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Electron Energy Loss Spectroscopy of Graphene Identified by Aberration Corrected TEM at 300kV

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Electron energy loss spectra (EELS) from each single-layer graphene and multi-layer graphite region are studied by a combination with novel aberration-corrected TEM, R005 [1-2], equipped with Gatan GIF Tridiem ER.

A thin film of graphite was cleaved from highly oriented pyrolytic graphite (HOPG) and was mounted to a double-tilt specimen holder of the R005 microscope. Neither glues nor solvents have been used during the specimen-preparation processes. No contaminations such as N and O were detected in core-loss spectra acquired from all the regions in the specimen. The HRTEM images were observed at focus steps of 1 nm, where the spherical aberration Cs was tuned to zero using Diffractogram tableau method [2].

Figure 1 (a) shows a high-resolution TEM image of a graphene sheet. The image of single-layer graphene was confirmed by the intensity profile and the quantitative agreement with simulation, and the detail analysis will be reported in the oral presentation [3].

The low-loss regions of graphene, graphite and related carbon materials are dominated by plasmon excitations of π and σ electron, as shown in Table 1 [4-11]. All the EELS spectra were acquired from region limited by the same aperture, whose size was indicated by solid circles in Fig. 1. The EELS spectrum as shown in Fig. 2 (a) was acquired from the graphene region in Fig. 1 (a). It was reported that the peak of π - π* plasmon from graphene was located to 4.7eV [4]. The shoulder of π - π* plasmon was located around 5eV in Fig. 2 (a), and was shifted to ~7eV with thickness as shown in Fig. 2 (b-c). The location of the loss signal and the tendency of the energy shift were similar to those in Ref. 4. It was reported that the peak of π + σ plasmon from graphene was located to 14.5eV [4]. The peak of π + σ plasmon was located to ~27 eV and the broad tail around its peak was observed, as shown in Fig. 2(a). The broad tail in Fig. 2(a) suggested that the contribution of π + σ plasmon ranged roughly from 10 to 40 eV.

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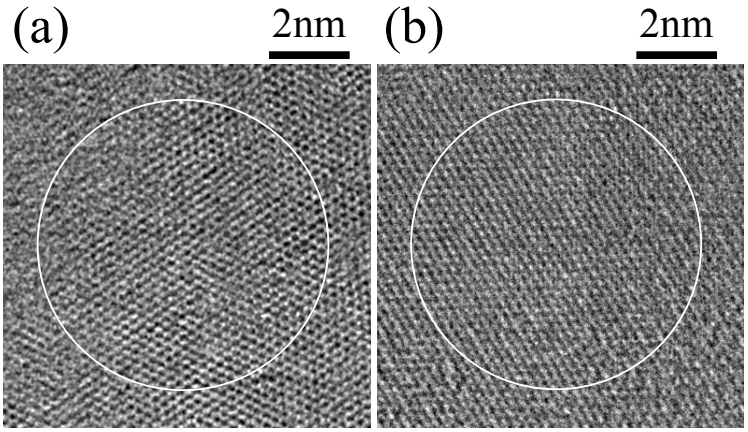

Fig. 1 Direct HRTEM image of (a) graphene and (b) graphite (Carbon atoms appear white) [3]. The EEL spectra in Fig. 2 (a) and (b) were acquired from the region limited by the aperture size, indicated by solid circle in Fig. 1 (a) and (b).

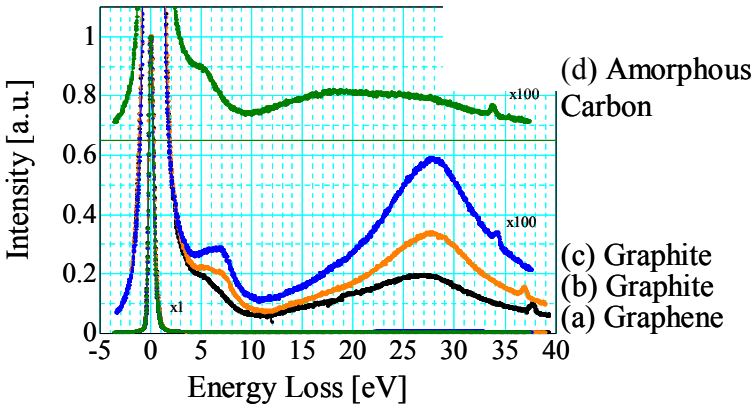

Fig.2 EELS spectra in (a) graphene, (b-c) graphite, and (d) amorphous carbon. The spectra of (c) is acquired from thicker region than that of (b).

Table 1. Plasmon peaks

Material	Method	Energy [eV]		Ref
		π-π^*	π+σ	
Graphene	STEM, EELS	4.7	14.5	4
Graphene	TEM, EELS	~5	~27	Present study
Graphite	TEM, EELS	~7	27-28	Present study
Graphite	EELS, XPS	6.2	15, 26	5
Graphite	Optical study	4.8	15	6,11
Graphite	EELS	10-11	15-16	7,11
Graphite	Optical study	5	10-40	8,11
MWCNT	STEM, EELS		23,27	9
SWCNT	Theory		15	10

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