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17. Hot Electrons in Semiconductor Devices

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17.1 What is a hot electron device ?

Hot-electron phenomena have become important for the understanding of all modern semiconductor devices. In many cases these phenomena are a nuisance that must be somehow cauterized, like for example is the hot carrier injection into the gate dielectric in silicon field-effect transistors. This unwelcome phenomenon gives rise to a degradation of transistor characteristics and may lead to circuit failure. Another well-known hot-electron effect in devices (with more benign consequences) is the saturation of drift velocity in high electric fields. Velocity saturation is ubiquitous in modern semiconductor devices and is sometimes of central importance for their operation. Thus, it is essential for the operation of all transit-time diode oscillators (Sze, 1990).

Commercial utilization of hot-electron phenomena began with the Gunn effect (Gunn, 1963; Kroemer, 1964), based on the intervalley transfer mechanism for a negative differential resistance, proposed by Ridley and Watkins (1961) and Hilsum (1962). The Gunn diode is undoubtedly the best-known hot-electron device, for which a mature technology has developed, see, e.g., Bosch and Engelmann (1975) and Shur (1987, 1990). Another successful application of a hot-carrier effect has been made in nonvolatile memory devices. The floating-gate avalanche injection memory device FAMOS invented by Frohman-Bentchkowsky (1971) bears conceptual similarity to some of the real-space-transfer devices discussed below. The FAMOS represents a p-channel MOSFET structure with a floating gate electrode. In the process of ‘‘writing’’ the memory, carriers, heated by the drain field, avalanche near the drain junction with hot electrons from the avalanche plasma injected into the floating gate. As the gate is

charged, its potential is lowered and the p-channel conductance increases. Pioneering papers in the development of FAMOS technology have been collected by Hu (1991).

This chapter is concerned with a special narrow class of semiconductor devices whose very principle is based on hot-electron effects. We shall not attempt to review the important mature hot-electron technologies mentioned above. Instead, we shall discuss rather exotic devices none of which have been used in practical electronic applications. Most of the recent research in this area has concentrated on demonstrating the existence of an effect in question, proposals of new structures and effects, and studies of their potential physical limitations. It should be remembered, of course, that the main purpose of this type of work is to come up with a device, which will find a practical application. Our review will comment on the viability of these ideas, their promise and shortcomings, as well as attempt to identify the key hurdles to their practical implementation.