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Towards the Fabrication and Measurement of High Sensitivity SiC-UV Detectors with Oxide Ramp Termination

G. Brezeanu⁽¹⁾, P Godignon⁽²⁾, E. Dimitrova⁽³⁾, C. Raynaud⁽³⁾, D. Planson⁽³⁾,
A. Mihaila⁽⁴⁾, F. Udrea⁽⁴⁾, J. Millan⁽²⁾, G. Amaratunga⁽⁴⁾, C. Boianceanu⁽¹⁾

¹University "POLITEHNICA", Splaiul Independentei 313, RO-77206, Bucharest, Romania

²CNM, Campus Universidad Autonoma de Barcelona, ES-08193 Bellaterra, Barcelona, Spain

³CEGELY, UMR 5005, INSA de Lyon, 21 av. Jean Capelle, FR-69621 Villeurbanne cedex, France

⁴Engineering Department, University of Cambridge, Trumpington Street, Cambridge CB2 1PZ, U.K.

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Abstract. The paper is focused on the simulation, fabrication and measurement of the high UV detection performances 6H-SiC *pn* photodiodes based on an efficient planar termination. The oxide ramp technology used for these photo-detectors is extensively presented. The OBIC technique was used for optical measurements of the samples. The impact of diode's bias as well as their photo-response on some incident light power values has been revealed by measurements and numerical simulations. The measurement shows a stronger diode's bias effect on its optical properties than the simulation data.

Introduction

Wide bandgap semiconductors are desirable for UV optical detection applications because of their insensitivity to longer wavelengths and their very small dark current levels, even at elevated temperatures. Low dark current enables SiC photodiodes to exceed Si UV detector sensitivities by 4 orders of magnitude [1,2]. Many of the applications for UV detection involve hostile environments such as in situ combustion monitoring and satellite based missile plume detection, where the ruggedness of SiC is an important advantage. Other applications capitalize on the sensitivity of wide bandgap semiconductor detectors, such as air quality monitoring, gas sensing and personal UV exposure dosimeter. Among the wide bandgap semiconductors, SiC is once again leading the way, being the first to reach the marketplace [1,2].

The photo-detectors are, usually, Schottky or *pn* junction diodes reverse biased. For SiC diodes we had previously proposed a simple planar edge termination based on a field plate overlapping on oxide ramp at the periphery of the contact. We have proved experimentally the use of this termination on 4H-SiC and 6H-SiC for high voltage Schottky barrier diodes and Schottky UV photo-detectors, respectively [3].

In this paper we use the oxide ramp edge termination for *pn* shallow junction barrier photodiodes. Extensive measurements based on OBIC technique have proved the high efficiency of SiC photo-diodes with oxide ramp profile. Medici simulations have also been carried out to demonstrate the excellent UV detection sensitivity of the fabricated SiC samples.

Structure

The *pn* junction photo-detectors, with oxide ramp termination, were realized on nn^+ 6H-SiC wafer. The n^+ substrate has a typical resistivity of $0.03\Omega\text{cm}$. The parameters of n epitaxial layer are $x_e=8\mu\text{m}$ and $N_d=8.5\times 10^{15}\text{cm}^{-3}$.

The main technological challenge of the targeted SiC diode is fabrication of an efficient oxide ramp profile [3]. A field plate termination is achieved by anode metal overlapping of the oxide ramp region. In order to obtain different oxide ramp angles various combinations of oxide layers have been

deposited on test samples. Two oxide ramp profiles, shown in Fig. 1, have been obtained. The first one is a typical ramp oxide termination, (Fig. 1a) while in the second one, the oxide profile, has two ramps (Fig.1b) and corresponds to a two level field plate configuration. This profile, which has been obtained using only a photolithographic process, is also very attractive termination.

For *pn* photo-detectors two insulating layers comprised of an undoped oxide layer and an 8% phosphorus doped oxide layer, with a total thickness of 1.1 μm , were grown onto the epilayer. Then two steps wet etching were used: an initial etching in a standard oxide etch solution followed by an over-etching in a P-etch solution. An oxide ramp termination as in Fig.1a was achieved. The oxide ramp angle is smaller than 4 $^\circ$.

A layout and a cross section of *pn* detectors with oxide ramp termination are shown in Fig. 2. After oxidation, Ni e-gun evaporation is performed on the heavily doped backside substrate and annealed at 1000 $^\circ\text{C}$ to obtain a good ohmic contact (M3 in Fig. 2.).

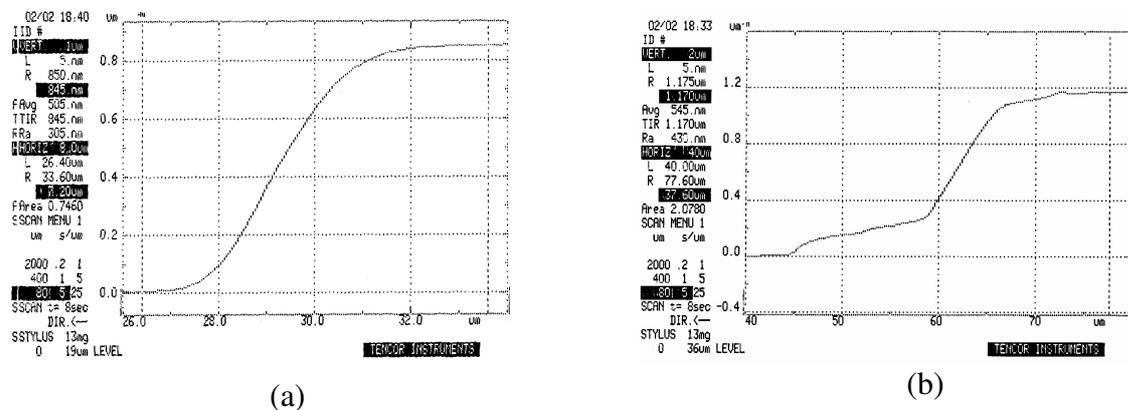


Fig. 1 Two types of oxide ramp termination: (a) with a single ramp and (b) with two ramps.

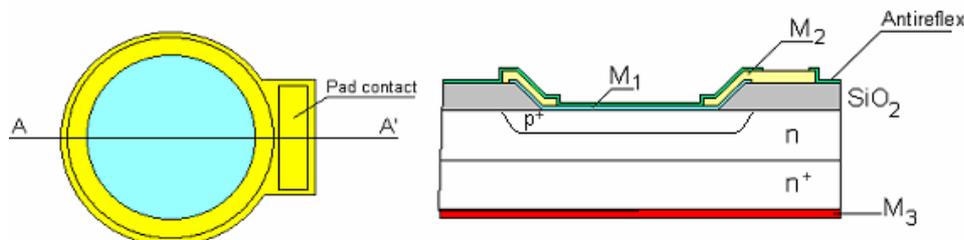


Fig. 2 Layout and cross-section of Schottky photo-detector structure.

The p^+ layer with a surface doping concentration of about 10^{19} cm^{-3} and a thickness of $0.15\ \mu\text{m}$, was formed by Al implantation. 140\AA platinum was deposited and patterned by lift-off as the anode ohmic contact on p^+ layer. Platinum (M1 in Fig. 2) is a transparency metal for the photon flux. In order to achieve the same surface potential two layers of Ti ($1000\ \text{\AA}$) and Al ($1\ \mu\text{m}$) were deposited on front-side (M2 in Fig. 2). An antireflection coating (which covers M1) is used to reduce the absorption losses.

Measurements

The SiC photo-detectors, with oxide ramp termination, have been optical tested using the OBIC technique. For these measurements, an Ar^{++} laser, which generates a UV fascicle with a wavelength in the range from 300 nm to 363.8 nm, is focused on the device and is modulated by a chopper of 70 Hz. The measurements have been performed at room temperature at several wavelengths, from the above mention interval, which ought to correspond to a light penetration depth in the 4H-SiC a little bigger the $11\ \mu\text{m}$. A synchronic sensor detects the local variations of the photocurrent induced by the incident flux, which has a diameter of $4\ \mu\text{m}$, on the device. A computer controls 2 motors, which

assure the left to right and up to down movement (with a 3 μm step) of the test sample under the laser beam, and registers the measured current as a function of the position of the UV fascicle, respectively. The output power of the laser beam was 10mW (which corresponds at an incident power density of 0.76 W/cm^2) or 20 mW.

Results. Discussion

Fig. 3 presents the measured photocurrent dependence as a function of UV laser beam position on the sample. A current peak appears on the two sides of the sample at any bias and wavelength, respectively. The right peak is always higher than the left peak. This asymmetry can be due to a difference in the surface planarity of the sample. When the wavelength is increased, the left peak becomes higher. The peak also rises with the reverse bias of the photo-detector and with incident laser beam power (Fig. 3a.). Normally, the current peak is multiplied by a factor of 2, for an increase of the incident light power from 10 to 20mW (Fig. 3b.).

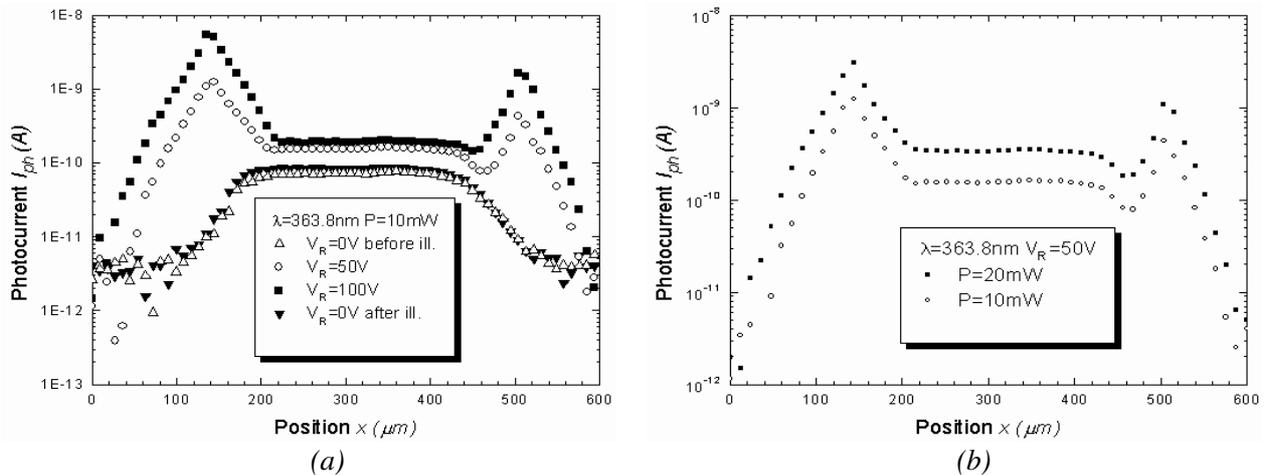


Fig. 3 J_{ph} measured on pn detectors at 363.8 nm: (a) bias and (b) incident power effect

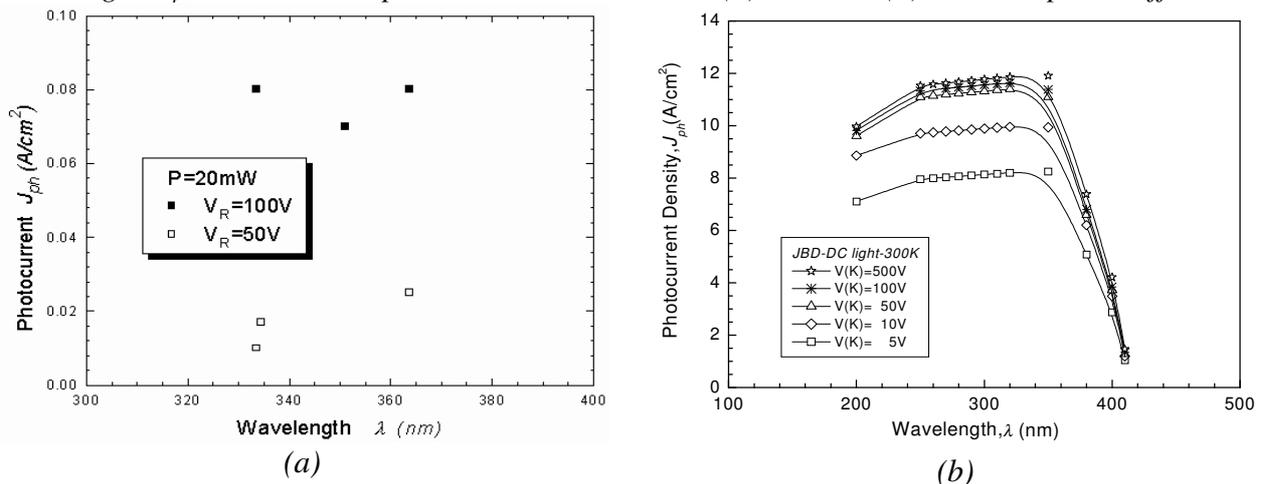


Fig. 4 (a) Measured and (b) simulated photocurrent vs. wavelength for different reverse biases

A comparison of measured and Medici simulated data [3] of the photocurrent density at different light wavelengths and biases are shown in Figs. 4. We can observe a significant increase of the photocurrent density at high voltage detector bias. Note, that the measurement data shows a higher increase than the one predicted by the simulations.

The differences between the measured and Medici simulated data for photocurrent density are due to different power densities use in measurements and simulations, respectively. Also, note that the simulated data (Fig. 4b) corresponds to a uniform light illumination of the sample.

Figs. 5 show simulated transient response of two photo-detectors for various pulse light durations (from 40 to 400ps). During the pulse light time the photocurrent increases exponentially. It subsequently decreases when the recombination process becomes predominant. At lower doping of n -epilayer the photocurrent density increases and the bias influence is reduced (Fig 5b). The effect of the photodiode bias voltage is more important in this case (Figs. 5) than for a uniform light illumination (Fig. 4b). The differences between the simulated photocurrent density (Figs. 5) and the measured ones (Fig. 4a) can be explained by the very short pulse time width used in the Medici investigation.

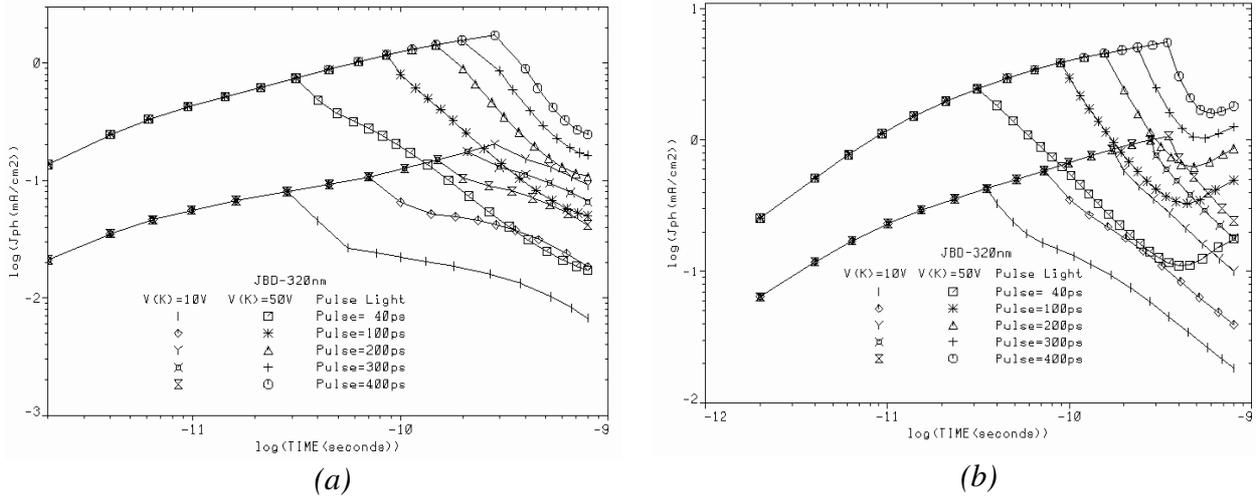


Fig. 5 Simulated transient photoresponse of pn detector having a n -epilayer with $x_e=8\ \mu\text{m}$ and: (a) $N_d=8.5\times 10^{15}\ \text{cm}^{-3}$ and (b) $N_d=2\times 10^{15}\ \text{cm}^{-3}$.

Conclusions

A simple termination of the planar pn junction structure was proposed and experimented on 6H-SiC photodiodes. This technique, which is based on oxide etching under small angles around anode contact window, assured a field plate surrounding the anode contact window. Extensive investigation have shown that an oxide with the thickness more than $1\ \mu\text{m}$ and ramp oxide profile smaller than 4° are recommended for a efficient edge termination.

We demonstrated that this termination is highly suitable for UV photo-detectors. The response at a pulse light excitation has been investigation. Measurements based on OBIC method have been performed at different biases of the device and various wavelengths and power of the incident laser. The photocurrent density increases with reverse bias and light power level and is almost flat over the spectral range from 300 to 360nm. The measured reverse voltage dependence is higher than the one predicted by the simulations. This photocurrent behavior was predicted by Medici simulations.

The transient response to a very short pulse light excitation has also been investigated. Owing to high photocurrents and high speed pn SiC photodiodes are a strong candidate for transient UV detection.

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