Generation and evaluation of graphene depends on the electron irradiation applied to the fullerene

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ABSTRACT

Graphene is an ideal two-dimensional material was chained to the planar six-member rings of carbon atoms. Electron of graphene behave as Dirac Fermion, this electron is unaffected to impurity scattering. Mobility of graphene with such characteristics is larger than mobility of silicon. But, mass production of graphene technology has not been established. As a new method, we have suggested a method using C_{61}-fullerene and electron beam irradiation. This study is one of many studies for new mass production and exactly patterning of graphene on substrate, this goal is to establish a method that change fullerene to graphene. To create variety of graphene samples by spin coat, anneal, electron irradiation on the silicon-oxide (by change of the dose and annealing temperature), electrical characteristics of graphene are revealed by *IV-measurement.* As a result, we have confirmed changing fullerene that should be insulator to conductor material.

Keywords: graphene, fullerene, electron beam

1 INTRODUCTION

In recent years, the high integration of semiconductor devices due to miniaturization has been underway. Moore was published is going to be twice the density in the 18-month cycle in 1965, it had been considered to improve the performance of the semiconductor is exponentially by Moore's law. This law is still widely used as an indicator of when to predict the performance of semiconductors, but this law will be expected not to approve by limit of miniaturization about 2020. Miniaturization technology has been advanced by the transition of the substrate material and processing technology and mainly wiring.

Recently, there is a possibility of stagnation in wiring technology miniaturization. In the integrated circuit industry is approaching scaling limits, The researchers are trying to migrate to CMOS process based on the new materials that focus on improving performance than miniaturization of the wiring width (include leakage power reduction, performance improvement and manufacturing cost down).

In this work, double-gated field effect transistors manufactured from monolayer graphene are investigated. Conventional top-down CMOS compatible processes are applied except for graphene deposition by manual exfoliation. Carrier mobility in single- and double- gated graphene field effect transistors are compared. Even in double-gated graphene FETs, the carrier mobility exceeds the universal mobility of silicon over nearly the entire measured range. At comparable dimensions, reported mobility for ultra-thin body silicon on insulator MOSFETs cannot compete with graphene values.

2 GRAPHENE'S CHARACTERISTICS

Graphene is a flat monolayer of carbon atoms tightly packed into a two-dimensional (2D) honeycomb lattice (figure 1 shows), and is a basic building block for graphitic materials of all other dimensionalities. Graphene is a semi-metal with an extremely small overlap between the valence and the conduction band (zero-gap material). In its three dimensional graphite form, graphene sheets are weakly coupled between the layers with van der Waals forces. Carrier mobility values between 3000 and 27000 cm2/V s have been reported for graphene and make it an extremely promising material for future nanoelectronic applications. It is further known that carrier transport in graphene takes place in the p-orbitals perpendicular to the surface. Intrinsically this translates into charge carrier transport with a mean free path for carriers of L = 400 nm at room temperature. This would make ballistic devices feasible even at relaxed feature sizes compared to state-of-the-art CMOS technology[1,2]. Electrons of graphene behave as Dirac Fermion, and they are unaffected by impurity scattering. Due to its characteristics, graphene's mobility is larger rather than that of silicon. Graphene has not yet been applied to the post-silicon technology as well as device materials in the mass production by using the lithography patterning. If we will be able to solve these problems, the integrated circuit industry will be able to go to next generation.

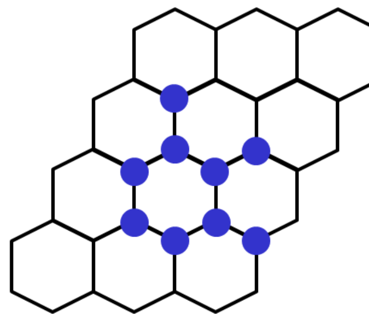


Figure 1: Schematic of Graphene

3 EXPERIMENT

We present a new method for the basic patterning technology, where C_{61}-fullerene-coated silicon substrate is drawn into graphene patterns by electron beam irradiation. This study is based on the character of the opening at the closed shell of the carbon by the electron beam impact. This study is to establish a method that changes fullerene to graphene. The specimen was made through processes of the spin-coating of the $C_{61,}$ anneal and one dimensional scanning of electron irradiation on the substrate for various and annealing temperature. This time, annealing temperature is 600 degree. Figure 2 shows image of open ring closure of C_{61}-fullerene by electron beam irradiation, it shows electrons that have large energy destroyed structure of fullerene.

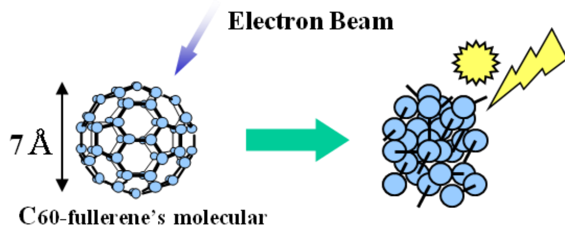


Figure 2: Image of open ring closure of C_{61}-fullerene by electron beam irradiation

Figure 3 shows flow of how to prepare the sample. 1: Prepare the silicon oxide on silicon substrate. 2: spin-coat solution that dissolved C_{61}-fullerenes to chloroform in order to thin fullerene film. 3: Anneal the specimen at 100 degrees for 12 hours (for evaporate the solution). 4: Electron beam irradiation to specimen. 5: Exfoliate fullerene film from the specimen. After that, anneal the specimen at 600 degrees for 6 hours in ultra high vacuum condition 6: Electrode deposition to edge of structure

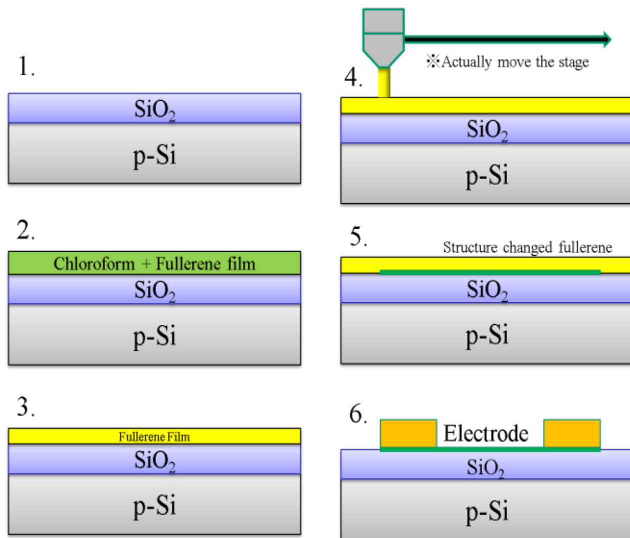


Figure 3: Flow of how to prepare the sample.

changed fullerene. Electrode material is titanium by Physical Vapor Deposition.

Figure 4 shows appearance of beam draw equipment and condition of electron beam irradiation. Dose of electron beam to the fullerene is determined by accelerating voltage E_B , beam current I_B, stage velocity ν_s. These values are set accordance with condition of the fullerene is destroyed. This time, $E_B = 20$keV, $I_B = 2$nA, $v_s = 3.67$µm/sec.

Figure 5 shows SEM image of electron beam irradiation

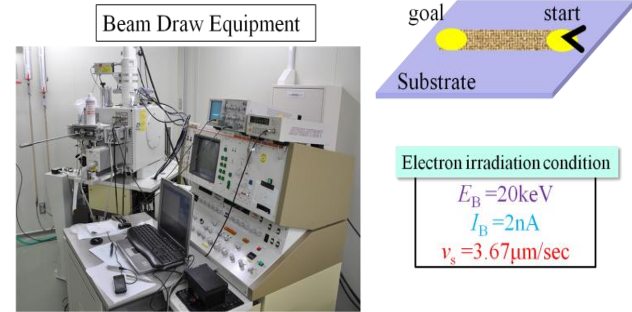


Figure 4: Appearance of beam draw equipment and condition of electron beam irradiation

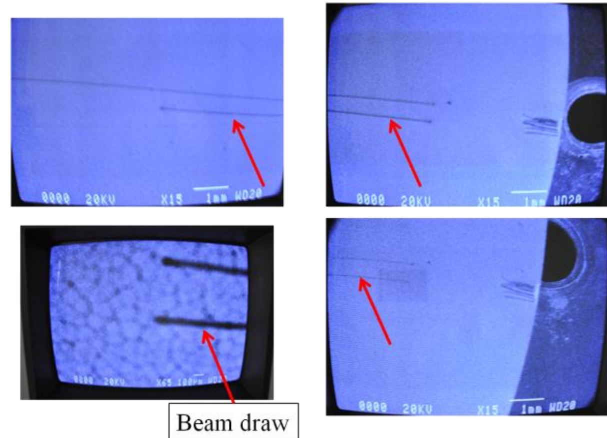


Figure 5: SEM image of electron beam irradiation to the fullerene on substrate

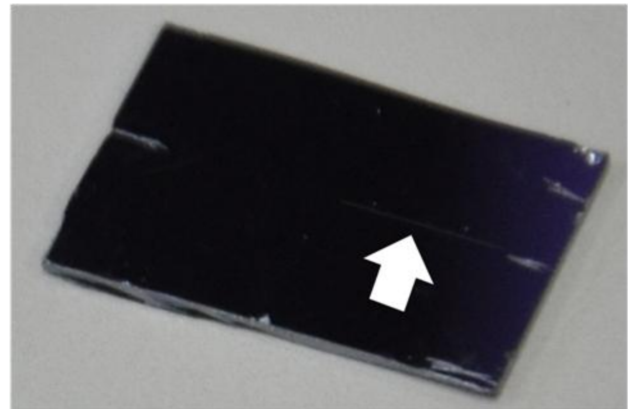


Figure 6: State of the substrate after exfoliated fullerene film from the specimen

to the fullerene on substrate. Directing arrows are electron beam irradiated lines. Figure 6 shows state of the substrate after exfoliated fullerene film from the specimen. Structure changed fullerene exists directing arrow.

Electrical characteristics of the thin wire specimens are evaluated by *IV*-measurement and structure for the graphene are decided with Raman spectroscopy. We ascertain whether the graphene from the results of two experiments.

4 RESULTS AND DISCUSSIONS

At first, figure 6 shows *IV*-measurement of structure changed fullerene (annealing temperature is 600 degrees), The average resistance value is about 500Ω by figure 6. Figure 7 shows result of step measurement of film thickness meter. The shape of specimen is revealed by step measurement. Specimen's maximum height about 240nm, width about 60μm. Volume resistivity is calculated using these values. Equation of volume resistivity as follows

Sample B

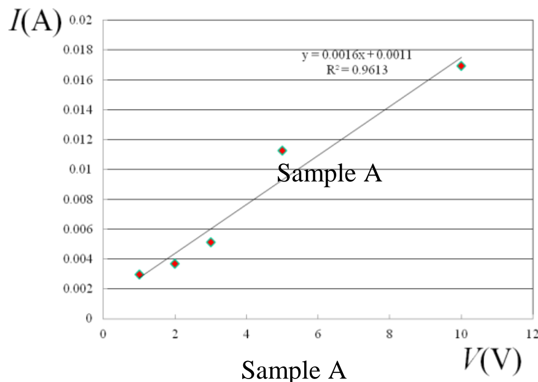
Formula $\rho = \frac{RS}{L}$ from $R = \rho \frac{L}{S}$ (1)

ρ is volume resistivity, *R* is resistance, *S* is surface area *L* is distance between electrodes. Using each electrode distance of sample A is 3mm, specimen (irradiated line) height, width and formula (1), volume resistivity of specimen is 1.2×10^{-4} Ωcm. Sheet resistance of the specimen is 2.1×10^{3} [Ω/□], which is seven times higher than that of graphene.

We prepared sample B which made another substrate under same conditions. Using each electrode distance of sample B is 5mm, specimen (irradiated line) height, width and formula (1) is same sample A, volume resistivity of specimen is 1.3×10^{-4} Ωcm.

We confirmed electron beam irradiated fullerene could be transformed from insulator to conductor (volume resistivity changed from 10^{8} Ωcm to 1.3×10^{-4} Ωcm), but which value is higher than that of graphene.

Figure 8 shows Raman spectrum of electron beam irradiated fullerene. This spectrum has two peaks between 1400cm^{-1} and 1600cm^{-1}. Graphene's peak is 1580cm^{-1} only in that range. It is similar to diamond like carbon or carbon black (amorphous carbon). In DLC peaks, there is a slight



Sample A

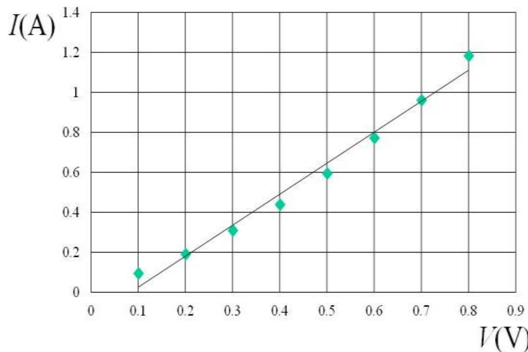


Figure 7: *IV*-measurement of structure changed fullerene after 600 degrees for 6 hours. Vertical axis shows current. Horizontal axis shows voltage.
Sample A: each electrode distance = 3mm ,Sample B: 5mm

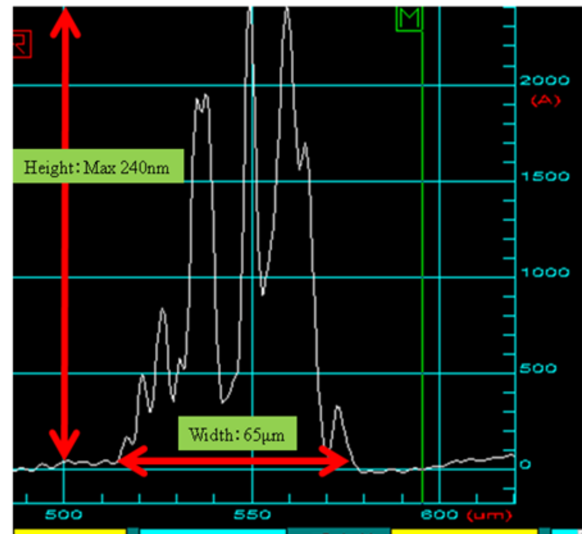


Figure 8: Result of step measurement of film thickness meter. Vertical axis shows specimen's height. Horizontal axis shows width.

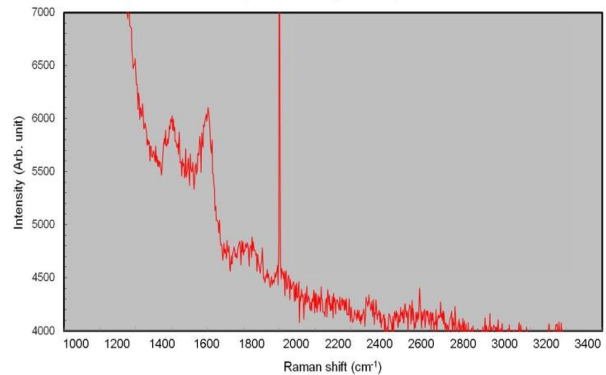


Figure 9: Raman spectrum of electron beam irradiated fullerene. Vertical axis shows intensity. Horizontal axis shows Raman-shift.

difference between first peak and second it, but carbon black peaks is little different between first peak and second it. In other words, specimen may be carbon black.

5 CONCLUSION

As results of this experience, electrical characteristics of the thin wire specimens are evaluated by *IV*-measurement and structure for the graphene are decided with Raman spectroscopy. This sample may be amorphous carbon, it is not graphene. We consider lack of annealing temperature and process. Our next experience will find appropriate annealing temperature for making graphene to fullerene.

REFERENCES

[1] K.S. Novoselov , Nature 438,197(2005); A.K. Geim and K.S. Novoselov, Nature Materials 6,183(2007);A.H. Castro Neto et al, Rev. Mod. Phys. 81, 109 (2009).
[2] D.S.L. Abergel, V. Apalkov, J. Berashevich, K. Ziegler and Tapash Chakraborty, Adv. Phys. **59** (2010) 261.