Extended Abstracts of the 1996 International Conference on Solid State Devices and Materials, Yokohama, 1996, p. 739 **AB-1-1**

Invited

Quantumphenomena in Nanoelectronics

Klaus von KLITZING

Max-Planck-Institut für Festkörperforschung, Heisenbergstr. 1, D-70569 Stuttgart, Germany

The transition from microelectronics to nanoelectronics is not just a question of scaling but leads to qualitatively new optical and electrical properties. In the extreme limit, the de Broglie wave length of electrons becomes comparable with the size of the active device and quantum phenomena dominate the electronic behaviour. The physics of such low-dimensional electronic systems will be discussed with the focus on transport measurements.

1. INTRODUCTION

Semiconductor heterostructures form the basis for a new class of devices with important consequences for applications. The quantum well laser or the HEMT device are already established and produced in large quantities but other structures like the quantum cascade laser, resonant tunnel diode, SEED device, single electron transistors, quantum wire or quantum dot laser or IR photodetectors based on quantum size levels absorption are still under development. Very fundamental physical phenomena form the basis for all these devices and some of the most fascinating properties of low dimensional electronic systems, starting with the two-dimensional electron gas and finishing with a quantum dot with one electron, will be summarized.

2. TWO-DIMENSIONAL ELECTRON GAS

The HEMT-device (normally GaAs-AlGaAs heterostructure) is the starting material for most of the research on two-, one- and zero-dimensional systems. In a certain way, the quantum Hall effect is „the crown of all quantum well studies“[1], since this phenomenon combines two-dimensional, one-dimensional (edge channels) and zero-dimensional (Wigner crystal, localized states) properties and shows results which are independent of material parameter. The physics of a two-dimensional system in strong magnetic fields can be used to discuss the properties of one-dimensional channels, the connection between superconductivity and fractional quantum Hall effect, the interpretation of the fractional quantum Hall effect as an integer quantum Hall effect of composite fermions or the properties of a spin ferromagnet if all spins of the two-dimensional electron gas are aligned. A summary of the latest developments in quantum Hall effect will be published elsewhere[2]. More connected to practical application seem to be the properties of quantum dots – first measurements on quantum dot lasers were successful and the single electron device seems to be the smallest electronic device useful for switching and for applications as an electrometer and in metrology as discussed by Martinis at this conference. Some of the interesting physical phenomena related to single electron transport are summarized in Section 3.

3. SINGLE ELECTRON TRANSISTORS

The electronic transport through quantum dots (lateral and vertical structures) were used to study quantum phenomena in small systems[3]. Single electron devices based on structures used for resonant tunneling diodes allow an analysis of the few electron system (artificial atom) and under special conditions a quantum dot can be used as an spectrometer to study the density of state of a highly doped semiconductor. Coupled quantum dots (or more accurately disks), realized for both vertical and planar arrangements of the disks, show new phenomena due to Coulomb interaction and tunneling phenomena.

The self-organized growth of quantum dots is at present an active research field, especially in connection with the realization of quantum dot laser. Relatively few attempts were made to grow directly single electron devices. However, it can be demonstrated that the overgrowth of a doped quantum well on patterned substrate leads to different growth rates for different facets which may be used to a simultaneous growth of a source, drain and gate contact (doped quantum well), two tunneling barriers (thin quantum wells on (311) surfaces) and a quantum dot (enhanced growth on a (100) plateau). Measurements of the spatially resolved luminescence confirm these properties. Such a directly grown quantum dot shows the characteristics of a single electron transistor.

References

1) Review article by Zh.I. Alferov: „The History and Future of the Semiconductor Heterostructures“, to be published in Physica B.
2) K. v. Klitzing, Proceedings of the ICPS 96, to be published by World Scientific.
3) For a summary see: R. Haug, K. v. Klitzing, FED Journal 6(2) (1995) 4.