 nm were used. They have been operated by constant currents of 2 mA...50 mA generated by a Keithley SMU 236 with the LEDs mounted on an air-cooled heat-sink in a room with stabilized temperature of 23 °C. Before starting of the measurements the LEDs were allowed to reach thermal equilibrium for at least 15 minutes which was verified by continuously monitoring their radiation intensity by measuring the photocurrent of a SiC-photodiode (DUT) in photovoltaic mode with a Keithley picoamperemeter 6514 while the photodiode itself was mounted on a thermoelectric cooler (TEC) with an air-cooled heat sink at room temperature. The temperature was measured by a thin-film Pt1000 sensor that was pressed onto the bottom face of the TO5 housing of the photodiode. From other experiments it is known that the temperature of the SiC-detector chip inside the package is in good correlation with the temperature of the bottom side of the package.

The photodiodes were heated via the TEC to a temperature of at least 65°C, then the TEC was totally switched off and the photodiodes cooled down to room temperature by thermal conduction through the heat sink. This downward ramp took around 15 minutes to reach 30°C. While the temperature decreased slowly the photocurrent at several temperatures was recorded. The same procedure was repeated for several photodiodes originating from different production batches.

Note: special care must be taken not to disturb the measured photocurrent of some nano-ampere by stray currents from the TEC system and the rest of the setup. Especially PWM driven TEC controllers seem to be a source of notable leakage currents. Therefore it was avoided to actively regulate the temperature during the measurement at all.

(1) Kalinina, Evgenia & Violina, G. & Nikitina, I. & Ivanova, Ekaterina & Zabrodski, V. & Shvarts, Maxim & Levina, Svetlana & Nikolaev, A.. (2020). Effect of Temperature on the Characteristics of 4H-SiC UV Photodetectors. Semiconductors 54(2):246-252, DOI 10.1134/S1063782620020128.

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RESULTS

The measurements of 6 different photodiodes with active areas of 0.5 mm (4 parts) and 1 mm (2 parts) are depicted in Figure 1

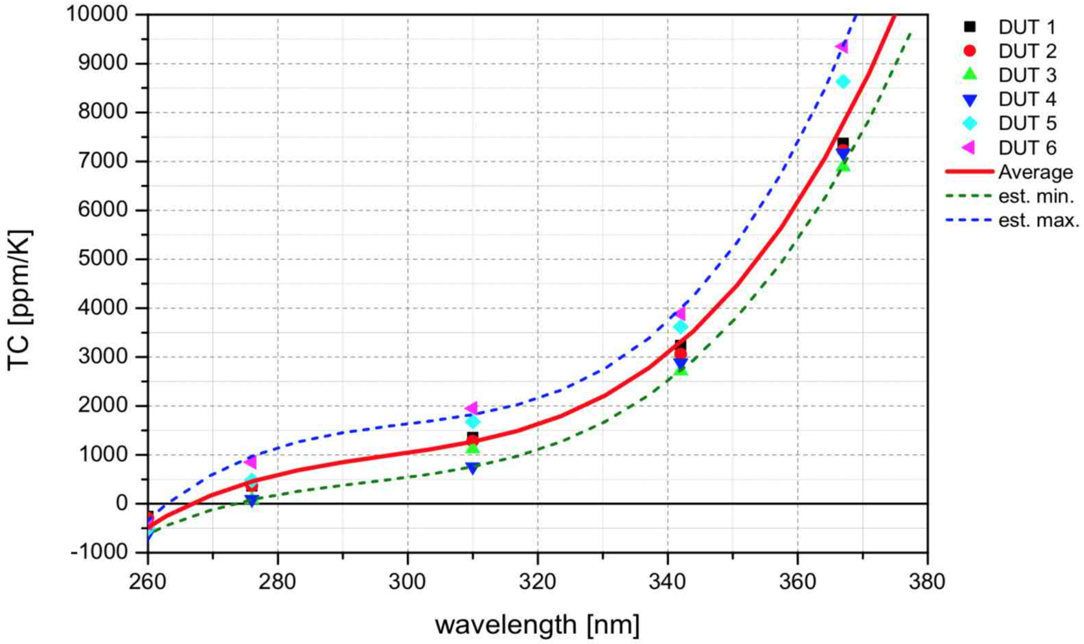

Figure 1: Temperature coefficient of SiC UV photodiodes between 260nm and 367nm

The TC was found to be negative at 260 nm with a value of (-430 ± 185) ppm/K. It crosses zero in the wavelength region between 260 nm and 275 nm which is near to the wavelength of the maximum spectral response. This fact is good news for many applications working in the UVC range.

At increasing wavelength not only the value of the TC itself but also the scatter of TC values increases. While this increase is moderate at and below 320 nm (twofold from 275 nm to 320 nm) it rises heavily towards 367 nm (five-fold increase compared to 320 nm).

Semiconductor material band-gap energy (lowest energy difference between valence band and conduction band) decreases with increasing temperature – this is known as band-gap narrowing - which extends the absorption to longer wavelengths and increases the absorption at a given wavelength. This leads to a higher generation of electron hole pairs within the intrinsic region of the pin-photodiode. SiC as well as Silicon are such indirect band-gap semiconductors where phonons are necessary to absorb a photon and generate an electron-hole-pair.

At higher temperatures more phonons are created which increases the number of indirect phonon assisted transitions and thus the absorption in SiC. The band-gap narrowing and increase of indirect transitions are obviously strongly affected by the total temperature and thus lead to large TC values between 355 nm and 400 nm. Therefore applications in this range might need some means of temperature compensation.

At wavelengths below 280 nm direct transition are possible which do not require phonons (2). Thus the temperature dependence of the generation of electron-hole pairs is smaller. Short wavelength photons are absorbed close to the surface of the pin-photodiode and surface recombination affects the carrier generation and transport. As the surface recombination increases with temperature this leads to a decrease in photocurrent at shorter wavelengths (3) .

It was also observed that the photodiode with the most negative TC at 260 nm also showed the smallest positive TC at all other wavelengths and had nearly zero-TC at 275 nm whereas the photodiode with the smallest negative TC at 260 nm showed the largest TC at 367 nm. The temperature coefficient with a unit of ppm/K for wavelengths from 260 nm to 380 nm can be approximated by a 3rd order polynomial:

$$TC(\lambda) = A + B\cdot\lambda + C\cdot\lambda^2 + D\cdot\lambda^3$$
$$where \quad A = -4.1014\cdot 10^5 \;\; ; B = 4122.11 \, ; C = -13.8392 \, ; D = 0.01556$$

Further investigation is required to get a broader statistical basis, a better understanding of the physical processes and additional boundary conditions involved and to define possibilities of influencing the temperature coefficient by design.

(2) Berenguier, Baptiste & Ottaviani, Laurent & Biondo, S. & Palais, O. & Lazar, Mihai & Milesi, Frédéric & Torregrosa, Frank & Kalinina, E. & Lebedev, A.A. & Vervisch, Wilfried & Lyoussi, A. (2014). 4H-SiC P+N UV Photodiodes: Influence of Temperature and Irradiation. MRS Proceedings 1693, DOI 10.1557/opl.2014.565.

(3) Shuoben Hou, Per-Erik Hellström, Carl-Mikael Zetterling, and Mikael Östling, (2016) 550°C 4H-SiC PIN Photodiode Array with Two-Layer Metallization.IEEE ELECTRON DEVICE LETTERS, 2016, DOI 10.1109/LED.2016.2618122