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Sensitivity Enhancement of Metal-oxide-semiconductor Tunneling Photodiode with Trapped Electrons in Ultra-thin SiO_2 Layer

Tzu-Yu Chen and Jenn-Gwo Hwu*

Graduate Institute of Electronics Engineering /
Department of Electrical Engineering,
National Taiwan University, No. 1, Sec. 4, Roosevelt
Road, Taipei, 10617 Taiwan
Tel: 886-2-33663646, Fax: 886-2-23671909,
*hwu@cc.ee.ntu.edu.tw

The enhancement in the photo sensitivity of ultra-thin SiO_2 based tunneling photodiode is demonstrated in this experiment. Treatments of negative constant voltage stress (negative CVS) with -2 V for 700 s are applied onto the SiO_2 based tunneling photodiode with Al/SiO_2/p-type structure. Figure 1 shows the photocurrents and dark current with and without the negative CVS. The photocurrent was measured with a light intensity of 20 mW/cm^2. The dark current at $V_G > 0$ after applying the negative CVS decreases greatly as compared to the one without the treatment. And the photocurrent also decreases but with a little amount. The figure shows that the dark currents with and without the negative CVS treatment almost merge together when the device is biased into accumulation. Besides, the photocurrents with and without the treatment also show the similar behaviors. These behaviors indicate that the device is prior to the production of stress-induced leakage current or the SiO_2 breakdown. Both photocurrent and dark current with and without the treatments diverge at $V_G > 0$. Thus, the sensitivity of this device is obtained in the positive voltage region. The sensitivity is defined as the ratio of photocurrent to dark current at $V_G > 0$. Clearly, the sensitivity is 1.14×10^4 at V_G= 1 V for the device with negative CVS. On the contrary, the sensitivity of the device without the treatment is 5.44×10^2 at V_G= 1 V. It shows that the enhanced sensitivity is about 21 times larger for the device with the negative CVS than the device without the negative CVS.

The presumable mechanism of the reduced dark current and photocurrent at $V_G > 0$ after the negative CVS is thus proposed for this observed phenomenon. Figure 2 shows the capacitance-voltage (C-V) curves with and without applying the negative CVS. The insets are the enlarged views at flat-band region. It seems that the two C-V curves are almost with the same value under any bias. However, if the figure is enlarged at the flat-band voltage (V_{FB}), the difference between the C-V curves is observed. The V_{FB} shows a positive shift after applying the negative CVS onto the device. This positive shift indicates that electrons are trapped in the SiO_2 layer. The amount of the trapped electrons is obtained from the positive V_{FB} shift. Therefore, we summarize that the trapped electrons in the SiO_2 result in the reduced dark current and photocurrent at $V_G > 0$.

Different amounts of trapped electrons are obtained after applying various negative CVS. They result in different extent of the reduced dark current and photocurrent. Figure 3 shows the dark current and photocurrent after various negative CVS with -2 V, -1.5 V, and -1 V for 700 s. It is observed that both the dark current and photocurrent increase with the decreasing amounts of trapped electrons. Thus, the sensitivities of the devices with different amounts of trapped electrons could be derived. Furthermore, the appropriate amount of trapped electrons resulting in the maximum value of the sensitivity also would be obtained.

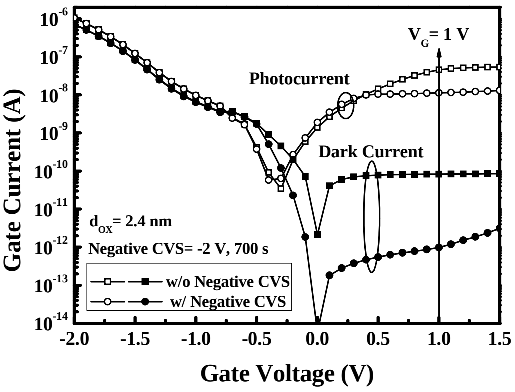

Figure 1. Photocurrent and dark current of ultra-thin SiO_2 based tunneling photodiode with and without applying -2 V negative CVS.

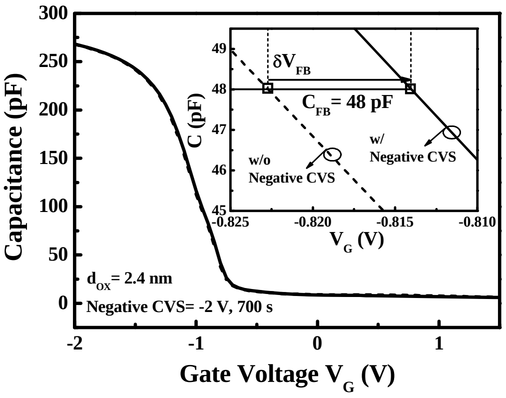

Figure 2. C-V measurements of ultra-thin SiO_2 based tunneling photodiode device with and without applying -2 V negative CVS.

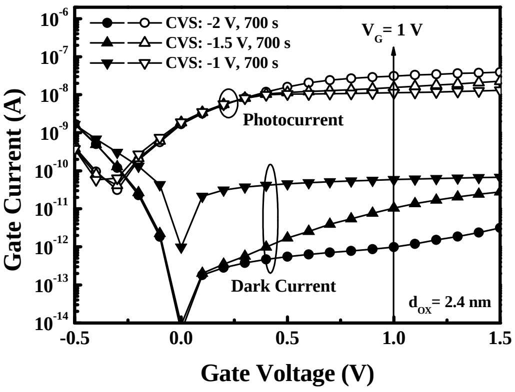

Figure 3. Photocurrent and dark current of ultra-thin SiO_2 based tunneling photodiodes after applying -2 V, -1.5 V, and -1 V negative CVS.