Graphene Quantum Electrical Metrology for National Measurement Standards

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Graphene represents a rare opportunity to dramatically improve metrology based on the fundamental constants, but application of the truly unique characteristics of graphene requires perfecting new fabrication methods. Our work has been successful in overcoming obstacles leading to monolayer epitaxial graphene with homogeneous carrier density and mobility. We begin with silicon carbide wafers aligned to the 4H-SiC(0001) surface to within 0.1 degree, which provides the orientation for the hexagonal carbon lattice [1-2]. The large-area graphene devices required for precise metrology must be treated by chemical doping to provide stable carrier density. Most covalent molecular bonds alter the in-plane bonds and thus reduce the mobility. Covalent chemisorption by $Cr(CO)_3$ ring-centered (hexahapto) bonds preserves the band structure and the planarity of graphene, and we observe an increase in mobility and a controllable decrease in carrier density with this technique, as predicted by theory [3-4].

New types of metrological standards can be fabricated with epitaxial graphene. The Dirac band structure allows quantum Hall effect (QHE) resistance standards to work efficiently over a wide range of magnetic field strength, temperatures, and current levels. To obtain more useful standards, multiple contact interconnections can be created to form arrays of devices with highly precise fundamental resistance values based on the Planck constant h and the elementary charge e [5-6]. Some of our first graphene QHE arrays fabricated using NbTiN superconducting interconnections provide the precise value $(h/26e^2) = 992.800287\ \Omega \pm 0.000002\ \Omega$, and as arrays such as this become available, more laboratories can affordably maintain the ohm unit [7-9].

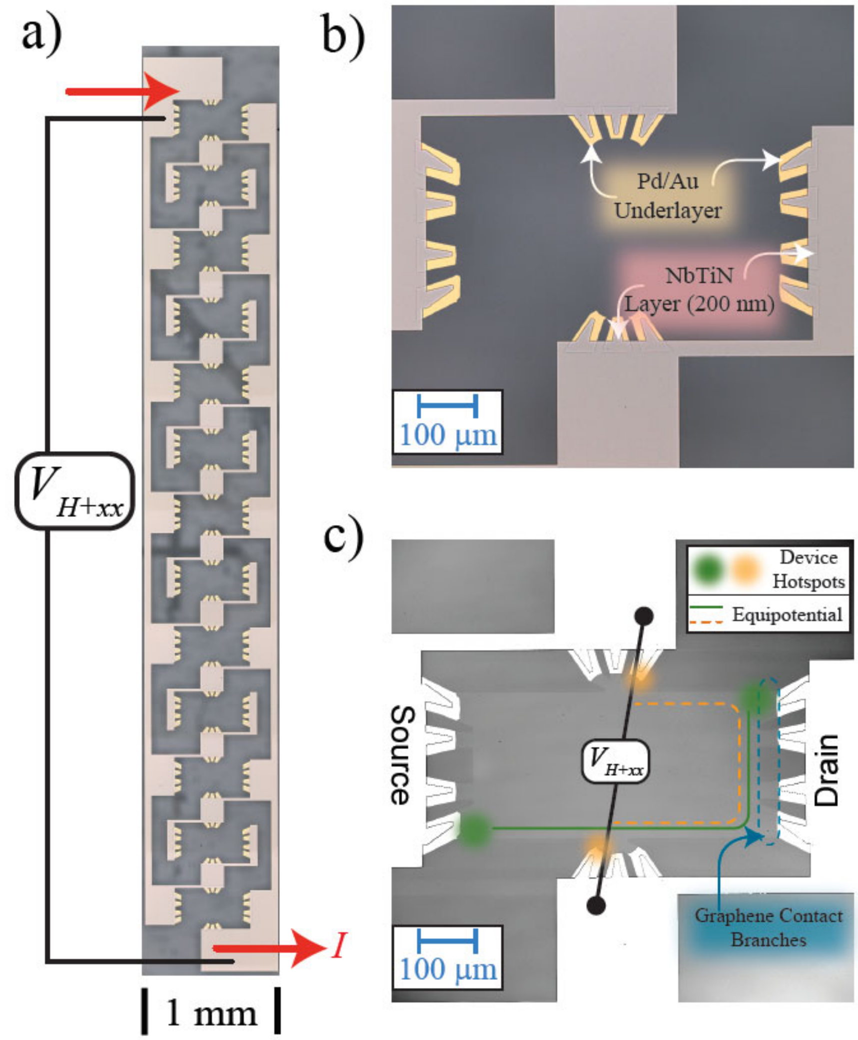

Fig. 1. Device layout and features in a quantizing magnetic field. a) Each of 13 array elements is 0.4 mm × 0.2 mm monolayer EG and has multiple contact branches. b) Single array element contact layout, with a Pd/Au underlayer that provides EG surface adhesion and ensures a normal metal interface with NbTiN superconductor. c) With strong quantization, boundaries of high and low electrochemical potential surround the EG, beginning at the two hotspots created by the power dissipation at the source and drain. These are labeled equipotential, although small changes may occur where current enters or leaves the device at intermediate contacts. The positions of hotspots depend on the orientation of *B*. In one field direction *B*+ (magnetic vector pointing into the page; equipotential boundary shown by the green line) the Hall voltage is nearly perpendicular to the source-drain current vector. This voltage is labeled V_{H+xx} to account for R_{xx} contributions due to the small diagonal offset of the voltage probes, as described in the text. The opposite field direction (*B*-) causes the voltage and current contact points to exchange positions and increases the sensitivity to longitudinal resistance due to the width of the regions labeled source and drain.

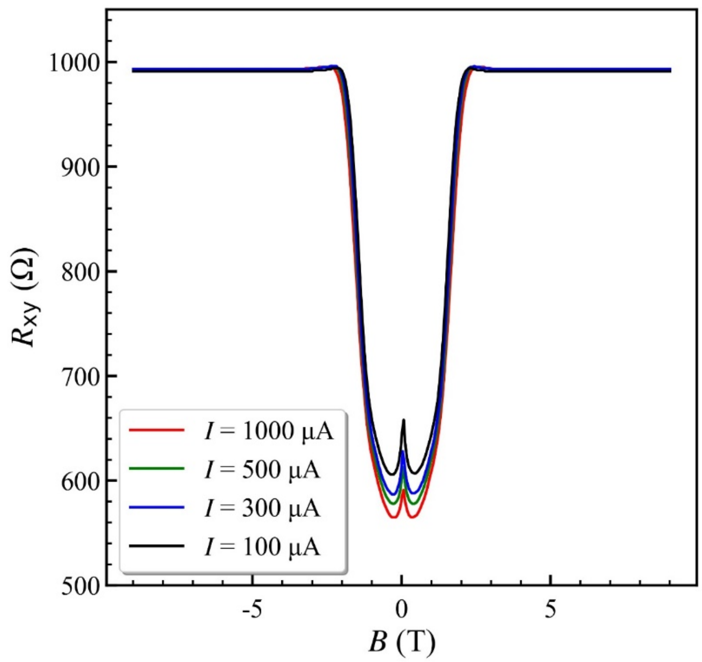

Fig. 2. Resistance of array device 2 as a function of magnetic field *B* measured using a current source and a digital voltmeter. The symmetric resistance profile for *B*- and *B*+ typifies the combined voltage and current interconnections of a parallel array.

References

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