Simulation of graphene photodetectors incorporating the photo-gating effect

Shingo Aida, Matsuto Ogawa and Satofumi Souma
Department of Electrical and Electronic Engineering, Kobe University,
1 Rokkodai, Nada, Kobe, 657-8501, Japan
E-mail: 202t201t@stu.kobe-u.ac.jp

Graphene-based photodetectors have been attracting great attention in recent years for their ability to detect weak optical signals, where the high electron mobility in graphene is beneficial for realizing the ultrafast photo detection. On the other hand, it has been proposed that high sensitivity can be realized by utilizing the photo-gating mechanism, where optical transparency of graphene and the strong electrostatic coupling between the graphene and photo-absorbing substrate play important roles. However, it has not been clarified theoretically enough how the sensitivity can be optimized by adjusting the device parameters such as the channel length and the back gate voltage. The aim of this research is to propose a scheme for the simulation of graphene photodetector (graphene/SiO2/p-Si structure) utilizing the photo gating effect and clarify the condition to obtain the high sensitivity. By calculating the current in graphene under the light illumination based on the tight-binding formalism and the top-of-barrier model, we estimated the photo-induced current and the resulting photo responsivity. Our calculations have shown that the photo responsivity originated from the photo-gating effect is significantly larger than that obtained by conventional photo-voltaic effect in the graphene channel itself, the detailed analysis of which is useful information for the design of graphene-based photodetectors.

Figure 1 shows the schematic illustration of graphene photodetectors discussed in this study and the capacitance-based model, which is used to calculate the current density flowing through the graphene channel. Figure 2 represents a photo-induced current density (left) and a responsivity (right), which is one of the most important figures of merit for photodetectors. A photo-induced current density is the difference between a current density in case the light is irradiated and that in case not irradiated. A responsivity is the ratio of photo-induced current to the total photon energy flowing into the upper surface of the graphene channel, which indicates the conversion efficiency from the optical signal to the electric signal. As demonstrated in Fig. 2, graphene photodetectors can realize 70 A/W, when the light power is 50 W/m^2 and the area of the graphene channel is 20 μm^2. Figure 3 shows the substrate voltage dependence of photo-induced current density for various light wavelengths (left) and the responsivity as a function of the intensity of light irradiated into the graphene channel (right). In these figures, we can recognize that a larger light intensity realizes a higher responsivity. For instance, the responsivity of 348 A/W is obtained under the light intensity of 600 W/m^2, which can be compared to recently reported experimental 321 A/W [1], meaning that our proposed simulation scheme is useful to interpret the experimental results and to design the higher responsivity photodetectors.

[1]S. Fukushima et al., Photogating for small high-responsivity graphene middle-wavelength infrared photodetectors Optical engineering **59**, 037101 (2020).

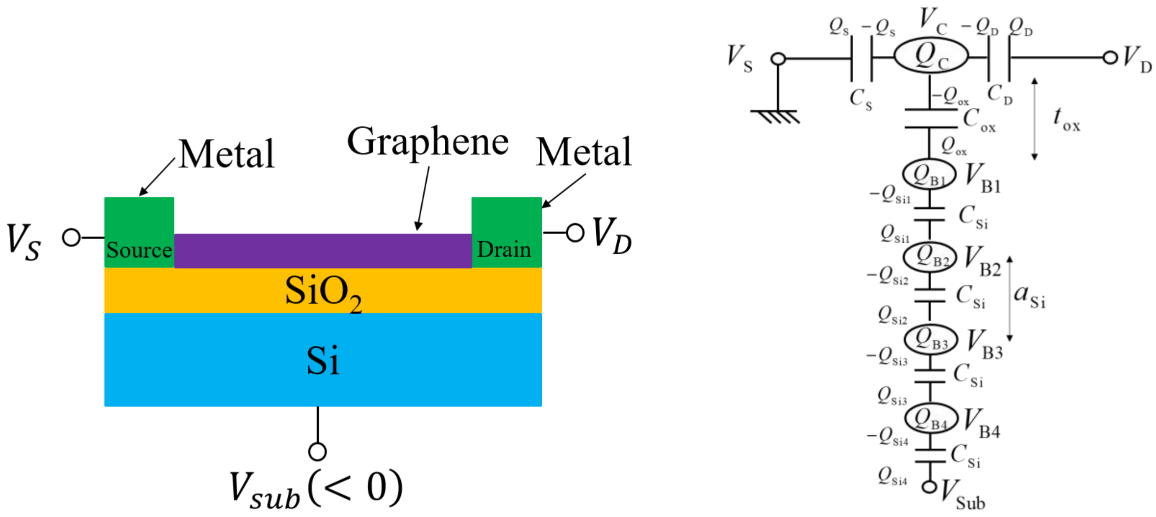

Fig.1: Schematic illustration of graphene photodetectors incorporating the photo-gating effect (left) and the capacitance-based model of the photodetectors (right).

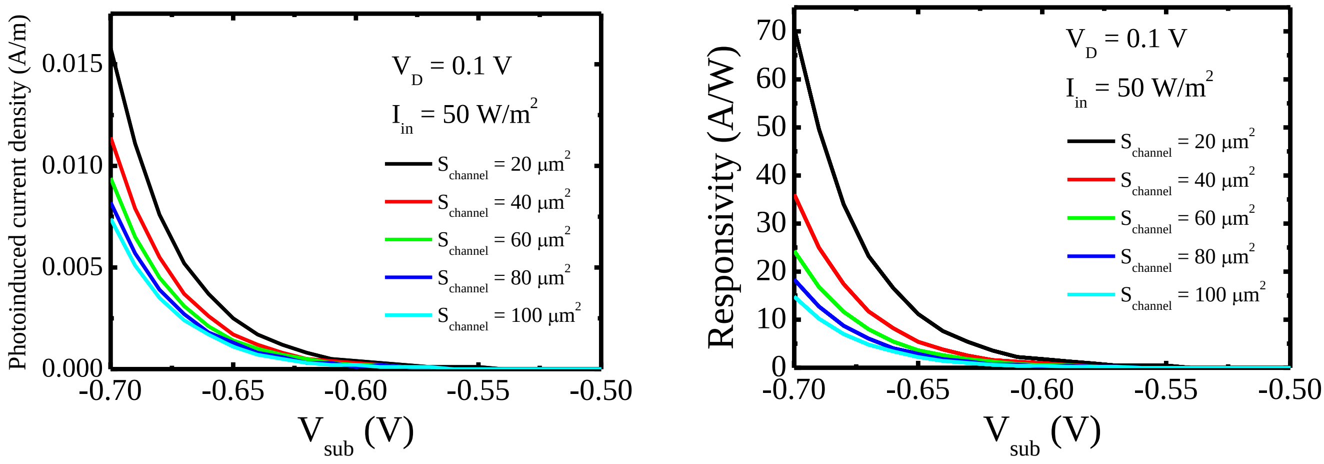

Fig.2: Photo-induced current density (left) and responsivity (right) as a function of the voltage applied at the bottom of the silicon substrate.

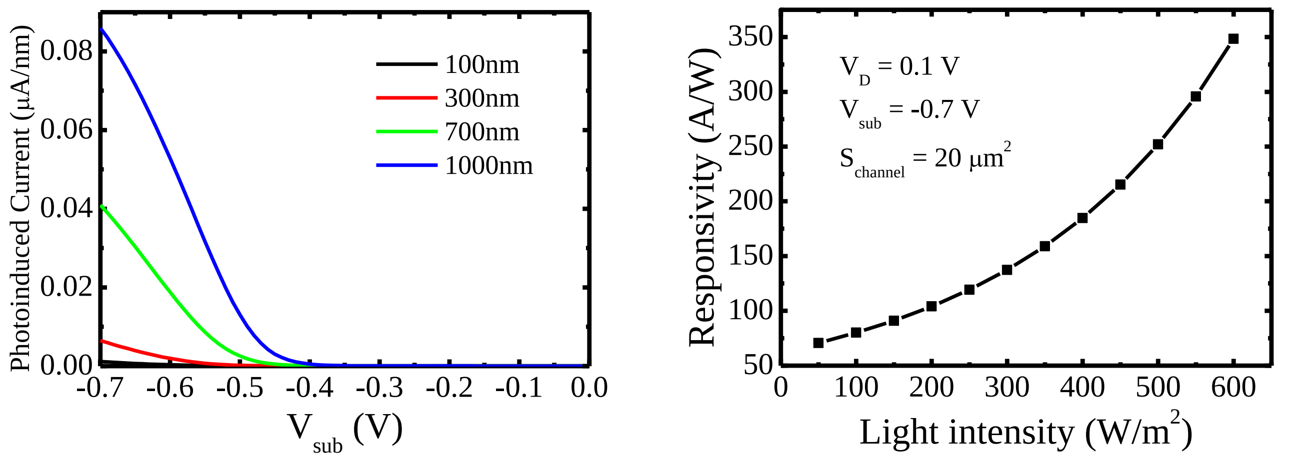

Fig.3: Photo-induced current corresponding to various wavelengths (left) and responsivity corresponding as a function of the intensity of light irradiated into the graphene channel (right).