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Photo-active traps effect on photo-detection time of single electron photodetector

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ABSTRACT

In this paper we report the photo-trapping effect of photogenerated charge in a few numbers of silicon nanocrystals (Si-NCs) embedded in SiO_2 layer tunnel oxide of small area single electron photodetector (Photo-SET or nanopixel). Using Current-Voltage measurements under illumination (photo-I–V) we find the photo-active traps effect in inversion zone at room temperature. Random Telegraphic Signal under illumination (photo-RTS analysis) confirms that is a photo-generated active trap inside into tunnel oxide layer ($E_{photo-act}\sim 0.2\ eV$) and capture section: $\sigma\sim 8.72\times 10^{-17}\ cm^2$). Moreover, an increasing about *10 pF* in capacity's values in the inversion region for inverse high voltage applied under photo-excitation at low temperature have been marked using photo-Capacitance-Voltage (photo-C–V) measurements. This result confirms the contribution of photo-active traps to better dots photo-charged. The increase of light excitation time-duration, increase the hysteresis width. At *100* μW optical power and *595* nm wavelength, the hysteresis width has their saturation for a 0,05V/s romp speed, and consequently, SiO_2 will not behave a dielectric, but as a metal. So we make think that total capacity of structure no more corresponds to the capacity related to the oxide, but to all structure capacity values. The nanopixel photo-detection time (∼400 s) estimated from the flat band evolution in time is affected by photo-active oxide traps presence.

1. Introduction

Current photodetectors mainly use the nano-crystalline inorganic elemental semiconductors, such as III–V semiconductors. Photodetectors made of solution-processed semiconductors — which include silicon nanocrystlas have recently emerged as candidates for the new generation. The silicon nanocrystals (Si-NCs) have been shown to possess intriguing properties for single charge photo-detection. Such as this proprieties we can cited: very fast optical transition [1], multiple carrier generation [2] and band-gap control with nanocrystals size [3–5]. Recently, we study the contribution of photo-generated charges in Si-NCs photo-charging/discharging mechanism [6]. Where we can confirm that the Si-NCs charging/discharging

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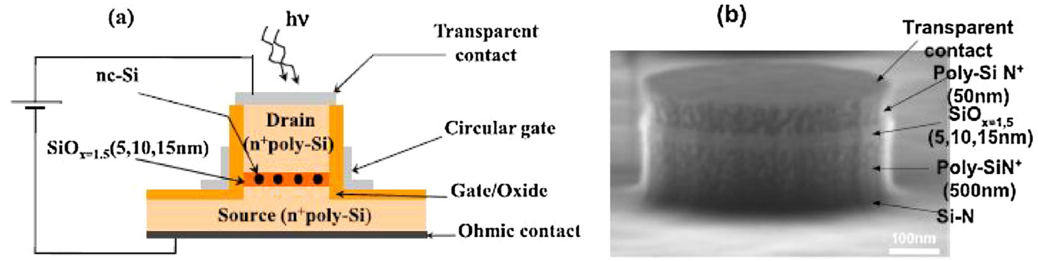

Fig. 1. (a) The schematic cross-sectional structure of nanopixel (Photo-SET); (b) SEM micrograph of nanopixel with 100 nm diameter.

photo-response time is influenced by the photo-generated-holes lifetime in the Si-NCs [6]. Moreover we confirm the direct exchange of photo-generated charges between Si-NCs and interfaces traps [7]. In this recent work, we study the effect of photo-active traps to photo-detection time of our nanopixel, using I–V, *RTS* and C–V measurements under illumination.

2. Experimental devices

The single electron photodetector (Photo-SET) or nanopixel was developed in the Sherbrooke University combining nanolithography and reactive ion etching (RIE) process. The schematic cross-sectional structure of nanopixel device discussed in this paper is shown in Fig. 1(a). We report the fabrication and insulation of nanopillars in which a layer of silicon rich oxide (SRO) deposited by low-pressure chemical vapor deposition (LPCVD) is present between two layers of highly doped polysilicon. The NCs are formed by annealing the SRO in nitrogen environment. After the annealing, Si dots appear in thick and thin layers. The oxide is composed of silicon NCs (Si-NCs) embedded in SiOx = 1.5 layer. The thick SiOx = 1.5 layer presents spherical Si crystallites with an average size around 5 nm extracted from transmission electron microscopy (TEM) measurements. The NCs-Si density is about 1.6×10^{-11} cm^{-2}. A second annealing step in oxygen was also performed. We used e-beam lithography and dry etching to obtain the vertical structures. These nanopillars are fabricated with diameters of 2 μm, 500 nm, 200 nm and 100 nm. Fig. 1(b) shows the scanning electron microscopy (SEM) image of nanopillar with 500 nm diameters. It is possible to get structures as small as 50 nm in diameter thus containing about 2–4 NC-Si. The electrical insulation is provided by planar photosensititve resist: it was spun and then etched back by O_2 plasma. Then chromium/gold electrodes are made by lift-off on the top of the columns. The substrate is used for electrical continuity.

The C–V measurements were performed using a HP 4280A C m/1 MHz C–V plotter. The current-voltage (*I*–*V*) measurements were registered using a Keithley 238. In order to varied the wavelength and optical power, the illumination technique used consist to passing a light beam, through a monochromator, from a tungsten lamp through an input slit, which will allow us to vary the excitation light wavelength. Then, the beam obtained at the exit of monochromatic will be focused on the sample using a lens. The device allows illuminating the sample on the side of the active layer and the side of the transparent substrate. The emitted radiation is relatively monochromatic; its optical power is of the order of a μW.

3. Results and discussions

3.1. Photo-I–V measurements

Fig. 2 shows the Current-Voltage measurements of nanopixel under illumination (Photo-I–V), at room temperature (Fig. 2). This last figure (Fig. 2) proved that the light effect limited only in the inversion zone. At first, we make think that is a photo-active traps effect for the voltage range comprised between (−6 V to 0 V).

Fundamentally, we recall the relationship between the Si-NCs absorbance and photon energy; this relationship is proportional to $(E_{photon}-E_{g})^{2}$ where E_{photon} is the exciting photon energy and E_{g} is band gap energy [8]. This relationship confirms the Si-NCs absorbance increasing is directly related to increase the emitted energy photon increase. Moreover, we see that Si-NCs have a fast optical transition [1], so facilitate their photo-charging. In addition, the capture of photo-generated charges carriers by the Si-NCs will be better by their quantum confinement effects [9]. Based on this last arguments and on our previous works [6,7], we can confirm, that this light effect in the inversion region is related to Si-NCs photo-charging/discharging mechanism [6] or a photo-active traps effect.

In order to find the physics origin of this light effect, we will investigate the presence of traps photo-active by Random Telegraphic Signal analysis under illumination (photo-RTS analysis)

3.2. Photo-RTS analysis

The RTS analysis is more detailed in [10–13]. This analysis based on investigation of capture and kinetics emission of single defects by the traps center for fixed voltage and other parameter from the zone where we show the noise in the I–V curves.