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Epitaxial Graphene Nanoribbons:
One-dimensional Confinement and pn-junction Array

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Wafer scale epitaxial graphene grown on Silicon Carbide (SiC) is regarded as a suitable candidate for carbon based electronics. In recent years, our group has demonstrated many possibilities to tune the electronic properties of this two-dimensional (2D) material by controlled doping schemes and intercalation between SiC substrate and the graphene layer [1-4]. However, for application in logical electronics, the necessity to define an off state is a key ingredient, which – due to the absence of an electronic bandgap – is so far out of reach in conventional pristine graphene layers. Spatial constriction of the material can provide a way to circumvent this problem. Indeed, arm-chair graphene nanoribbons (AGNRs) were theoretically predicted to display a bandgap. However, lithographical patterning of the graphene creates irregular edges. The self-assembly of molecular precursors is restricted to metallic substrates which introduce an electrical short-circuit. Instead, in this work we grow high-quality AGNRs on 6H-SiC, i.e., a semi-insulating substrate. The SiC substrate is patterned into a periodic array of mesas and trenches by electron beam lithography and reactive ion etching [5]. Graphene growth leads to the development of tilted sidewalls with an inclination of about 26°. Within the sidewalls, a ladder of narrow facets evolves which in turn host the AGNRs. Angle-resolved photoelectron spectroscopy (ARPES) and scanning tunneling spectroscopy measurements reveal the development of a width-dependent semiconducting gap driven by quantum confinement effects. Furthermore, ARPES demonstrates an ideal one-dimensional (1D) electronic behavior that for the first time is realized in a graphene-based environment, consisting of well-resolved subbands, dispersing and non-dispersing along and across the ribbons, respectively [6]. Our experimental findings, coupled with tight-binding calculations, set the grounds for a deeper exploration of quantum confinement phenomena and may open intriguing avenues for new low-power electronics.

On the facets, the nano-sized AGNRs are defined by a periodic ladder of nano-buffer stripes and free-standing ribbons as demonstrated by low-energy electron diffraction (LEED), spot-profile analysis (SPA)-LEED and scanning tunneling microscopy (STM). By hydrogen intercalation the buffer stripes become decoupled, so that the series of 1D confined nanoribbons is transformed into a single 2D graphene sheet rolling over the 6H-SiC mesa structures. Simultaneously, the buffer layer sheets on the mesas and trenches are also decoupled and turn into the well-known quasi-free standing monolayer graphene (QFMLG). The different constituents of the graphene-SiC interface are identified using X-ray photoelectron spectroscopy (XPS). Due to the different surface terminations of the basal and vicinal SiC planes constituting the mesa structures, different types of charge carriers are locally induced into the graphene layer. By ARPES, we can selectively measure the electronic band structure of the two graphene regions, finding two symmetrically doped phases with p-type being located on the basal planes and n-type on the facets. Our results demonstrate that through a careful structuring of the substrate, combined with H-intercalation, an array of graphene pn-junctions could be engineered at the nanoscale [7]. Such graphene pn-junctions represent potential building-blocks for a broad spectrum of future technologies, ranging from electronic lenses analogous to metamaterials in optics, to high-performance photodetectors important for a variety of optoelectronic applications.

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