

Preface

The Josephson effect was theoretically predicted by Brian Josephson in 1962. Experimental observation of the stationary Josephson effect was firstly realized by Anderson and Rowell, and the nonstationary Josephson effect was realized by Yanson et al. Up to now, there is a growing interest in the fundamental physics and applications of Josephson effect. The developments in Josephson junction (JJ) fabrication technology have made it possible to implement a variety of devices for detecting ultralow magnetic and electromagnetic fields. In addition, discovery of Josephson effect has also enabled the fabrication, testing, and application of ultra high frequency Rapid Single Flux Quantum (RSFQ) based logic circuits for signal processing and general purpose computing.

The Josephson effect still remains one of the most noble manifestations of quantum effects in all of experimental science. In principle, the Josephson effect is nothing more than the electronic analogue of interference phenomena in optical physics. Physical phenomena and electronics applications which are based on Josephson junction still remain challenging at the heart of physics research.

The Josephson effect may be observed in a various structures. The realization of such structures may be achieved in two ways: i) by just fabricating a “weak” inclusion that interrupts the Josephson current flow in a superconductor ii) suppressing the ability of a superconductor to carry a current using different methods such as by deposition of a normal metal on its top, by implantation of impurities within a restricted volume, or by changing the geometry of a sample.

Chapter 1 is devoted to description of theoretical foundation of Josephson dynamics. The emphasis of this chapter is on the general nature of the Josephson effect and on fundamental physical mechanisms that control the current-phase relation (CPR). At the same time, some details are provided regarding types of Josephson junctions (JJs) and their fabrication. We present briefly derivation of Josephson relation using tunnel Hamiltonian method, Ginzburg–Landau (GL) equations and Bogoliubov-de Gennes equations. Second section contains results of investigations the influence of anisotropy and multiband effects of superconducting state on the physical properties of JJ. In this chapter, we also provide a modern aspects for the dependence of the supercurrent I_S on the phase difference ϕ and to discuss the forms

this dependence takes in JJ of different types: superconductor-normal-superconductor (SNS), superconductor-insulator-superconductor (SIS), double barrier (SINIS), superconductor-ferromagnet-superconductor (SFS), and superconductor two-dimensional electron gas superconductor (S-2DEG-S) junctions, and superconductor-constriction-superconductor (ScS) point contacts. Unconventional symmetry in the order parameter of a high- T_c superconductor, as manifested in the CPR, will also be discussed. Dynamical properties of JJ and the influence of anharmonic effects of CPR on Josephson dynamics are considered in Chap. 1. Finally, macroscopic quantum dynamics of JJ (escape rate in JJ at low temperatures, influence of multigap and d-wave symmetry of order parameter and effects of Coulomb blockade in nano-size JJ) included in this chapter.

Chapter 2 contains results of recent achievement of analog superconductivity electronics. First, we present results of experimental and theoretical study of superconducting edge bolometers. Second section includes description dynamics, time resolution and sensitivity of Josephson single junction and balanced comparators. Furthermore, we discuss single junction and double junction interferometers and superconducting quantum interference devices (SQUIDs) on these bases. Influence of the d-wave order parameter symmetry on the flux quantization in a superconducting ring is discussed. Ultimate characteristics of alternating current (AC) and direct current (DC) SQUIDs are presented. Next section in this chapter deals with superconducting microwave devices and metrological applications. At the end of the Chap. 2, a short description of the multi-terminal devices is included.

Chapter 3 contains results of recent achievement of digital superconductivity electronics. Energy efficiency is one of the most important parameters in electronic systems, where the efficiency and performance of computer systems depends on the consumption of time and usage of resources compared to accomplished useful work. As the necessity of high performance computers, especially for research and development in various fields, continuously increases; the last two decades have shown us that straightforward use of conventional complementary metal oxide semiconductor (CMOS) logic circuits are encountering a fundamental obstacle in terms of power consumption. For the future high performance computer systems, power consumption is the main barrier in CMOS technology. At the same time, resistive single flux quantum (RSFQ) based circuits are recognized as the next generation very-large-scale integration technology by providing low energy barrier between states, which implies high operating speed with low power consumption. The main goal of the introduction part of this chapter is the description of foundations of digital superconducting electronics. Second section devoted to latching Josephson logic. Given basic gates of this logic and described main parameters. Third section deals with description of RSFQ logic circuits. RSFQ electronics is a digital logic family based on the transfer and storage of single flux quantum (SFQ). JJs act as current-controlled gates and allow the implementation of any logic function for deterministic data processing. Final section of this chapter includes recent development of RSFQ logic in past few years.

In Chap. 4, we have summarized the possible applications of JJ and interferometers in the field of quantum computation. The quantum processor then performs a quantum mechanical operation on this input state in order to derive an output which is also a quantum coherent superposition. The basic element of a quantum computer is known as a qubit, which is a linear superposition of the two quantum basis states $|0\rangle$ and $|1\rangle$. For the realization of qubit operations based on JJ and their application requires the mK temperature regions. Energy spectrum of phase and charge qubits on a JJ and superconducting single junction interferometer is analyzed using Hamilton formalism. As followed from presented discussion, anharmonic character of CPR becomes important at temperatures mK and as a result anharmonicity must be taken into account in consideration of JJ qubits. Silent qubit using anharmonic character of CPR has also been discussed. At the end of this chapter, attention is paid to the three JJ qubit systems. Last sections of this chapter describe adiabatic measurements and Rabi oscillations in qubit systems.

The last chapter of the book, Chap. 5, is devoted to chaotic phenomena in JJ systems. JJ devices could be useful for ultrahigh-speed chaotic generators for applications of code generation in spread-spectrum communications and true random number generation in secure communication and encryption. From this point, the dynamics of JJs is of great importance in contemporary superconducting electronics. The ordinary chaotic systems have one positive Lyapunov exponent and this exponent helps to mask the message. In this chapter, first we discuss physical foundation and characteristics of chaotic dynamics of single JJ with generalized CPR, including anharmonic effects. Influence of control parameters on the dynamics of fractal JJ are discussed in second section. In the next section of this chapter, chaotic dynamics of resistively coupled two JJ systems is presented. We further explore the system parameters and focus on the regions where a higher complexity is encountered. In Sect. 4 it will be shown that a simpler DC-driven JJ device can generate a wide region of hyperchaos without using an AC source compared to other studies existing in the literature. Last section related to discussion of synchronization of chaos in system of JJ with resistive coupling.

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