Preface

Single-electron devices provide a means to control electronic charge at the level of one electron, by means of the single-electron charging or 'Coulomb blockade' effect. These devices operate by controlling the transfer of charge across tunnel barriers onto nanometre-scale conducting regions or 'islands'. In such a process, the energy needed to charge an island with even one electron can be large enough to influence the tunnelling process. This energy, the 'single-electron charging energy', must be overcome to allow current to flow across the island, preventing current flow at low applied voltage and temperature.

The possibility that the single-electron charging energy of a nanostructure could influence the tunnelling of even one electron onto the nanostructure was identified as early as the 1950s. In 1951, C.J. Gorter proposed that the observed increase in resistance in thin, granular metal films at low electric fields and temperatures was associated with the need to overcome the single-electron charging energy of the nanometre-scale grains in the film. In the mid-1980s, K.K. Likharev and co-workers predicted, in great detail, effects relating to single-electron charging in nanometre-scale tunnel junctions. By this stage, advances in nanofabrication techniques had led to the ability to fabricate well-defined, nanometre-scale, islands and tunnel junctions. In 1987, this led to the first demonstration, at low temperature, of a *designed* single-electron device, the single-electron transistor (SET) of Fulton and Dolan.

Over the following two decades, a wide variety of single-electron devices, in many material systems, were demonstrated. These included numerous different types of SETs, single-electron memory devices, single-electron logic circuits, and devices for the controlled transfer of charge packets formed by single or small numbers of electrons. Furthermore, there were many demonstrations of the room-temperature operation of single-electron devices, particularly in silicon semiconductor material.

The great interest in single-electron devices has been driven in part by the potential of these devices for applications in large-scale integrated (LSI) circuits. In comparison with conventional semiconductor devices, devices such as the SET and the single-electron memory cell are inherently nanometre-scale, and tend to improve in performance when scaled down in size. Furthermore, these devices possess the advantages of very low power consumption, associated with the small amounts of charge they use, and control over any statistical fluctuations in this charge.

This book discusses the design, fabrication and electrical characterization of single-electron devices and circuits in silicon. We concentrate on single-electron devices in silicon, as these are of particular interest for LSI circuit applications. Single-electron devices in metals, and in other semiconductor systems such as GaAs/AlGaAs heterostructures, are discussed only when necessary to understand the operation of particular device types, or when device implementations in silicon are limited. This book considers the physics of single-electron charging effects. This is followed by a review of the fabrication and operation of SETs in crystalline and nanocrystalline silicon materials. Single-electron memory devices are then discussed, where the stored 'bits' are defined by single, or at most a few, electrons. We then consider few-electron charge transfer devices, such as single-electron pumps and turnstiles, where small numbers of electrons can be transferred through the device using radio frequency signals. Finally, we discuss single-electron logic circuits. Throughout this book, we follow an approach where the various types of single-electron devices are reviewed first, and then explained in more detail using examples from the author's research.

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