



Universiteit  
Leiden  
The Netherlands

## Insights from scanning tunneling microscopy experiments into correlated electron systems

Benschop, T.

### Citation

Benschop, T. (2023, September 26). *Insights from scanning tunneling microscopy experiments into correlated electron systems*. *Casimir PhD Series*. Retrieved from <https://hdl.handle.net/1887/3642190>

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/1887/3642190>

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

# Insights from Scanning Tunneling Microscopy Experiments into Correlated Electron Systems

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 dinsdag 26 september 2023  
klokke 10.00 uur

door

**Tjerk Benschop**

geboren te Spijkenisse

in 1995

**Promotores:**

Dr. M.P. Allan

Prof. dr. J. Aarts

**Promotiecommissie:**

Dr. M. Rösner

(Radboud Universiteit Nijmegen)

Prof. dr. C. Schönenberger

(University of Basel)

Dr. S. Bhattacharyya

Prof. dr. E.R. Eliel

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



Universiteit  
Leiden



*Casimir*  
research school



Casimir PhD series, Delft-Leiden 2023-20

ISBN 978-90-8593-568-1

An electronic version of this dissertation is available at

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

*Printed by Gildeprint*

*The cover was designed by Xingchen Chen*

This work was financed by the Dutch Research Council (NWO) as part of the Frontiers of Nanoscience program (NanoFront).

Copyright © 2023 Tjerk Benschop.

# Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	Motivation . . . . .	1
1.2	Thesis outline . . . . .	3
<b>2</b>	<b>Puddle formation, persistent gaps, and non-mean-field breakdown of superconductivity in overdoped <math>(\text{Pb,Bi})_2\text{Sr}_2\text{CuO}_{6+\delta}</math></b>	<b>7</b>
2.1	Introduction . . . . .	8
2.2	Gap Quantification . . . . .	9
2.3	Breakdown of superconductivity through filling of the gap . . . . .	13
2.4	On what is filling the gap . . . . .	15
2.5	Summary . . . . .	17
<b>3</b>	<b>Measuring local moiré lattice heterogeneity of twisted bilayer graphene</b>	<b>19</b>
3.1	Introduction . . . . .	20
3.2	Methods . . . . .	22
3.3	Spatial lock-in algorithm . . . . .	24
3.4	Results . . . . .	26
3.5	Conclusion . . . . .	29
<b>4</b>	<b>Amplifier for scanning tunneling microscopy at MHz frequencies</b>	<b>31</b>
4.1	Introduction . . . . .	32
4.2	Noise sources in STM . . . . .	33
4.3	Amplifier and circuit . . . . .	35
4.3.1	General idea . . . . .	35
4.3.2	Circuit elements and printed circuit board design . . . . .	35
4.4	Noise spectroscopy performance on atomically Au(111) . . . . .	38
4.5	Conclusions and outlook . . . . .	39
<b>5</b>	<b>Noise enhancement in the tunneling current between an STM tip and <math>\text{Sr}_2\text{IrO}_4</math></b>	<b>41</b>
5.1	Introduction . . . . .	42
5.2	STM on $\text{Sr}_2\text{IrO}_4$ . . . . .	43
5.3	Noise measurements . . . . .	44
5.4	Random telegraph noise . . . . .	47

## Contents

---

5.5	Summary and outlook . . . . .	50
<b>A</b>	<b>Supplementary information to puddle formation, persistent gaps, and non-mean-field breakdown of superconductivity in overdoped (Pb,Bi)<sub>2</sub>Sr<sub>2</sub>CuO<sub>6+δ</sub></b>	<b>51</b>
A.1	Experimental Methods . . . . .	52
A.2	The phenomenological model to fit spectra . . . . .	52
A.2.1	The d-wave gap model . . . . .	52
A.2.2	Statistical analysis with and without the excluded spectra . . .	53
A.2.3	Fit parameters figure 2.2c . . . . .	58
A.2.4	Energy range for fitting and approximations for the normal density of states . . . . .	58
A.2.5	An alternative model . . . . .	60
A.3	Temperature dependence . . . . .	63
A.4	Intrinsic Metal-Induced Pair-Breaking Effects Within a Superconducting Puddle Embedded in a Metallic Matrix . . . . .	63
A.5	Rigid band shift in overdoped Bi2201 . . . . .	69
A.6	Gap filling and DOS from other experiments . . . . .	71
A.7	Pair breaking, Gap filling and competing orders . . . . .	71
<b>B</b>	<b>Supplementary information to measuring local moiré lattice heterogeneity of twisted bilayer graphene</b>	<b>73</b>
B.1	Spatial Lock-in Algorithm . . . . .	73
B.1.1	Deformations of a lattice . . . . .	73
B.1.2	Properties of the deformation . . . . .	74
B.1.3	Determination of the displacement field $\mathbf{u}(\mathbf{r})$ . . . . .	75
B.1.4	Additional notes on choice of reference vectors . . . . .	76
B.2	Relation of moiré lattice to relative displacement . . . . .	77
B.2.1	Relation to uniaxial strain models . . . . .	79
B.3	Phase unwrapping & singularities . . . . .	80
B.4	Device overview . . . . .	80
B.5	Accuracy of the algorithm . . . . .	81
B.6	Validity check with more data . . . . .	83
B.7	Heterogeneity comparison with other devices and data overview . . . .	84
B.8	Homogeneity quantification . . . . .	86
B.9	Artificial resolution limitation for comparison with SOT . . . . .	86
B.10	Error estimation of the heterostrain model . . . . .	87
B.11	Twist angle homogeneity overview . . . . .	88
B.12	Data processing . . . . .	88
	<b>Bibliography</b>	<b>91</b>
	<b>Summary</b>	<b>105</b>
	<b>Samenvatting</b>	<b>109</b>

## Contents

---

Curriculum Vitae	113
List of publications	115
Acknowledgments	117

## Contents

---