ULTRAHIGH RESPONSIVITY OF DIAMOND-BASED SOLAR-BLIND PHOTODETECTORS USING HYDROGEN PLASMA TREATMENT

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Novelty / Progress Claim(s)

We report the high sensitivity solar-blind deep-ultraviolet detector based on hydrogenated (H)-terminated Ib-type diamond substrate. The photodetector shows an ultrahigh responsivity of 16683 A/W with a superhigh external quantum efficiency (EQE) ~ 10^6%, far superior to the reported semiconductor solar blind PDs.

Background / State of the Art

Solar blind deep-ultraviolet (UV) photodetectors (PDs) detect the UV light, and it is not sensitive to the wavelengths longer than 280 nm [1]. Recently, numerous PDs with varied structures based on MgZnO [2], AlGaN [3], Ga_2O_3 [4], and diamond [5] had been reported. Nevertheless, the doping process of MgZnO and AlGaN is difficult to control precisely, and the high oxygen vacancy concentration and extremely low thermal conductivity of Ga_2O_3 cause the higher dark current and lower heat dissipation speed rate. Diamond is considered as the most desirable candidate for solar blind PDs owing to its fascinating properties, such as ultrawide bandgap (5.5 eV), high carrier mobility, high breakdown field, super-high thermal conductivity, and high radiation resistance [6]. Researchers typically attempt to grow high quality homogeneous and heterogeneous epitaxial diamond on commercial Ib diamond to fabricate high performance PDs. In spite of continuous efforts have been devoted, the responsivity still needs to be greatly improved to cope with multifaceted applications. Herein, we only treated the surface of commercial type-Ib diamond with simple hydrogen plasma to fabricate PDs with ultrahigh performance, instead of preparing epilayer. The responsivity and EQE reach to 16683 A/W and 9.41×10^6% respectively.

Description of the New Method or System

The H-terminated Ib diamond based-PDs with the facile metal-semiconductor-metal (MSM) device configuration were fabricated, as shown in **Figure 1**. The surface of Ib diamond treated with hydrogen plasma forms two-dimensional hole gas (2DHG) due to the adsorption of negative polar ions. The duration of hydrogen plasma treatment was set at 20 min and 30 min to tailor the density of 2DHG by using a microwave plasma chemical vapor deposition (MPCVD) apparatus. The photoresponse of the device was measured from 210 nm to 630 nm.

Experimental Results

The current of the PD with 20 min H-plasma treatment reaches to 7.00×10^{-8} A under 220 nm UV light from 1.99×10^{-12} A in dark at 5 V bias voltage (**Figure 2**). **Figure 3** represents the dark current of the 30 min hydrogenated detector is 2.34×10^{-5} A at 5 V, seven orders of magnitude higher than that of the 20 min hydrogenated detector, illustrating that the 2DHG density is proportional to the hydrogen plasma processing time. In addition, the photocurrent of the 30 min hydrogenated detector reaches an ultrahigh value of 1.90×10^{-4} A at 5 V. The responsivity and EQE of the PD with 30 min H plasma treatment are 16683 A/W and 9.41×10^6 % @5 V respectively, which are much higher than those of the PD with 20 min H plasma treatment (**Figure 4 and Figure 5**), demonstrating that the PD with 30 min H-plasma treatment has a higher photoresponse performance to solar blind DUV light. **Figure 6 and Figure 7** show the time-dependent photoresponse of the PDs, the current of the PDs increases and decreases with the light on and off, the response speed is low because the accumulation and recombination of carriers takes a long time. **Figure 8** and **Figure 9** illustrate the dependence of the responsivity on the wavelength of light for PDs treated with H-plasma treatment for 20 min and 30 min, respectively. The PDs exhibit ultra-high responsivity in the solar blind deep ultraviolet range, but as the wavelength increases, it shows a sharp downward trend. The R_{220nm}/ R_{400nm} of PDs with 20 min and 30 min H plasma treatment are 8.3×10^4 and 6.6×10^5, respectively, revealing that the 30 min hydrogenated PD has excellent spectral selectivity.

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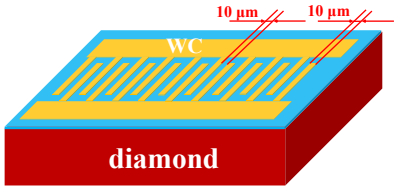

Figure 1: Structure diagram of the diamond photodetector.

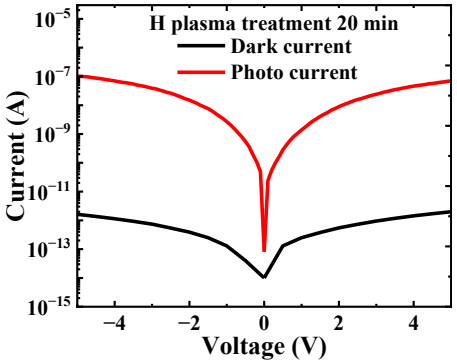

Figure 2: Dark and photo current-voltage characteristics of photodetector based on diamond with 20 min H - plasma treatment.

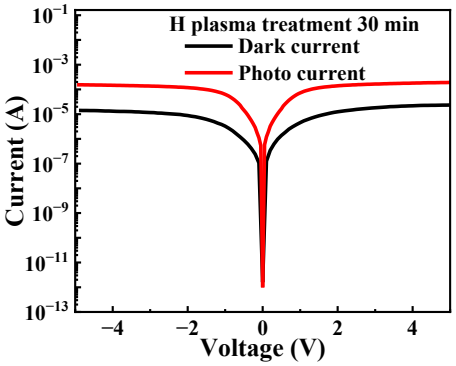

Figure 3: Dark and photo current-voltage characteristics of photodetector based on diamond with 30 min H plasma treatment.

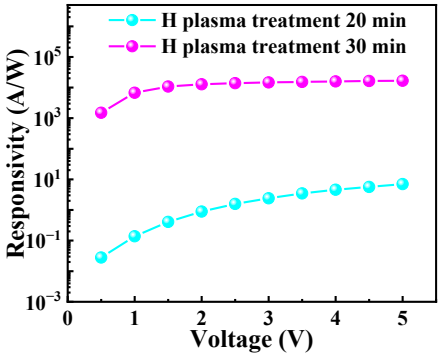

Figure 4: Responsivity of the photodetectors based on diamond with 20 min and 30 min H plasma treatment.

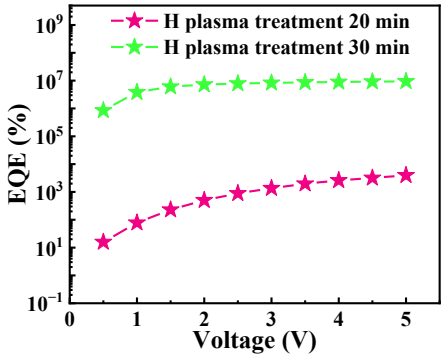

Figure 5: External quantum efficiency of photodetectors based on diamond with 20 min and 30 min H plasma treatment.

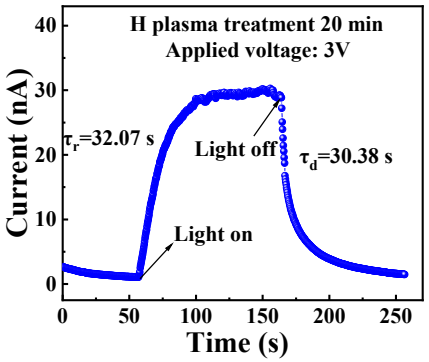

Figure 6: Time-dependent photoresponse of the photodetector based on diamond with 20 min H plasma treatment.

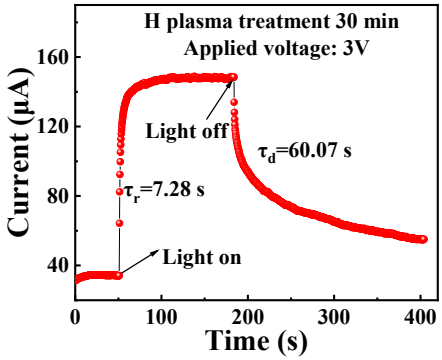

Figure 7: Time-dependent photoresponse of the photodetector based on diamond with 30 min H plasma treatment.

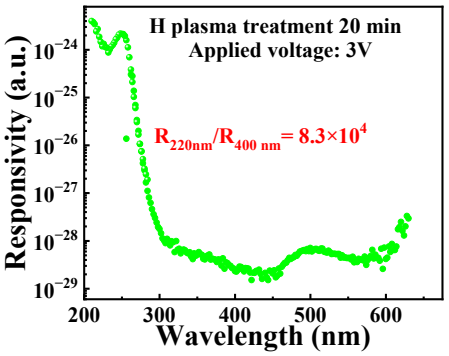

Figure 8: Spectral responsivity of the photodetector based on diamond with 20 min H plasma treatment.

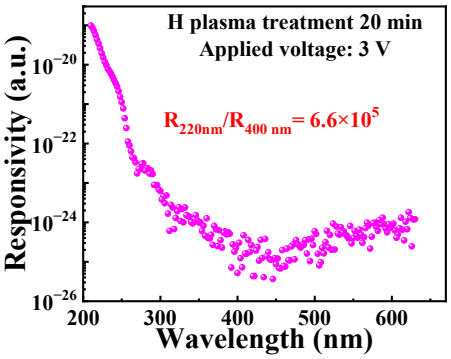

Figure 9: Spectral responsivity of the photodetector based on diamond with 30 min H plasma treatment.

References

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