

Cover Page



Universiteit Leiden



The handle <http://hdl.handle.net/1887/56260> holds various files of this Leiden University dissertation

Author: Antonov, Pavel

Title: Towards thermo- and superlubricity on the macroscopic scale : from nanostructures to graphene and graphite lubrication

Date: 2017-10-18

**Towards thermo- and superlubricity
on the macroscopic scale: from nanostructures to
graphene and graphite lubrication**

Proefschrift

ter verkrijging van
de graad van Doctor aan de Universiteit Leiden,
op gezag van Rector Magnificus prof. mr. C.J.J.M. Stolker,
volgens besluit van het College voor Promoties
te verdedigen op woensdag 18 oktober 2017
klokke 16.15 uur

door

Pavlo Volodymyrovych Antonov

geboren te Kharkov, Oekraïne
in 1990

Promotor: prof. dr. J.W.M. Frenken

Promotiecommissie:

prof. dr. D. Bonn (Universiteit van Amsterdam)
prof. dr. A. Fasolino (Radboud Universiteit, Nijmegen)
prof. dr. ir. T.H. Oosterkamp
prof. dr. E.R. Eliel

Casimir PhD series, Delft-Leiden 2017-28 ISBN 978.90.8593.312.0. An electronic version of this thesis can be found at openaccess.leidenuniv.nl

The work described in this thesis was performed at the Huygens-Kamerlingh Onnes Laboratory, Leiden University and at the Advanced Research Center for Nanolithography (ARCNL), Amsterdam, The Netherlands.

This research has been supported by the ERC-AG project *Science F(r)iction* of the European Research Council and the Program *Fundamental Aspects of Friction* of the Netherlands Organisation for Scientific Research (NWO).

Cover: Henk-Jan Boluijt

Content

Chapter 1	
Introduction	1
Chapter 2	
Towards superlubricity at the macroscopic scale	7
2.1 Introduction	8
2.2 Design of nanopillar array	13
2.3 Experimental setup	19
2.4 Experimental results and discussion	19
2.5 Sliding flat surfaces over nanopillar arrays	33
2.6 Summary	42
2.7 Bibliography	43
Chapter 3	
Fabrication of high-aspect ratio silicon nanopillars for tribological experiments	47
3.1 Introduction	48
3.1.1 Overview of relevant nanomanufacturing techniques	48
3.2 Nanopillars fabrication	49
3.3 Removal of resist residues	52
3.4 Summary	55
3.5 Bibliography	56
Chapter 4	
Microscopic investigations of the lubrication mechanism of Diamond-Like Carbon	59
4.1 Introduction	60
4.2 Experimental	61
4.3 Results and discussion	69

4.4	Summary	89
4.5	Bibliography	91
Chapter 5		
Dynamic and static tribological properties of micropatterned Diamod-Like Carbon under different humidities		97
5.1	Introduction	98
5.2	Experimental	100
5.3	Experimental results	100
5.4	Discussion	105
5.5	Conclusions	115
5.6	Bibliography	117
Chapter 6		
Towards superlubricity of graphene on the macroscopic scale		125
6.1	Introduction	126
6.2	Experimental	129
6.3	Experimental results	131
6.4	Discussion	145
	6.4.1 Graphene as the thinnest lubricant	145
	6.4.2 Towards superlubricity on the macroscale	147
	6.4.3 Effect of substrate oxidation on nanoscale friction of graphene	149
6.5	Summary	154
6.6	Bibliography	155
Summary		161
Samenvatting		165
List of publications		169
Acknowledgements		170
Curriculum Vitae		172