Contents

Preface – Superconductivity and Little's Phase Slips in Nanowires IX

v

Abbreviations – Short List XI

Notations – Short List XIII

Color Plates XV

- 1 Introduction 1
- 2 Selected Theoretical Topics Relevant to Superconducting Nanowires 15
- 2.1 Free or Usable Energy of Superconducting Condensates 15
- 2.2 Helmholtz and Gibbs Free Energies 18
- 2.3 Fluctuation Probabilities 23
- 2.4 Work Performed by a Current Source on the Condensate in a Thin Wire 27
- 2.5 Helmholtz Energy of Superconducting Wires 29
- 2.6 Gibbs Energy of Superconducting Wires 31
- 2.7 Relationship between Gibbs and Helmholtz Energy Densities 35
- 2.8 Relationship between Thermal Fluctuations and Usable Energy 36
- 2.9 Calculus of Variations 38
- 2.10 Ginzburg–Landau Equations 39
- 2.11 Little–Parks Effect 46
- 2.12 Kinetic Inductance and the CPR of a Thin Wire 50
- 2.13 Drude Formula and the Density of States 51

3 Stewart–McCumber Model 53

- 3.1 Kinetic Inductance and the Amplitude of Small Oscillations 60
- 3.2 Mechanical Analogy for the Stewart–McCumber Model 62
- 3.2.1 Defining the Supercurrent Through Helmholtz Free Energy 65
- 3.2.2 Cubic Potential 66
- 3.2.3 Thermal Escape from the Cubic Potential 67
- 3.3 Macroscopic Quantum Phenomena in the Stewart–McCumber Model 68
- 3.3.1 MQT in a Cubic Potential at High Bias Currents 71

VI Contents

3.4	Schmid–Bulgadaev Quantum Phase Transition in Shunted Junctions 74
3.5	Stewart–McCumber Model with Normalized Variables 76
4 4.1 4.2 4.3	Fabrication of Nanowires Using Molecular Templates79Choice of Templating Molecules86DNA Molecules as Templates86Significance of the So-Called "White Spots"88
5 5.1 5.2	Experimental Methods 91 Sample Installation 91 Electronic Transport Measurements 95
6 6.1 6.2 6.3 6.4 6.5	Resistance of Nanowires Made of Superconducting Materials101Basic Properties101Little's Phase Slips105Little's Fit108LAMH Model of Phase Slippage at Low Bias Currents115Comparing LAMH and Little's Fit122
7	Golubev and Zaikin Theory of Thermally Activated Phase Slips 125
8 8.1 8.2 8.3 8.4 8.5 8.6 8.7 8.8 8.9	Stochastic Premature Switching and Kurkijärvi Theory131Stochastic Switching Revealed by V–I Characteristics131"Geiger Counter" for Little's Phase Slips135Measuring Switching Current Distributions139Kurkijärvi–Fulton–Dunkleberger (KFD) Transformation143Examples of Applying KFD Transformations148Inverse KFD Transformation152Universal 3/2 Power Law for Phase Slip Barrier153Rate of Thermally Activated Phase Slips at High Currents157Kurkijärvi Dispersion Power Laws of 2/3 and 1/3160
 9.1 9.2 9.3 9.4 9.5 9.6 9.7 	 Macroscopic Quantum Tunneling in Thin Wires 163 Giordano Model of Quantum Phase Slips (QPS) in Thin Wires 165 Experimental Tests of the Giordano Model 175 Golubev and Zaikin QPS Theory 183 Khlebnikov Theory 185 Spheres of Influence of QPS and TAPS Regimes 187 Kurkijärvi–Garg Model 189 Theorem: Inverse Relationship between Dispersion and the Slope of the Switching Rate Curve 195
10 10.1	Superconductor–Insulator Transition (SIT) in Thin and Short Wires197Simple Model of SIT in Thin Wires207

Bardeen Formula for the Temperature Dependence of the Critical Current 213

Appendix A Superconductivity in MoGe Alloys 215

Appendix B Variance and the Variance Estimator 217

Appendix C Problems and Solutions 223

References 241

Index 247