Demostration of the First 4H-SiC EUV Detector with Large Detection Area

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Introduction:
Ultraviolet (UV) and Extreme Ultraviolet (EUV) detectors are very attractive in astronomy, photolithography and biochemical applications. For EUV applications, most of the semiconductor detectors based on PN or PIN structures suffer from the very short penetration depth. Most of the carries are absorbed at the surface and recombined there due to the high surface recombination before reach the depletion region, resulting very low quantum efficiency. On the other hand, for Schottky structures, the active region starts from the surface and carriers generated from the surface can be efficiently collected. 4H-SiC has a bandgap of 3.26eV and is immune to visible light background noise. Also, 4H-SiC detectors usually have very good radiation hardness and very low noise, which is very important for space applications where the signal is very weak. The EUV photodiodes presented in this paper are based on Schottky structures. Platinum (Pt) and Nickel (Ni) are selected as the Schottky contact metals, which have the highest electron work functions (5.65eV and 5.15eV, respectively) among all the known metals on 4H-SiC.

Device Fabrication:
The 2-inch 4H-SiC wafer for Schottky EUV photodiodes has an n- epilayer on an n+ substrate. A thermal oxidation layer is deposited on the wafer at 1050°C for 3 hours as the passivation layer, followed by a 300nm PECVD oxidation layer and a 250nm PECVD Si_3N_4 layer. Ni is sputtered at the backside n+ layer after removing the oxidation layer by hydrofluoric acid. The n-contact metal is annealed at 1050°C in N_2-H_2 forming gas. After annealing, the front side 2mm×2mm Schottky contact window is opened by ICP dry etching and HF wet etching. A semi-transparent metal layer (75Å Pt or 100Å Ni) is deposited as Schottky contact metal with lift-off processing. Finally a thick Schottky metal layer and a gold layer is sputtered in the bonding pad region. The top view and the cross-section view are shown in the insets of Fig. 1.

Characterizations:
The I-V measurement is made by HP 4145B (Fig. 1). 4H-SiC has an electron affinity of 3.60eV [1]. From the forward current, based on thermionic emission theory, the barrier height is estimated as 1.42eV and 1.68eV for Pt and Ni, respectively. The work functions of the Pt and Ni can be calculated as 5.02eV and 5.28eV. The ideality factor is 1.1 for the Pt Schottky diode and 1.3 for the Ni Schottky diode. Also a previous study [2] for 4H-SiC Schottky contact indicates that the Schottky barrier height and metal function follows the relationship of $\Phi_B=0.7\Phi_M-1.95$, with Φ_B being the barrier height and Φ_M being the metal function. The work functions are thus calculated as 4.8ev for Pt and 5.18eV for Ni. The results imply the existence of surface defects and inhomogeneous Schottky contact for these large area devices. Another possible reason for the parameter deviations from the ideal case is the thickness of the metal. By reducing the film thickness to 100Å or less, the Schottky barrier height might not be the same as the case of very thick film. More detailed analysis requires temperature-dependence measurements.

The spectral quantum efficiency (QE) of the Schottky diodes is measured from 400nm down to 20nm, covering all the UV region and most of the EUV region (Fig. 2 and Fig. 3). The McPherson system measures the photo response from 21.5nm to 77.5nm, by ionizing Argon. The Acton system uses Deuterium gas and operates from 120nm to 220nm. Both RUECE and

Oriel system use Xenon lamp as the light source. The peak QE in the UV range appears at 260nm~280nm, with a value of ~45% for Pt and ~40% for Ni. In the EUV range, between 120nm to 200nm, the devices show reasonable QE from 4% at 120nm to about 15% at 200nm. For the wavelength below 100nm, the "increase" of QE indicates that multiple electron-hole pairs are generated in the semiconductors by one photon. For comparison, a measured 1.5mm×1.5mm 4H-SiC PIN diode has a 63% QE at 270nm. But the QE quickly dropped to 0.06% at 213.8nm, and about 0.015% at 160.8nm. Most of the carriers are believed to be recombined on the surface. The electron-hole pair creation energy W is one of the material property of a semiconductor. Due to the lack of data of 4H-SiC spectral refraction index (n and k) in the UV and EUV range, it is hard to calculate the reflection and absorption due to the semitransparent films. By assuming $s_r=1$ and taking the absorption coefficient of 6H-SiC, the upper limit of the pair creation energy could be determined as 5eV in the EUV range.

Conclusion

The 2mm×2mm 4H-SiC EUV detectors show high quantum efficiency in almost all the UV (40~45%) and EUV range (4~15%). The barrier heights of Ni and Pt Schottky contact are estimated according to the forward current measurement and are closed to the ideal parameters.

References

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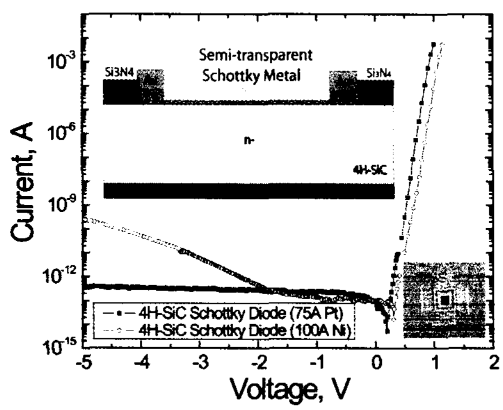

Fig. 1 I-V measurement for the SBDs. The top view and cross-section view is shown in the inset of the figure.

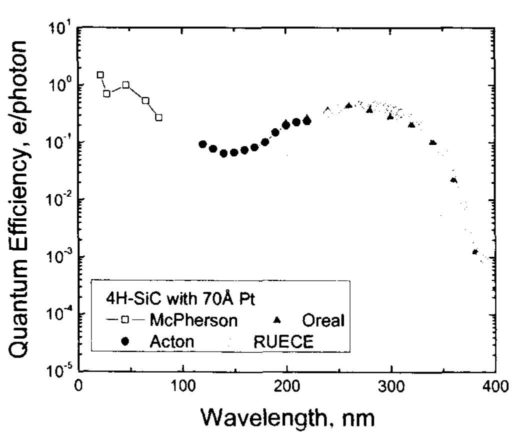

Fig. 2 QE measurement and pair creation energy for Pt SBDs.

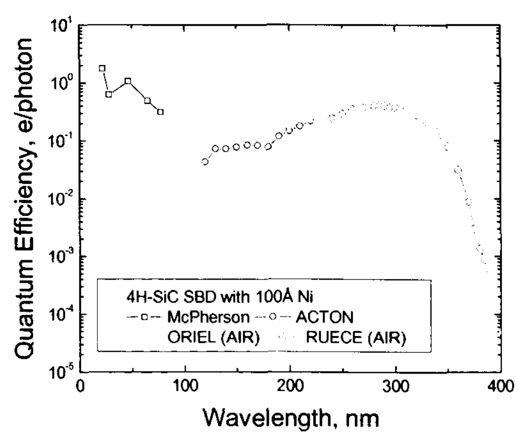

Fig. 3 QE measurement and pair creation energy for Ni SBDs,

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The first 4H-SiC extreme ultraviolet (EUV) photo detector has been designed, fabricated, and characterized. Spectral quantum efficiency (QE) from 20nm to 400nm is determined. The device has a 2mm×2mm active area and less than 1pA leakage current at low bias. The peak of QE is 40%~45% around 270nm. Between 100~200nm, the detector QE is about 4%~15%. EUV light generate multiple electron hole pairs in the wavelength range from 21nm to 78nm.

Index Terms: SiC, Photodetectors, EUV