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STM study of single-layer graphene nanoribbons adsorbed on fcc(111) noble metals by using drop cast and vacuum spray

Single-layer graphene nanoribbons (sGNR) (width ~45 nm) were unzipped from double-walled carbon nanotubes (diameter ~15 nm) with a use of ultrasonic waves in a liquid solution [1,2]. The obtained GNR solution was drop casted on a Au(111) film substrate in air. Subsequently, the sample was introduced into our home-built ultrahigh vacuum (UHV) scanning tunneling microscopy (STM) setup. In UHV, the sample was further annealed and STM measurements were performed at 78 and 300 K [1].

In contrast to the atomically-flat GNRs via the bottom-up process, the drop casted sGNRs were bucked on Au(111) (see Figure 1). Most of local areas of the sGNR floated from the substrate (GNR-substrate distance: 1-3 nm). Only some points of the sGNR contact with the substrate (GNR-substrate distance: 0.5 nm). However, STM spectroscopy maps directly showed that the buckled sGNR have very uniform local density of states (LDOS) and metallic property (our DFT calculation confirmed that GNRs with a width larger than 19 atoms has no gap). The conductance through the buckled sGNR was ~3.5 Go measured by contacting the STM tip to the edge of the sGNR [1].

Because we prepared the sGNRs on Au(111) by drop casting, sGNRs frequently formed stacked structures. When we placed the GNR droplet on Au(111) in air, sGNR were sunk and deposited on Au(111) one by one. By a chance, one sGNR sit on another sGNR, forming a stacked crossing structure. STM spectroscopy mapping found that the crossing areas have an energy gap (250 meV gap between -50 meV and +200 meV around the Fermi energy, p-type semiconductor). We found that this is not due to the bending of the sGNR, but the electronic interactions between the up and down sGNRs are driving force [1], i.e., only the upper sGNR changes the electronic property from metal to semiconductor.

Using the drop cast method, we succeeded to fabricate the unique backed sGNRs on Au(111). However, this process required to perform in air. Therefore, the sample surface contaminations cannot be excluded.
We developed a home-built vacuum spray setup combined with our UHV-STM. The vacuum spray setup consists of three room. The first room was pumped by a rotary pump, second room was pumped by a small turbo molecular pump, and the third room is an introduction chamber of our UHV-STM setup. Each room was separated by a 5 mm hole. A 0.05 mm hole was set at the entrance of the first room. The sGNR solution was placed on a 0.05 mm hole, and immediately sucked into the vacuum of the first room. The sucked solution was sprayed and pass through the second room. In the third room, the cleaned Au(111) or Cu(111) was set and the sGNRs were adsorbed. We show sGNRs on Au(111) or Cu(111) using this new vacuum spray method.

References

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Figures

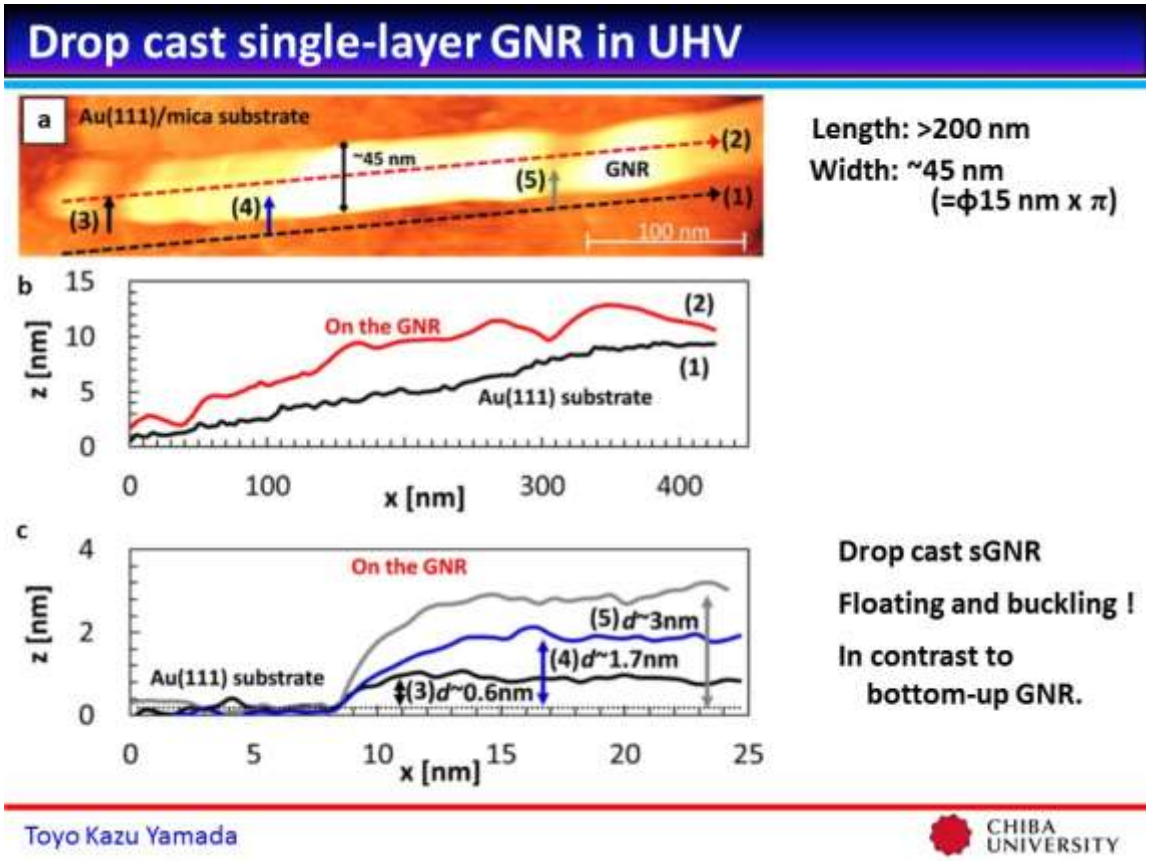

Figure 1: (a) STM image obtained on a single-layer graphene nanoribbon (sGNR) adsorbed on an atomically-flat Au(111) substrate by using drop cast in air [1]. (b) Line profiles along the substrate and the sGNR (arrows No. 1 and 2 in (a), respectively). (c) Line profiles along the arrows No. 3, 4, and 5 in (a), showing heights of sGNR from the substrate.