Laser-Irradiated Direct Synthesis of Graphene and Device Application

Keisuke Koshida, Yasuhide Ohno, Kenzo Maehashi, Koichi Inoue and Kazuhiko Matsumoto

The Institute of Scientific and Industrial Research, Osaka Univ.

8-1 Mihogaoka, Ibaraki, Osaka 567-0047, Japan

Phone: +81-6-6879-8412 E-mail: koshi11@sanken.osaka-u.ac.jp

Abstract

We have demonstrated a simple method of synthesizing graphene directly on dielectric surfaces using laser irradiation. Moreover, channels of graphene FETs were formed at the same time as the graphene synthesis by scanning the laser beam. As compared with conventional graphene-FET fabrication processes, this shows quite simple and useful method.

1. Introduction

Recently, carbon materials have attracted attention as a pot-silicon material. In particular, graphene was discovered relatively recently among the carbon materials. Graphene consists of one atomic layer of carbon atoms in a hexagonal lattice as its features. Owing to its remarkable mechanical and electronic properties [1], it has a tremendous potential in the application of electronics devices using field-effect transistors (FETs) such as chemical and biological sensors [2, 3]. In general, graphene is formed by mechanical -exfoliation [4], thermal chemical vapor deposition (CVD) [5], and so on. However, in the former, the size and location of graphene cannot be controlled. In the latter, a transfer process is needed from a metal catalyst layer to proper substrates. Currently, we have investigated graphene synthesis without transfer processes [6].

In this study, direct graphene synthesis from amorphous carbon (a-C) on dielectric substrates has been demonstrated by laser irradiation (Fig. 1). After annealing the Ni layer by laser irradiation, dissolution of carbon occurs, and then graphene layers are synthesized on SiO₂ substrates owing to retraction of the Ni layer. Using this method, graphene can be synthesized at only desired position without using transfer process and carbon source gasses. Moreover, when the technique is applied to a fabrication of graphene FETs, ambipolar characteristics were clearly observed.

2. Experimental Procedure

A thin a-C and Ni layer was sequentially deposited on a a SiO₂/Si substrate using an electron beam evaporator without exposure to ambient conditions. Figure 1(a) shows a schematic of graphene synthesis. The graphene synthesis was carried out in a vacuum chamber. A continuous wave Ar-ion laser with a wavelength of 514.5 nm was used to rise a local temperature on the Ni layer. The substrate was locally irradiated with the laser for 1 min, and laser power density was controlled at 10 - 30 mW/ μ m². The heater was attached to the backside of the substrates, and three different temperatures of 25, 200, and 400 °C were utilized to

synthesize graphene. The laser-irradiated area was investigated by optical microscopy and Raman spectroscopy (514.5 nm).



Fig.1. (a) Schematic of graphene synthesis by laser irradiation. (b) Optical image at laser-irradiated area.

3. Results & Discussion

Figure 1(b) shows an optical image after laser irradiation to the sample. The purple center circle corresponds to the laser-irradiated area. The formation of the hole was easily confirmed. Figure 2 shows Raman spectra at laser-irradiated area in a vacuum at the heater temperature [(a) 400, (b) 200 and (c) 25 °C]. The Raman intensities for the samples were normalized to that of G band. At 200 °C, relatively sharp G and G' bands were clearly observed, indicating that graphitization of a-C was promoted by the Ni catalytic action deposited on a-C. However, the Raman spectrum obtained at 400 °C is close to the spectrum of amorphous carbon, indicating that a hole was formed before enough carbon is dissolved into the Ni layer



Fig.2. Raman spectra for samples which were irradiated with a laser at (a) 400 °C, (b) 200 °C, (c) 25 °C in a vacuum.

Moreover, the laser was irradiated in a hydrogen atmosphere at 200 °C, revealing that G/D ratio and G'/G ratio were improved about 1.3 and 1.7 times, respectively [Fig. 3(b)], for comparison with Fig. 3(a). In addition, the full width at half maximum (FWHM) of G and G' bands became 30 - 40 % narrower by synthesis in a hydrogen atmosphere. The results suggest that naturally oxidized Ni layer was reduced by hydrogen at laser-irradiated area, and that the Ni catalytic action was enhanced. Thus, the result indicates that multilayer graphene was formed using the laser-irradiation.



Fig.3. Raman spectra for samples which irradiated with a laser in (a) vacuum and (b) H_2 .

Finally, a graphene FET was fabricated by scanning the laser beam under a hydrogen atmosphere at 200 °C [Fig. 4(a)]. Figure 4(b) shows an optical image after scanning the laser beam, indicating that formation of the channel was clearly obtained. Figure 5 shows a transfer characteristic of the graphene FET, where the remaining Ni regions were utilized as source and drain electrodes. An ambipolar characteristic was clearly observed, indicating the device acted as FETs fabricated by scanning the laser beam.



Fig.4. (a) Schematic of scanning the laser beam. Graphene and channel are formed simultaneously. (b) Optical image after graphene and channel formation by laser irradiation.



Fig.5. Transfer characteristic. $I_{\rm D}$ versus $V_{\rm BG}$ in back-gate voltage in a vacuum.

4. Conclusions

We have demonstrated the direct synthesis of multilayer graphene from a-C on Si/SiO_2 substrates by laser irradiation. The quality of the graphene showed improvement by optimizing the synthesis conditions. In addition, graphene devices were simply fabricated by scanning the laser beam, and we have succeeded in operation as a FET. As compared with the conventional graphene-FET fabrication process, this method shows significantly simple. Then, the method can be useful for practical application of device applications.

Acknowledgements

This research was partially supported by the Core Research for Evolutional Science and Technology (CREST) from the Japan Science and Technology Agency (JST), by Grants-in-Aid for Scientific Research for Scientific Research B (No. 24310105) from the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT), and by Management Expenses Grants for National University Corporations from MEXT.

References

- [1] K.Geim and K. S. Novoselov: Nat. Mater. 6 (2007) 183.
- [2] Y. Ohno, K. Maehashi, Y. Yamashiro and K. Matsumoto: Nano Lett. 9 (2009) 3318.
- [3] Y. Ohno, K. Maehashi, and K. Matsumoto: Biosens. Bioelectron. 26 (2010) 1727.
- [4] K. S. Novoselov, D. Jiang, F. Schedin, T. J. Booth, V. V. Khotkevich, S. V. Morozov, and A. K. Geim: Proc. Natl. Acad. Sci. U.S.A 102 (2005) 10451.
- [5] S. Y. Kwon, C. V. Ciobanu, V. Petrova, V. B. Shenoy, J. Bareno, V. Gambin, I. Petrov, and S. Kodambaka: Nano Lett. 9 (2009) 3985.
- [6] K. Gumi, Y. Ohno, K. Maehashi, and K. Matsumoto: Jpn. J. Appl. Phys. 51 (2012) 06FD12.