Carrier Transport and Electrical Conduction in Alloy-Mediated Graphene on Silicon

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Abstract

The possibility of graphene-based micro- and nanoelectronic devices that exploit the extraordinary electronic properties of graphene is the biggest inspiration behind the accelerated development of graphene science and technology. Although the remarkable efforts for establishing graphene as a new electronic material began over 15 years ago, the actual realisation of graphene devices on a large-scale remains elusive, mainly due to feasibility, cost-effectiveness and compatibility issues with the existing semiconductor technology and processes. Significant advancements have been achieved in the synthesis and establishment of transport properties of epitaxial graphene (EG) on 4H- and 6H-SiC, while equivalent progress using silicon (Si) as a platform (via a thin film of 3C-SiC) with reliable electrical transport measurements has not been elucidated to date, due to limitations such as non-uniform coverage of graphene on 3C-SiC/Si and high density of defects within the 3C-SiC.

In this work, we first show that the heteroepitaxial 3C-SiC on Si as the substrate should be carefully approached, as the 3C-SiC/Si heterojunction is electrically unstable and prone to severe leakage or parallel conduction. Subsequently, we find that the interface instability is due to the diffusion of carbon into the silicon matrix during the 3C-SiC growth, creating electrically active interstitial carbon. We overcome these challenges using 3C-SiC on a highly-resistive silicon substrate.

By addressing the parallel conduction issue of the 3C-SiC/Si heteroepitaxial system, in this work, we isolate the charge transport properties of epitaxial graphene (EG) grown directly on 3C-SiC over large areas via an alloy-mediated method and present corresponding physical ab-initio models. Here, we study the properties of EG synthesised on 3C-SiC(100) and 3C-SiC(111). The transport properties of EG on 3C-SiC follow a similar power-law dependence of sheet carrier concentration and mobility and comparable sheet resistance values with the EG on bulk-SiC – although the grain sizes for both are vastly different. Furthermore, we find that the transport properties of graphene within the observed regime are dominated by the substrate interaction, resulting in a large p-type doping, especially for the graphene on 3C-SiC(100). In the case of EG on 3C-SiC(111), the presence of buffer layer reduces the substrate interaction and the charge transfer up to an extent. This work demonstrates a more compelling need to focus on the engineering of the graphene-substrate interface as opposed to graphene grain sizes in order to tune the charge transport properties of the epitaxial graphene for the integration of 2D materials in functional nanosystems.

Certificate of original authorship

I, Aiswarya Pradeepkumar declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the Faculty of Engineering at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Aiswarya Pradeepkumar

30/01/2020

Dedication

This thesis is dedicated to my parents Pradeepkumar P and Vasanthakumari V

for giving me invaluable educational opportunities

and my husband Nikhil Das

for his support, constant encouragement and care

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List of Acronyms

CMOS	Complementary metal-oxide-semiconductor
2D	Two dimensional
CVD	Chemical vapour deposition
LPCVD	Low-pressure chemical vapour deposition
EG	Epitaxial graphene
3C-SiC	Cubic silicon carbide
SiC	Silicon carbide
SF	Stacking faults
APB	Anti phase boundaries
UHV	Ultra-high vacuum
FET	Field-effect transistor
CNP	Charge neutrality point
MEMS	Micro-electro-mechanical systems
HOPG	Highly oriented pyrolytic graphite
QFMLG	Quasi free-standing monolayer graphene
SEM	Scanning electron microscopy
HRTEM	High-resolution transmission electron microscopy
FIB	Focused ion beam
TLM	Transfer length measurement
ICP	Inductively coupled plasma
RIE	Reactive ion etching
NEXAFS	Near edge X-ray absorption fine-structure spectroscopy
ARPES	Angle-resolved photoemission spectroscopy
XPS	X-ray photoelectron spectroscopy
FWHM	Full width at half maximum
IMFP	Inelastic mean free path
LEEM	Low-energy electron microscopy
DFT	Density functional theory