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MOSFET Device Physics and Operation

1.1 INTRODUCTION

A field effect transistor (FET) operates as a conducting semiconductor channel with two ohmic contacts – the *source* and the *drain* – where the number of charge carriers in the channel is controlled by a third contact – the *gate*. In the vertical direction, the gate-channel-substrate structure (gate junction) can be regarded as an orthogonal two-terminal device, which is either a MOS structure or a reverse-biased rectifying device that controls the mobile charge in the channel by capacitive coupling (field effect). Examples of FETs based on these principles are metal-oxide-semiconductor FET (MOSFET), junction FET (JFET), metal-semiconductor FET (MESFET), and heterostructure FET (HFETs). In all cases, the stationary gate-channel impedance is very large at normal operating conditions. The basic FET structure is shown schematically in Figure 1.1.

The most important FET is the MOSFET. In a silicon MOSFET, the gate contact is separated from the channel by an insulating silicon dioxide (SiO_2) layer. The charge carriers of the conducting channel constitute an inversion charge, that is, electrons in the case of a *p*-type substrate (*n*-channel device) or holes in the case of an *n*-type substrate (*p*-channel device), induced in the semiconductor at the silicon-insulator interface by the voltage applied to the gate electrode. The electrons enter and exit the channel at n^+ source and drain contacts in the case of an *n*-channel MOSFET, and at p^+ contacts in the case of a *p*-channel MOSFET.

MOSFETs are used both as discrete devices and as active elements in digital and analog monolithic integrated circuits (ICs). In recent years, the device feature size of such circuits has been scaled down into the deep submicrometer range. Presently, the 0.13-μm technology node for complementary MOSFET (CMOS) is used for very large scale ICs (VLSIs) and, within a few years, sub-0.1-μm technology will be available, with a commensurate increase in speed and in integration scale. Hundreds of millions of transistors on a single chip are used in microprocessors and in memory ICs today.