



Universiteit
Leiden
The Netherlands

Formation of graphene and hexagonal boron nitride on Rh(111) studied by in-situ scanning tunneling microscopy

Dong, G.

Citation

Dong, G. (2012, November 7). *Formation of graphene and hexagonal boron nitride on Rh(111) studied by in-situ scanning tunneling microscopy*. *Casimir PhD Series*. Kamerlingh Onnes Laboratory, Leiden Institute of Physics, Faculty of Science, Leiden University. Retrieved from <https://hdl.handle.net/1887/20105>

Version: Corrected Publisher's Version

License: [Licence agreement concerning inclusion of doctoral thesis in the Institutional Repository of the University of Leiden](#)

Downloaded from: <https://hdl.handle.net/1887/20105>

Note: To cite this publication please use the final published version (if applicable).

Cover Page



Universiteit Leiden



The handle <http://hdl.handle.net/1887/20105> holds various files of this Leiden University dissertation.

Author: Dong, Guocai

Title: Formation of graphene and hexagonal boron nitride on Rh(111) studied by in-situ scanning tunneling microscopy

Date: 2012-11-07

**Formation of graphene and hexagonal boron nitride on
Rh(111) studied by in-situ scanning tunneling microscopy**

Guocai Dong

**Formation of graphene and hexagonal boron nitride on
Rh(111) studied by in-situ scanning tunneling microscopy**

PROEFSCHRIFT

ter verkrijging van

de graad van Doctor aan de Universiteit Leiden

op gezag van Rector Magnificus prof. mr. P.F. van der Heijden

volgens besluit van het College voor Promoties

te verdedigen op woensdag 7 november 2012

klokke 11:15 uur

door

Guocai Dong

geboren te Heilongjiang, China

in 1981

PROMOTIECOMMISSIE

Promotor: Prof. Dr. J. W. M. Frenken (Leiden University)

Overige leden: Prof. Dr. J. Aarts (Leiden University)

Prof. Dr. E.R. Eliel (Leiden University)

Prof. Dr. T. Greber (University of Zürich)

Prof. Dr. T. Michely (University of Cologne)

Prof. Dr. P. Rudolf (University of Groningen)

Prof. Dr. R. Tromp (IBM, Leiden University)

Dr.ir. S.J. van der Molen (Leiden University)

Dr. A. Yanson (Leiden University)

Casimir PhD series, Delft-Leiden 2012-31

ISBN: 978-90-8593-138-6

An electronic version of this thesis can be found at
<https://openaccess.leidenuniv.nl> and at <http://www.interfacephysics.nl>.

The work described in this thesis was made possible by financial support from the Foundation for Fundamental Research on Matter (FOM/NWO), the EU project 'Nanomesh' (No. FP6-013817), and an ERC Advanced Investigator Grant. This work has been performed at the Kamerlingh Onnes Laboratory, Leiden Institute of Physics, Leiden University, The Netherlands.

To my family

Contents

CHAPTER 1 INTRODUCTION	1
1.1 ULTRATHIN FILM DEPOSITION.....	1
1.2 NANOMESH.....	2
1.2.1 <i>The structure and properties of nanomesh</i>	2
1.2.2 <i>h-BN growth on other metals</i>	4
1.2.3 <i>Formation mechanism of the nanomesh structure</i>	4
1.3 GRAPHENE	5
1.3.1 <i>The properties of graphene</i>	7
1.3.2 <i>Potential applications of graphene</i>	8
1.3.3 <i>Graphene production</i>	9
1.3.4 <i>Graphene growth on transition metals</i>	10
1.4 THIS THESIS	12
CHAPTER 2 EXPERIMENTAL	13
2.1 EXPERIMENTAL SETUP.....	13
2.1.1 <i>Vacuum chamber and equipment</i>	13
2.1.2 <i>The Variable-Temperature STM</i>	15
2.1.3 <i>The heating of the sample</i>	18
2.2 THE RH(111) SAMPLE.....	20
2.3 THE MOIRÉ PATTERNS.....	21
PART I NANOMESH FORMATION ON RH (111)	26
CHAPTER 3 INTRODUCTION OF PART I	27
3.1 BACKGROUND.....	27
3.2 EXPERIMENTAL METHODS.....	28
3.3 THIS PART OF THE THESIS.....	31

CHAPTER 4 NANOMESH FORMATION AT DIFFERENT TEMPERATURES ON RH(111) ..	33
4.1 INTRODUCTION	33
4.2 NANOMESH FORMATION FROM BORAZINE DEPOSITED AT ROOM TEMPERATURE.....	33
4.3 NANOMESH FORMATION FROM BORAZINE DEPOSITED BETWEEN 627 K AND 865 K	36
4.4 NANOMESH FORMATION FROM BORAZINE DEPOSITED AT 978 K.....	38
4.4.1 <i>The growth unit</i>	39
4.4.2 <i>Nanomesh island shape</i>	39
4.4.3 <i>Nanomesh growth along different edges</i>	40
4.4.4 <i>Growth barriers of the nanomesh structure at various sites</i>	42
4.5 CONCLUSIONS	46
CHAPTER 5 ADSORPTION AND DECOMPOSITION OF BORAZINE	49
5.1 THE BREAKING OF B-N BONDS	49
5.2 DESORPTION OF BORAZINE MOLECULES AND B AND N ATOMS.....	50
5.3 FROM WHICH BORAZINE IS THE <i>h</i> -BN OVERLAYER FORMED?	51
5.4 DISCUSSION	58
5.5 CONCLUSION.....	58
CHAPTER 6 DEFECTS IN THE NANOMESH LATTICE.....	59
6.1 STRUCTURE AND FORMATION OF DOMAIN BOUNDARIES.....	59
6.2 REMOVAL OF DOMAIN BOUNDARIES.....	62
6.3 CONCLUSION.....	65
PART II GRAPHENE FORMATION ON RH(111)	66
CHAPTER 7 INTRODUCTION TO PART II.....	67
7.1 GENERAL BACKGROUND.....	67
7.2 EXPERIMENTAL METHOD.....	68
7.3 THIS PART OF THE THESIS	69

CHAPTER 8 PARAMETERS INFLUENCING GRAPHENE AND CARBIDE FORMATION.....	71
8.1 INTRODUCTION	71
8.2 THE TEMPERATURE DEPENDENCE OF GRAPHENE AND CARBIDE FORMATION	71
8.3 THE CRUCIAL ROLE OF THE HISTORY OF THE SAMPLE.....	77
8.4 CONCLUSION	80
CHAPTER 9 TOWARDS THE OPTIMAL GROWTH RECIPE	81
9.1 INTRODUCTION	81
9.2 USING SEGREGATED CARBON TO FORM GRAPHENE	81
9.3 FURTHER ETHYLENE DEPOSITION	83
9.4 CONCLUSION	84
CHAPTER 10 RH ISLAND FORMATION INDUCED BY GRAPHENE GROWTH.....	85
10.1 INTRODUCTION	85
10.2 EXPERIMENT.....	85
10.3 TUNNELING CURRENT VS. ADATOM DENSITY.....	89
10.4 MODELS	91
10.5 CONCLUSION	93
CHAPTER 11 GROWTH KINETICS	95
11.1 INTRODUCTION	95
11.2 HOW THE MOIRÉ PATTERN INFLUENCES THE GROWTH	98
11.3 THE INFLUENCE OF CORNER STRUCTURE ON KINK CREATION.....	101
11.4 THE INFLUENCE OF CORNER ENERGY	103
11.5 DIFFERENCE BETWEEN GROWTH AT EXTERNAL AND INTERNAL GRAPHENE EDGES.....	103
11.6 FROM WHICH CARBON DOES GRAPHENE GROW?.....	105
11.7 CONCLUSION	106
CHAPTER 12 THE STRUCTURE OF GRAPHENE ON RH.....	107
12.1 INTRODUCTION	107

Contents

12.2 EXPERIMENT	108
12.3 RESULT AND CONCLUSION	110
CHAPTER 13 A UNIVERSAL DESCRIPTION OF GRAPHENE FORMATION ON TRANSITION METALS	113
REFERENCES	119
SUMMARY	126
SAMENVATTING	132
ACKNOWLEDGEMENTS	139
PUBLICATIONS AND PATENTS	140
CURRICULUM VITAE	141