Dynamics and Switching of Photoinduced Carrier Polarity at the Si/SiO₂ Interface Observed by Graphene Transport

J. Miura[1], F. Inamura[1], T. Ikuta[1], K. Maehashi[1], and K. Ikushima[1]
[1]*Department of Biomedical Engineering, Tokyo University of Agriculture and Technology*
2-24-16 Naka-cho, Koganei, Tokyo, 184-8588, Japan
jmiura@st.go.tuat.ac.jp

Carrier doping technology plays a crucial role in semiconductor devices, such as p-n junctions, metal-oxide semiconductor (MOS) structures, and heterostructures. Carrier doping is usually achieved by introducing impurities through ion implantation or solid-phase diffusion. The doping process is irreversible, leading to a fixed carrier type in semiconductors. In contrast, reversible photoinduced doping has been reported for graphene and other two-dimensional materials to control n- or p- type behavior without introducing impurities [1,2]. However, if optical control of carrier polarity is achieved on standard Si MOS platform, it would significantly enhance the integration of photon-electron conversion processes and facilitate the development of optically programmable Si CMOS logic circuits.

Recently, we have observed photoinduced carrier accumulation at the Si/SiO_2 interface using a MOS based graphene device (graphene/SiO_2/lightly p-doped Si) [3]. Photoexcited carriers in the Si substrate are collected at the Si/SiO_2 interface due to the gate voltage, and the polarity of the photoinduced carrier is reversibly controlled by the polarity of the gate voltage. In this work, we investigated the carrier accumulation induced by the light pulse irradiation to check the speed of carrier-polarity switching.

Figure 1 shows the schematic of the MOS based graphene device. CVD graphene was transferred to an undoped silicon substrate with a SiO_2 dielectric layer and served as a charge sensor for detecting the accumulation of photoinduced carriers. The device was cooled to 4.2 K to lose the intrinsic carriers in the Si substrate. Light pulses were generated by applying a square wave with a pulse width of 50 μs to an LED.

The photoresponse ΔR due to carrier accumulation at the Si/SiO_2 interface is shown in Fig. 2. A transient phenomenon is observed in the photoresponse, indicating a transient time $t_{\mathrm{tr}} \sim 150\ \mu\mathrm{s}$ to reach the equilibrium state. The magnitude of ΔR (corresponding to the photoinduced carrier density n) increases with the intensity of light pulses (the magnitude of pulsed LED current, I_{LED}), while t_{tr} is almost independent of I_{LED}. This result suggests a limit to the speed of carrier polarity switching. In this talk, we will also report the switching of carrier polarity (e.g., p to n conversion) in Si MOS structures and discuss the dynamics of photoinduced carriers.

References

[1] L. Ju *et al.*, Nat. Nanotech. **9**, 348 (2014). [2] E. Wu *et al.*, Sci. Adv. **5**, eaav3430 (2019).
[3] J. Miura *et al.*, Jpn. J. Appl. Phys. **63**, 02SP65 (2024).

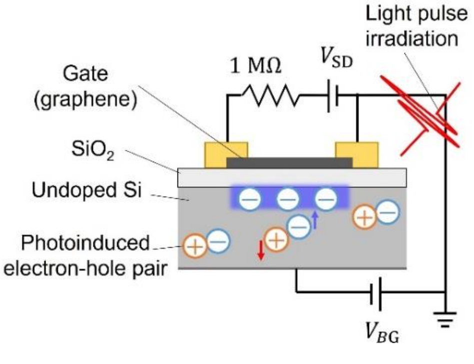

Fig. 1 Schematic of the graphene device. Two-terminal resistance of graphene was measured by applying a constant current of 1 μA.

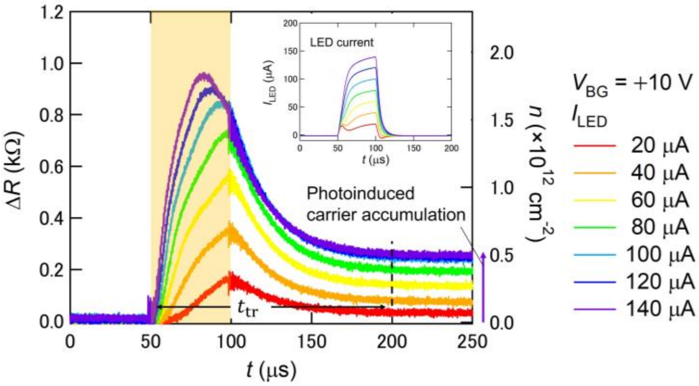

Fig. 2 Photoresponse due to carrier accumulation at the Si/SiO_2 interface under the initial gate condition of $V_{\mathrm{BG}} = +10$ V. Photoresponse ΔR is defined as the change in resistance due to light irradiation. The shaded region indicates the duration of light pulse irradiation. The inset shows the time trace of LED current I_{LED}.