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Extended Abstract

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1D electron confinement in a graphene nano wrinkle

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One of the unique properties of the sp2-carbon allotropes, such as fullerenes, carbon nanotubes and graphenes, is that their electronic structures differ significantly among them according to characteristic electron confinement based on their dimensionality and geometric structures, which can be influenced not only by charge injection and chemical bonding but also structural modification. In this talk, I will discuss the electronic structures of various sp2-carbon allotropes on metal substrates investigated by scanning tunneling microscopy and spectroscopy. In particular, it is focused on the one dimensional (1D) electronic structure in a graphene nano wrinkle (GNW) of an epitaxially grown graphene (EG) sheet on Ni(111), the width of which was small enough (less than 5 nm) to cause 1D electron confinement. Use of spatially resolved, scanning tunneling spectroscopy revealed band-gap opening and a 1D van Hove singularity in the GNW, as well as the chemical potential distribution across the GNW. Our demonstration of 1D electron confinement in an EG is the novel possibility of controlling its electronic properties not by chemical modification but by mechanical structuring in a controlled manner.

Graphene-based carbon materials such as fullerenes, carbon nanotubes, and graphenes have distinct and unique electronic properties that depend on their dimensionality and geometric structures. Graphene wrinkles with pseudo one-dimensional structures have been observed in a graphene sheet. However, their one-dimensional electronic properties have never been observed because of their large widths. Here we report the unique electronic structure of graphene nanowrinkles in a graphene sheet grown on Ni, the width of which was small enough to cause one-dimensional electron confinement. Use of spatially resolved, scanning tunnelling spectroscopy revealed bandgap opening and a one-dimensional van Hove singularity in the graphene nanowrinkles, as well as the chemical potential distribution across the graphene nanowrinkles. This observation allows us to realize a metallic-semiconducting-metallic junction in a single graphene sheet. Our demonstration of one-dimensional electron confinement in graphene provides the novel possibility of controlling its electronic properties not by chemical modification but by ‘mechanical structuring’.

Graphene wrinkles, which are one-dimensional (1D) folded graphene structures, have generally been observed in graphene produced by chemical vapour deposition. These structures have been thought to be the result of the difference in the thermal expansion coefficient between graphene and its substrate. A graphene wrinkle is chemically bonded with surrounding planar epitaxial graphene. Therefore, its unique geometric structure is distinct from those of carbon nanotubes and graphene nanoribbons which are indisputably 1D structures. Hence, we define a graphene wrinkle as a ‘pseudo 1D structure’ to indicate that it has a 1D shape, but is still a part of a two-dimensional structure.

In the following, we demonstrate the 1D electron confinement in graphene nanowrinkle (GNW) by scanning tunnelling microscopy/spectroscopy (STM/STS), whose width is <5 nm. Moreover, spatially resolved electronic structures have been investigated, and the manipulation of graphene geometry by STM tip has been demonstrated. Our results imply that a semiconducting property can be realized by the mechanical deformation of the graphene geometry not by chemical modification, which is analogous to the case of a strain-induced pseudo magnetic field that was discovered in deformed ‘graphene nanobubbles’. The lack of surface functionalization in our approach can prevent the mobility decline due to chemical defects. Moreover, the covalent bonding at the metallic pEG-semiconducting GNW junction can reduce the contact resistance. Our results demonstrate that the interfacial interaction between graphene and the metal substrate provides a novel way to realize a metallic-semiconducting-metallic junction within a single graphene sheet.

Results:

Structural characterization of GNWs

Epitaxial graphene with GNWs was synthesized by dissociating acetylene on a clean Ni(111) surface. A rapid cooling process is necessary, which is the most critical step to synthesize GNWs. Most of the GNWs were observed in the region where the terrace width of the underlying Ni surface was as small as several tens of nanometres. These GNWs have been recoloured with orange, and a line profile along the white arrow, which shows that the GNWs on the terrace have larger widths and lower heights than the GNWs at the step edges. We should note that all GNWs were formed at the step edges (red triangles or propagated from kinks at the step edges of the Ni surface, the implication being that the geometrical structure of the underlying Ni must play a crucial role in the formation of GNWs To analyse the structure of the GNWs in detail, we obtained atomically resolved STM images from an isolated GNW on the terrace under different scanning conditions. The top and bottom regions of the GNW in were scanned at a sample bias (Vs) of 1 V and a feedback current (If) of 1 nA, whereas the centre region was scanned with a smaller tip–sample distance.

Bottom Note: *This work is partly presented at International Conference on Physics June 27-29, 2016, New Orleans, USA*