



Universiteit  
Leiden  
The Netherlands

## Low energy electron transmission through layered materials and chiral organic films

Neu, P.S.

### Citation

Neu, P. S. (2024, June 12). *Low energy electron transmission through layered materials and chiral organic films*. Retrieved from <https://hdl.handle.net/1887/3762501>

Version: 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/1887/3762501>

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

LOW ENERGY ELECTRON TRANSMISSION  
THROUGH LAYERED MATERIALS  
AND CHIRAL ORGANIC FILMS

Proefschrift

ter verkrijging van

de graad van doctor aan de Universiteit Leiden,

op gezag van rector magnificus prof.dr.ir. H. Bijl,

volgens besluit van het college voor promoties

te verdedigen op woensdag 12 juni 2024

klokke 13:45 uur

door

Peter Sebastian Neu

geboren te Duisburg, Duitsland

Promotores:

Prof.dr.ir. S.J. van der Molen

Prof.dr.ir. R.M. Tromp

Promotiecommissie:

Prof.dr. C. Kumpf (Forschungszentrum Jülich GmbH)

Dr. Z. Zanolli (Universiteit Utrecht)

Prof.dr. J. Aarts

Prof.dr. M.P. van Exter

Prof.dr.ir. T.H. Oosterkamp

Prof.dr. J.M. van Ruitenbeek

An electronic version of this thesis is available at

<https://scholarlypublications.universiteitleid.nl/>.

Printed by Gildeprint in Enschede.

The work presented in this dissertation was funded by the Dutch Research Council (NWO).

The cover shows an optical micrograph of molybdenum disulfide ( $\text{MoS}_2$ ) flakes during sample preparation. The mechanically exfoliated  $\text{MoS}_2$  flakes are brought into contact with a holey transmission electron microscopy grid. The colorful optical interference fringes appear when the polymer stamp (with the  $\text{MoS}_2$  flakes attached) is almost in contact with the substrate.





# CONTENTS

<b>1 INTRODUCTION</b> .....	<b>1</b>
1.1 VAN DER WAALS MATERIALS .....	2
1.2 PROBING VAN DER WAALS MATERIALS WITH ELECTRONS .....	3
1.3 ELECTRON-MATTER INTERACTIONS .....	5
1.3.1 Elastic electron scattering: the electron wave .....	5
1.3.2 Elastic and Inelastic Mean Free Path.....	8
1.4 CHIRALITY.....	9
1.4.1 Chirality-Induced Spin Selectivity (CISS).....	11
1.5 OUTLINE OF THIS THESIS.....	14
REFERENCES .....	15
<b>2 LOW-ENERGY ELECTRONS: MICROSCOPY AND SPECTROSCOPY</b> .....	<b>19</b>
2.1 INTRODUCTION .....	20
2.2 THE ESCHER SETUP.....	20
2.3 LOW-ENERGY ELECTRON MICROSCOPY (LEEM).....	21
2.4 ELECTRON VOLT-TRANSMISSION ELECTRON MICROSCOPY (eV-TEM) .....	23
2.5 PHOTOEMISSION ELECTRON MICROSCOPY (PEEM) WITH POLARIZED LIGHT .....	25
REFERENCES .....	27
<b>3 EXTRACTING TRANSVERSE ELECTRON MEAN FREE PATHS IN GRAPHENE AT LOW ENERGY</b> .....	<b>29</b>
ABSTRACT.....	29
3.1 INTRODUCTION .....	30
3.2 INTERFERENCE MODEL WITH LOSSES .....	31
3.3 RESULTS.....	33
3.4 CONCLUSIONS .....	38
APPENDIX.....	39
REFERENCES .....	40
<b>4 SYMMETRIES OF ELECTRON INTERACTIONS WITH HBN-GRAPHENE HETEROSTACKS</b> .....	<b>43</b>
4.1 INTRODUCTION .....	44
4.2 RESULTS .....	44
4.2.1 Geometry and images.....	44
4.2.2 Spectra.....	47
4.2.3 Calculated spectra and electron density distributions.....	51
4.2.4 Elastic and inelastic mean free paths.....	54
4.2.5 Symmetry upon flipping the sample .....	56
4.3 CONCLUSION .....	60
APPENDIX.....	62
Sample fabrication .....	62
Flipped sample.....	63
Free-standing hBN.....	63
REFERENCES .....	65

<b>5 ELECTRON TRANSMISSION AND MEAN FREE PATH IN MOLYBDENUM DISULFIDE AT ELECTRONVOLT ENERGIES .....</b>	<b>69</b>
ABSTRACT.....	69
5.1 INTRODUCTION.....	70
5.2 EXPERIMENT.....	70
5.3 RESULTS.....	71
5.4 DISCUSSION.....	76
5.5 SUMMARY .....	77
APPENDIX.....	78
<i>Optical Images</i> .....	78
<i>Projected Density of States</i> .....	78
<i>Mean Free Path: comparing with previous work</i> .....	79
REFERENCES .....	80
<b>6 PHOTOEMISSION FROM CHIRAL MOLECULE FILMS .....</b>	<b>83</b>
6.1 INTRODUCTION.....	84
6.2 EXPERIMENTAL .....	86
6.2.1 <i>Linear polarization and photoemission</i> .....	86
6.2.2 <i>Principal tests on gold structures</i> .....	88
6.2.3 <i>Polarization-dependent Photoemission from BINAP</i> .....	90
6.2.4 <i>Further calculation of transmitted polarization</i> .....	98
6.3 CONCLUSIONS AND RECOMMENDATIONS .....	99
REFERENCES .....	101
<b>SUMMARY.....</b>	<b>105</b>
<b>SAMENVATTING.....</b>	<b>107</b>
<b>ZUSAMMENFASSUNG .....</b>	<b>111</b>
<b>ACKNOWLEDGEMENTS.....</b>	<b>115</b>
<b>CURRICULUM VITAE .....</b>	<b>117</b>
<b>LIST OF PUBLICATIONS.....</b>	<b>119</b>





