Demonstration of the First 4H-SiC Metal-Semiconductor-Metal Ultraviolet Photodetector

Z. Wu\textsuperscript{1,2}, X. Xin\textsuperscript{1}, F. Yan\textsuperscript{1}, J. H. Zhao\textsuperscript{1}
\textsuperscript{1} SiCLAB, ECE Dept., Rutgers University, 94 Brett Road, Piscataway, NJ 08854, USA
\textsuperscript{2} Physics Department, Xiamen University, Xiamen, China

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Abstract. This paper demonstrates the first 4H-SiC metal-semiconductor-metal (MSM) UV photodetector. Two types of MSM photodetectors are fabricated for comparison: one in p-type 4H-SiC and the other in n-type 4H-SiC. The n-type SiC photodetectors show a low dark current less than 10nA at -15V bias while the p-type ones show a lower dark current of 0.3nA at -25V. Photoresponsivity is measured from 200nm to 400nm and found to increase linearly with the increase of the bias. A very high peak responsivity of 50A/W is measured for n-type SiC MSM UV photodetector. The responsivity ratio of solar-blind UV to visible is larger than 1000, indicating a good visible-blind performance, immune to any visible and IR background noise, which is better than any Si UV detectors or other types of 4H-SiC UV detectors reported to date.

Introduction

SiC is well known for its applications in high power, high temperature, high frequency and high radiation environments. It also has many unique properties for UV detection based on either p-n junction or Schottky barrier structures [1-7], including ultra low dark current, inherent insensitivity to visible and IR light because of the large bandgap, and a large ratio $k$ of hole to electron impact ionization coefficients, which makes SiC especially attractive for low noise UV APD or photon counter applications. In comparison, GaN has a $k$ value close to unity. In addition, SiC photodetectors like many other SiC power devices provide much better radiation tolerance and can operate at significantly higher temperatures. These advantages make SiC superior to Si or GaN devices in UV and X-ray detection. Of all SiC photodetectors, metal-semiconductor-metal (MSM) photodetectors have many advantages, including easy fabrication, simple wafer structure and excellent potential to achieve high quantum efficiency and high speed [5, 8]. In this paper, the first demonstration of 4H-SiC metal-semiconductor-metal (MSM) UV photodetector is reported. Two types of MSM photodetectors are fabricated for comparison: one in p-type 4H-SiC and the other in n-type 4H-SiC.

Device Fabrication

Low doping concentration and narrow finger spacing are critical for achieving better performance of MSM photodetectors. The 4H-SiC wafer used in this experiment has a 1.5$\mu$m p-type epitaxial layer with doping level at $3\times10^{16}$/cm$^3$ grown on top of a 3.4$\mu$m n-type epitaxial layer with doping level at $3.1\times10^{15}$/cm$^3$. The substrate is n+ doped. It is not a wafer particularly designed for MSM UV detector fabrication but is a structure that can be used to compare UV detectors simultaneously fabricated in n-type and p-type 4H-SiC. To compare the MSM device performance on both p-type and n-type SiC, part of the top p-type layer is removed by Inductively Coupled Plasma (ICP) dry etching so that MSM UV detectors can be fabricated on n-type surface as well as on p-type surface on the other half at the same time. After ICP dry etching, the surface inevitably deviates from the original high surface quality of the epilayer. After ICP dry etching, the sample is thoroughly
cleaned by wet chemical RCA cleaning before oxidation. A sacrificial oxide layer is grown before passivation oxidation to reduce the surface roughness and remove any contaminations. After removing the sacrificial layer, passivation oxidation is done which further consumes part of the top thin layer, resulting in a final thermal oxide layer of ~ 60nm. Contact window is opened by wet etching instead of dry etching to minimize subsurface damage due to dry etching so that better Schottky contacts can be achieved. Planar interdigitated MSM Schottky contact of Al is defined by a lift-off processing. Thick Al overlay bonding pad is finally formed by wet etching.

Fig.1 Top view and cross-sectional illustration of a fabricated 4H-SiC UV MSM photodetector with the finger width and spacing both equal to 2.5μm and a finger length of 200μm.

The interdigitated area of the photodetectors is designed to be 100×200μm². Fig.1 shows the cross-sectional view of the device and the photo of a fabricated MSM photodetector with a finger width and spacing of the interdigitated electrodes of 2.5μm. The bonding pad is 100×100μm². Dimensions for the other finger spacing include 3.5μm and 5.5μm for n-type UV detectors and up to 9.5μm for the p-type UV detectors.

Fig.2 Dark and illuminated I-V curves of MSM UV photodetectors for 4H-SiC.
Results and Measurements

The photocurrent and dark current of the fabricated detectors have been measured and are shown in Fig. 2. Xe-light [4] source is used for photocurrent measurements. The calculated flat band voltages are about 19V and 180V for the n/n⁺ and p/n/n⁺ structures, respectively. However, higher reverse voltage data is needed to verify the flat band voltages.

The MSM detector fabricated in p-type SiC shows a low dark current of less than 0.3nA at 25V reverse bias. The n-type detector however, shows a higher dark current of 1.3nA at a reverse bias of 5V. The dark currents for both type devices are still below 10nA at a reverse bias of 15V, and the photocurrent is at least one order of magnitude higher than the dark current. The higher dark current in n-type MSM detectors is likely due to dry-etching induced surface degradation after removing the 1.5µm p-type surface layer. The sacrificial oxidation improves the surface conditions for the n-type sample but it seems that the surface quality even after sacrificial oxidation is not fully recovered. The finger spacing dependence of the dark current is shown in Fig. 3 and Fig. 4 as a function of reverse bias. It is very clear that the n-type has higher dark current and stronger spacing dependence than the p-type. As the MSM finger spacing increases, the dark current drops in n-type devices, but keeps constant in p-type devices. More works are needed to clearly identify the source of the dark current.

The photoresponse spectra of the MSM detectors are measured and calibrated using the system described in [4]. The photoresponsivity of the MSM detectors under different biases is shown in Fig. 5 for the n-type MSM detector and in Fig. 6 for the p-type MSM detector. The photoresponsivity is reasonably flat over a wide range, with a peak response wavelength at about 275nm and a cut-off wavelength at about 375nm, which is attractive for visible-blind detector applications. The flat responsivity around 275nm is a blessing for solar-blind detectors, which emphasize the photoresponsivity from 245nm to 285nm. The ratio of the photoresponsivity at 275nm to that at 375nm is greater than 1000, implying that the MSM detectors have a greatly improved visible-blind performance compared to other SiC UV detectors [4].
It is seen from Fig.5 and Fig.6 that the responsivity increases with the reverse bias voltage. At -45V, the responsivity reaches a high value of about 50A/W for MSM UV detectors in n-type 4H-SiC. The responsivity for the MSM UV detectors in p-type structure is lower, which is likely due to the top p-type absorption layer being thinner than that of the n-type absorption layer. In Fig.6, the responsivity increases with bias first then saturates at the bias voltage about 40V, implying that there is little photoconductive gain in this device [8]. Further work is to be focused on as-grown thicker epi layers with semitransparent finger contact.

**Conclusions**

The first MSM 4H-SiC UV photodetector has been demonstrated. A peak responsivity of 50A/W, the highest to date for non-avalanche SiC detectors at 275nm and a dark current of 10nA at 15V bias has been achieved for n-type detectors. The ratio of responsivity at solar blind UV to visible is greater than 1000, which is better than Si or other SiC UV detectors. It will be interesting to fabricate UV detectors with semitransparent Schottky metal to achieve higher photoresponsivity.

**References**