HOT-ELECTRON SPECTROSCOPY AND TRANSISTOR DESIGN

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ABSTRACT

The generation of hot electrons and their relaxation over short distances has been investigated in multilayer semiconductor structures. Scattering due to electron-electron interactions has been identified as the principal reason why hot-electron transistors have so far failed to give adequate current gain. Novel structures have been designed to circumvent this interaction in different ways, leading to the observation of ballistic transport and viable hot-electron transistors.

INTRODUCTION

The quest for a hot-electron transistor is twenty-five years old. The generic structure is of three low resistance regions, emitter, base, and collector separated by two barriers, the emitter-base barrier taking the signal and the base-collector barrier the load (see Figure 1). If one imagines the signal driving a current of which a fraction of the electrons cross the base and are collected by the barrier, the current gain of this device is . If electrons were to cross ballistically then would become very large. Furthermore, if the base is very thin, the transit time ~0.1 psec for 100 nm thickness is short and a high speed device is also promised. (In fact it is now appreciated that the charging time of the emitter-base barrier is a major limitation on speed). Until recently only ~0.3 was achieved, and it is the progress
over the last two years on hot-electron spectroscopy, made possible with specially designed structures, that is giving the hot-electron transistor a new lease of life. With a careful understanding of why previous generations of hot-electron transistor failed, it has been possible to achieve $\approx 0.9$ in new test structures grown by molecular beam epitaxy or metal-organic chemical vapour deposition. For the first time, a viable hot-electron transistor looks possible.

The recent spectroscopy work has been carried out in four laboratories, at AT&T Bell\textsuperscript{2,3}, IBM\textsuperscript{4,5}, Fujitsu\textsuperscript{6,7} and GEC\textsuperscript{8,9}. In figure 1 we show the types of structure being considered. With the one exception described below in section 3, the base is a thin, n-doped layer ($< 100$ nm, 10$^{18}$ cm$^{-3}$) of GaAs. The barriers are of two forms - either compositional with Al$_x$Ga$_{1-x}$As, or doping, with the planar doped barrier (a thin p-doped region, surrounded by undoped GaAs, the former being depleted). The compositional barriers can be used either as graded layers as launching pads (at GEC), or as tunnelling injectors (at IBM and Fujitsu, the latter using resonant tunnelling). The AT&T work has concentrated on the planar-doped barrier (also part of the GEC spectrometer), which has the advantage of greater flexibility in designing the I-V characteristics: the height of the barrier comes from the total p-doping, and the lever arm from the position of the doping layer with respect to the base and collector. It is less capable of injecting or analysing a very narrow energy spread of carriers, because of the local potential fluctuations on the 10 nm scale that characterises the typical doping level. Indeed these fluctuations result, not in a knife edge discrimination of electron energies either in injection or in analysis but rather in a serated edge. Similarly the tunnelling injector admits a distribution equal in width to

Fig. 1 The hot electron transistor (left) and conduction band profiles (right) of various hot-electron spectrometer structures, with the full (dashed) lines indicating composition (space charge) barriers.