5–6 Fast Molecules Passing through Carbon-Atom Net

—Discovery of Oxygen Molecules Slipping through Graphene—

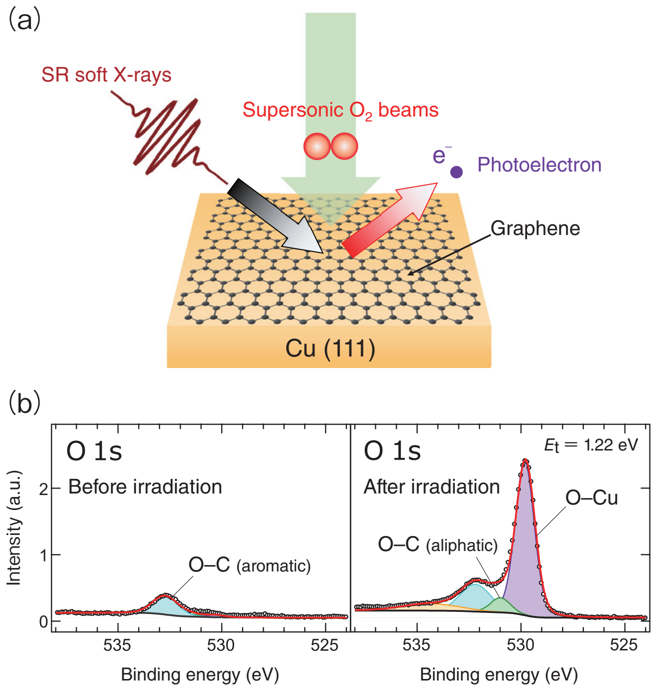

Fig.5-12 Gas barrier experiment by using real-time synchrotron radiation X-ray photoelectron spectroscopy (SR-XPS) combined with supersonic molecular beams and experimental evidence of O_2 permeation through graphene
(a) Conceptual diagram of SR-XPS measurements for irradiating graphene on a Cu substrate with oxygen beams. (b) X-ray photoelectron spectral change after irradiation with O_2 beams with the translational energy of 1.22 eV. The increase in the O–Cu component (purple) is evidence that O_2 penetrates graphene and oxidizes the Cu surface.

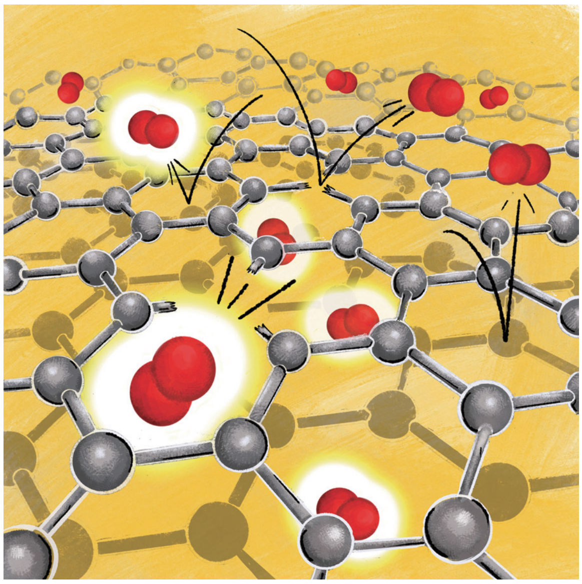

Fig.5-13 An image of an oxygen molecule passing through graphene (a net made of a single layer of carbon atoms)
A slow oxygen molecule bounces off the carbon net and cannot pass through, while a fast molecule (> 0.8 eV) can pass through.

Graphene, a carbon-atom net, has been attracting attention as a next-generation functional material because of its excellent physical properties such as low electrical resistance. Due to its unique physical properties, the Nobel Prize in Physics was awarded in 2010 for its discovery. Furthermore, as it is known that graphene has excellent gas barrier property, it is expected to be used as a protective film for easily oxidized transition metal catalysts (Ni, Cu, etc.). However, details of gas barrier properties remain unclear.

As is well known, the majority of O_2 in an environment such as the atmosphere have kinetic energy (Et) of about 26 meV, however there are also small amounts of O_2 with higher energies, which may overcome activation barriers in reaction pathways. Real-time SR-XPS using X-rays at 700 eV was applied to analyze the graphene/Cu(111) after O_2 irradiation with various Et controlled by the supersonic molecular beams technique (Fig.5-12(a)). All experiments were conducted at the surface experimental station of the JAEA soft X-ray beamline (BL23SU) at SPring-8.

Fig.5-12(b) shows O 1s photoelectron spectra before (left) and after (right) irradiation for O_2 with 1.22 eV. An increase in the peak exhibiting surface oxidation was clearly observed. A similar change in the spectrum was observed for O_2 higher than 0.8 eV. Furthermore, it was found that the gas barrier property was maintained even after permeation. In addition to synchrotron experiments, computer simulations clarify that the permeation of O_2 with higher energies occurs nondestructively with the aid of defects in graphene (Fig.5-13). The discovery of nondestructive transmission of O_2 with high incident energies is expected to be applied to molecular filters. Since high-speed O_2 are all around us, it is expected to produce a new type of protective films that prevent food deterioration, metal rusting and so on.

This research is part of the results of a joint research project with Tohoku University entitled “Synchrotron Radiation Realtime Photoemission Spectroscopic Study of Material Surface Processes”.

(Akitaka Yoshigoe)

Reference

Ogawa, S., Yoshigoe, A. et al., Gas Barrier Properties of Chemical Vapor-Deposited Graphene to Oxygen Imparted with Sub-electronvolt Kinetic Energy, The Journal of Physical Chemistry Letters, vol.11, issue 21, 2020, p.9159–9164.