

Contents

Contents	ix
Introduction	1
1. Yu-Shiba-Rusinov states in superconducting bilayer graphene	3
1.1. Introduction	3
1.2. Model of superconducting bilayer graphene	6
1.2.1. Lattice structure	6
1.2.2. Tight binding Hamiltonian of bilayer graphene	7
1.2.3. Tight binding Hamiltonian in Bloch basis	9
1.2.4. Bogoliubov-de Gennes Hamiltonian	11
1.3. Green's function of superconducting bilayer graphene	12
1.3.1. Resolvent Green's function	12
1.3.2. Resolvent Green's function of bilayer graphene	13
1.3.3. Green's function in the real space basis	14
1.4. Yu-Shiba-Rusinov states	18
1.4.1. Model of the full system	18
1.4.2. Connection between the Yu-Shiba-Rusinov states and the Green's function	19
1.4.3. Downfolding of the adatom potential	19
1.4.4. Matrix representations	21
1.4.5. Results	22
2. Crossed Andreev reflection in topological insulator nanowire T junctions	27
2.1. Introduction	27
2.2. Introduction to 3D TI nanowires	29
2.2.1. 3D TI nanowires with parallel magnetic field	30
2.2.2. 3D TI nanowires in a perpendicular magnetic field	32
2.2.3. Superconducting 3D TI nanowires	32

2.3.	3D TI nanowire NS junction	33
2.4.	T junction	35
2.5.	Methods	36
2.5.1.	Model	37
2.5.2.	Local and nonlocal conductances	38
2.6.	Results	39
3.	Topological insulator nanowire Josephson junctions	45
3.1.	Introduction	45
3.2.	Geometry and model Hamiltonian	47
3.3.	Semiclassical method	51
3.3.1.	Method	51
3.3.2.	Classification of the paths	52
3.3.3.	Trajectories	53
3.3.4.	Phase space integration	55
3.4.	Andreev bound states and current contributions	59
3.4.1.	Andreev bound states from the scattering formalism	59
3.4.2.	Effect of the magnetic field	60
3.4.3.	Asymmetric junctions	62
3.4.4.	Current	63
3.5.	Minimal model	63
3.5.1.	Model	64
3.5.2.	Supercurrent oscillations in the minimal model	65
3.5.3.	Implications for more realistic systems	68
3.6.	Semiclassical model for the quadratic Hamiltonian	69
3.6.1.	Scattering matrix of the NS interface	69
3.6.2.	Andreev bound states	70
3.6.3.	Supercurrent oscillations	71
3.7.	Semiclassical model for the Dirac Hamiltonian	76
3.7.1.	Scattering matrix of the NS interface	76
3.7.2.	Andreev bound states	78
3.7.3.	Supercurrent oscillations	78
	Concluding remarks	81
	Conclusion	85

Appendices to the first chapter	89
A. Integral representations of $\tilde{g}_0$	89
B. Some useful mathematical identities	90
Appendices to the second chapter	93
C. Numerical implementation and finite difference method	93
Appendices to the third chapter	95
D. Alternative derivation of the superconducting phase	95
E. Unitary transformation of the Hamiltonian	96
F. Andreev bound states for imperfect interfaces	97
F.1. Two imperfect interfaces	97
F.2. One imperfect interface	97
G. Scattering matrix of a TI NS junction	98
G.1. Scattering states	98
G.2. Matching condition	100
G.3. Andreev approximation	101
G.4. Scattering matrix	102
H. Critical current in dependence of the maximum crossing number . .	104
Bibliography	107
List of publications	129
List of Figures	131
List of Acronyms	133
Acknowledgments	135