COMPARISON STUDIES OF GRAPHENE SEY RESULTS IN NSRL AND DL*

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Abstract

Graphene has many excellent properties, such as high electron carrier mobility, good thermal conductivity and transparency etc. The secondary electron yield (SEY) of graphene with copper substrate had been studied in National Synchrotron Radiation Laboratory (NSRL) of China. The results show that the maximum SEY ($\delta_{\max}$) of 6~8 layers graphene film with copper substrates is about 1.25. Further studies indicate that many factors can affect the SEY test results. The recent SEY tests of graphene films with copper substrates in Daresbury Laboratory (DL) gave the maximum SEY of as-received copper, graphene samples with copper substrates are 1.89, 1.83, and 1.68, respectively, under the incident charge per unit surface (Q) of 7.6×10^{-8} C mm^{-2}. Meanwhile, the SEY test parameters and measurement results of graphene in both laboratories are compared and analysed. The effect of defects on the SEY results of graphene films with copper substrate is also discussed.

INTRODUCTION

The use of low SEY materials is an effective way for electron cloud mitigation of high intensity accelerators [1-6]. In order to obtain low SEY materials, many surface treatment techniques are proposed and used, such as laser treated surfaces [2], surface cleaning [3], grooved surfaces [2, 3, 6] etc. On the other hand, searching for new low SEY material is another way.

It has been reported that graphene film has low SEY in several articles [4, 7-10]. However, there are many parameters which may affect the SEY results of graphene, such as the number of layers, the substrate materials, the SEY measurement principle, the electron gun operation mode, etc. For example, Ref. [9] shows that the intrinsic SEY of graphene with silicon dioxide substrates is about 0.1 when the energy of primary electron is 1000 eV. Ref. [8] indicates that the SEY values of graphene micro and nanoplatelets in the range of 0.1–1 μm vary from 0.5 to 1.0 in the cases of different layers. In addition, Ref. [4] gives the SEY of graphene with copper substrates varying from 1.51~1.25. Note that these SEY results were measured based on different test principles.

In order to compare the SEY results obtained from the NSRL and DL, in this paper, we analyse the effects of graphene films defects with copper substrate on SEY measurement results. The SEY of graphene films with copper substrates were obtained in DL based on the same test principle and calculation method. Furthermore, the parameters during the SEY measurement in DL were compared with the ones in NSRL.

COMPARISONS OF APPARATUS AND METHODS

SEY Measurement Method

The SEY values obtained in both labs are based on the same principle, as shown in Eq. (1). Here I_p, I_s and I_f are the current of incident electrons, sample-to-ground current and Faraday cup-to-ground current, respectively. The schematic of SEY measurement equipment in DL is shown in Fig. 1. Comparing with the schematic of SEY test equipment in Ref [4], the main differences are biased voltage on the sample holder, -18V in DL and -40V in NSRL, and working distance, 1mm in DL and 10mm in NSRL.

$$\delta_{SEY} = \frac{I_f}{Ip} = \frac{I_f}{(I_f + I_S)} \quad (1)$$

The SEY test equipment in DL consists of EGPS-2B electron gun, Faraday cup, sample holder, source of X-ray, two Keithley 6485 picoammeter, vacuum chamber, electron energy analyzer, electron detector, sample transfer frame, and power supply. The sizes of the samples are 20 mm ×20 mm × 0.025 mm.

SEY Test Parameters

The electron dose per unit in DL was 7.6×10^{-8} C mm^{-2}, while it was 1×10^{-7} C mm^{-2} in NSRL. The electron gun scans over an energy spectrum from 50 eV to 5000 eV on the samples at Emission Current Control (ECC) mode in

* Work supported by the National Nature Science Foundation of China under Grant Nos. 11475166, National Natural Science Funds of China (Grant No. 11205155), Fundamental Research Funds for the Central Universities (WK2310000041) and China Scholarship Council.
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NSRL. However, it sans over the energy range from 50 eV to 1000 eV in DL. Furthermore, the thicknesses of copper substrates are all 25 μm in both labs. In addition, the background pressure of the chamber before the SEY test was (4-8) $\times 10^{-10}$ Torr and it was (2-8) $\times 10^{-9}$ Torr during the SEY test in DL. Therefore, the pressures were basically the same in both labs. Also, the test temperature was the same, 300 K. The details of comparison of SEY test parameters are shown in Table 1.

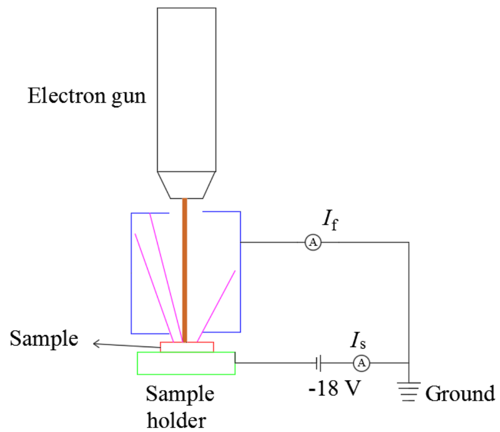

Figure 1: The schematic of SEY measurement equipment in DL.

RESULTS

Raman Spectrum of Graphene Films

The Raman spectrums of graphene samples, #1 and #2 are shown in Fig. 2. The Raman parameters of these two samples shown in table 2 indicate that the graphene is not uniform. According to the ratio of I (2D) and I (G), there is one layer graphene film on the surface of sample #1. While, there exits 1-2 layers of graphene on the surface of sample #2.

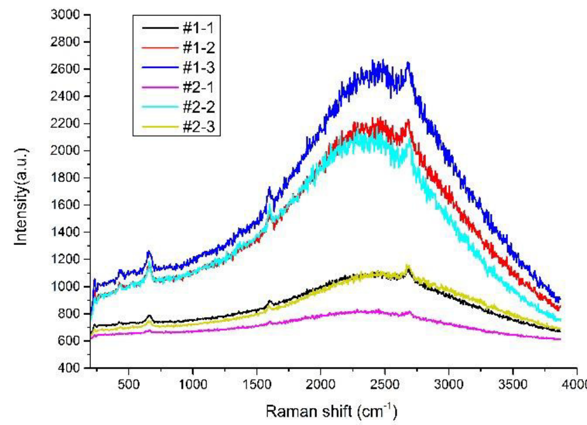

Figure 2: Raman spectra of graphene samples #1 and #2 in DL.

Table1: Comparison of SEY Test Parameters

samples	electron dose per unit	The range of incident energy /eV	δ_{max}	Temperature /℃	Step/eV	E_{max}
#1 in DL	7.6×10^{-8} C mm^{-2}	80~1000	1.83	25	【400-100】, 25	257
#2 in DL			1.68		【1000-400】, 100	307
1 layer″ in NSRL	1×10^{-7} C mm^{-2}	50~3000	1.51		【100-50】, 50	500
2 layers″ in NSRL			1.43		【100-600】, 20/30	470
3-5 layers″ in NSRL			1.41		【600-1000】, 50	450
6-8 layers″ in NSRL			1.25		【1000-3000】, 100	500

Table 2: Raman Parameters of Graphene Samples with 1, 2, 3~5, 6~8 Layers, Respectively

Sample	D		G		2D		I (2D)/ I (G)	Number of layers
	Raman shift/cm^{-1}	Intensity /au	Raman shift/cm^{-1}	Intensity /au	Raman shift/cm^{-1}	Intensity /au		
#1-1	1358.78	818.6	1596.93	896.2	2682.02	1139.6	1.27	1
#1-2	1403.39	1300.5	1596.93	1547.4	2682.02	2228.2	1.44	1
#1-3	1358.78	1430	1601.27	1734	2682.02	2650.8	1.53	1
#2-1	1390.03	710	1601.27	745.3	2693.4	820.5	1.10	2
#2-2	1367.72	1330.1	1601.27	1605.1	2693.4	2095.5	1.31	2
#2-3	1390.03	780.9	1592.58	862.1	2670.62	1161.6	1.35	1

ISBN 978-3-95450-182-3

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The wavenumber of 2D peak of #2-1 is shifted up by about 9 cm^{-1} which indicates the number of graphene film is bigger than the ones of sample 1 [11]. The number of layers of different colour regions of these two samples is shown in Table 2.

SEY Curves

When the incident charge per unit surface (Q) is 7.6×10^{-8} C mm^{-2}, the maximum SEY of as-received copper, graphene samples #1 and #2 with copper substrate are 1.89, 1.83, 1.68, and the corresponding energy are 257 eV, 257 eV, 307eV, respectively, as shown in Fig. 3. The maximum SEY of one layer graphene sample #1 decreases 0.06, about 3.2%, compared with the maximum SEY of as-received copper. Nonetheless, the maximum SEY of one layer graphene in Ref. [4] decreases 0.06, about 3.8%, compared with the maximum SEY of polished copper. Furthermore, the maximum SEY of a mixture of one layer and two layers graphene sample #2 decreases 0.21, about 11.1%, compared to the maximum SEY value of as-received copper. Whereas, the maximum SEYs of two layers graphene in Ref. [4] decreases 0.14, about 8.9 %, compared to the maximum SEY of polished copper.

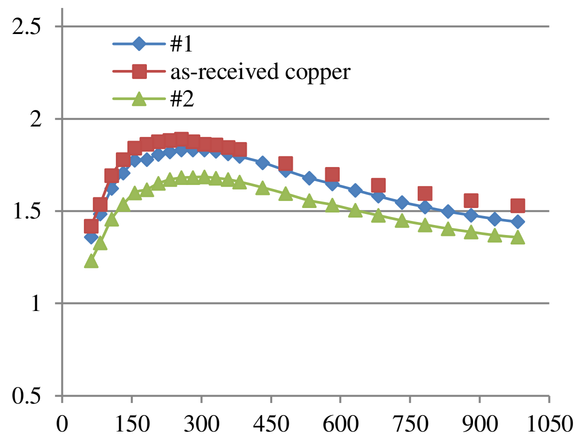

Figure 3: SEY of graphene films with copper substrate tested in DL.

The difference of maximum SEYs between the as-received copper in DL and the polished copper is mainly caused by that the surface grooves on the polished copper [4]. The maximum SEY of one layer graphene with copper substrate in DL is bigger than the one in NSRL, about 0.32. The difference perhaps is induced by the different SEY test parameters, especially by the different biased voltage and working distance. In addition, the maximum SEY of 1~2 layers graphene with copper substrate in DL is bigger than the 2 layers graphene sample in NSRL, about 0.25. Two factors mainly contributed to the difference. One is the different SEY test parameters. For example, the secondary electron yield can decrease with the increase of the incident electron dose, so the SEYs obtained in NSRL are higher than the ones in DL to some extent [12]. And the other one is the inhomogeneity and discontinuity of graphene for sample #2. Based on the Raman spectrum analysis above, the ratio of 2 layers graphene with copper stubstate is about 60%.

CONCLUSION

The effects of inhomogeneity and discontinuity of grapheme coating and the number of graphene layers on SEY values are analysed in this paper. The Raman spectra and the SEY test results show that the inhomogeneity and discontinuity of graphene films affect the decrease of the maximum SEY to some extent. The coverage ratio and the number of layers of the graphene film on the surface of the samples are more important factors for reducing the maximum SEY of the graphene samples. The SEY results of graphene films in DL are essentially in agreement with the one in NSRL.

ACKNOWLAGEMENT

The authors thank Fan Wu from University of Manchester for discussing about the measurements of Raman spectrum.

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ISBN 978-3-95450-182-3