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HIGH ELECTRON VELOCITY FOR HIGH FREQUENCY TRANSISTORS

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With substantially increased electron velocity and reduced dimensions, compound semiconductor transistors will be able to reach below 1 psec. transit time and f_T above 150 GHz. The electron velocity obtainable is nearly the ballistic limit, where the electron kinetic energy equals the potential drop. The maximum electron group velocity in the [100] crystal direction in GaAs and related materials is about 1×10^8cm/s. If the electrons are gradually accelerated throughout their transit, the time average electron velocity would not exceed $4.5\text{-}5.0 \times 10^7$ cm/s. Experimental values up to 4.4×10^7cm/s for .22 μm drift length, and 4.0×10^7cm/s for .36 μm drift length have been obtained in lightly doped GaAs. If the electrons are quickly accelerated to the group velocity limit, by using .2-.30 eV potential drop over a 100-500 Å distance, then the electrons will travel a few thousand Å distance in lightly doped material before the momentum is substantially reduced. Average electron transit velocity values above 8×10^7cm/s are expected in such devices. The presence of a large number of impurity ions and free carriers can cause plasmon and ion scattering as well as phonon scattering, making it necessary to reduce the high velocity drift length.

A set of fourteen ballistic electron transistor projects are underway in our laboratory. First, the gradual acceleration cases will be reviewed. Selectively doped heterojunction transistors using both GaAs and $In_{.53}Ga_{.47}As$ as active layers are being pursued. With longer gate length (over 1 μm) average electron velocity at 77°K of 2.4×10^7cm/s and 3.0×10^7cm/s, respectively, are obtainable in these devices. When the effective electrical length, over which high electric fields are present, are reduced below .6 μm and .75 μm, respectively, the ballistic average electron velocity at 77°K of over 4×10^7cm/s is expected. Ordinary MESFETs of GaAs and Heterojunction MESFETs of $In_{.53}Ga_{.47}As$ are both being studied at room temperature with the usual doped channel. When the effective electrical lengths are below .40 μm and .50 μm, respectively, the ballistic average electron velocity at room temperature of over 4×10^7cm/s is obtainable. Vertical periodic MESFETs with gates deposited in etched grooves, have yielded 3×10^7cm/s at room temperature with active layers less than .5 μm, and can be expected to reach over 4×10^7cm/s for effective electrical lengths below .4 μm.

Next, the impulse acceleration cases of ballistic electron acceleration will

be reviewed. Four unipolar devices with triangular potential barriers between emitter and base, and between base and collector are under study. Both planar doped barriers and heterojunction potential steps are useful for launching and collecting ballistic electrons in these devices. Both GaAs and $In_{.53}Ga_{.47}As$ are being studied for these devices. The initial electron energy at launch is below the upper valley energy of the conduction band, with values of .31 and .55 eV, respectively. In early GaAs experiments, .45 fraction of the initial electron momentum existed after 2000 Å drift distance, with 1200 Å of this drift distance doped at $7 \times 10^7/cm^3$. The second barrier should hold off the thermionic emission of base carriers, but 77^oK operation is helpful for this purpose. Two heterojunction ballistic bipolar transistors are under study, one has Al,GaAs/GaAs emitter-base junction, and the other has Al,InAs/Ga,InAs emitter base junction. In these devices, high current gain and ballistic electron transport across the base can be traded-off for optimized design. Current gains above 100 and values of f_T beyond 100 GHz will be possible. No conduction band barrier is required at the collector in this device, so its momentum can be greatly reduced before the electron is reaccelerated at the collector-base junction. Finally, a set of three GaAs ballistic electron Schottky-gated transistors with impulse acceleration during electron injection are being studied. These are vertical devices with metal gates in submicron etched grooves. The impulse acceleration at the negative electrode is caused either by planar doped barrier, heterojunction step, or a thin, undoped region followed by a doped drift region. In all of these ballistic injection devices, there is enough doping in the drift region for space charge neutrality at the desired current density.

In conclusion, several structures for obtaining average electron velocity near the ballistic limit are being pursued for EHF and high speed logic applications, and 1 psec or less transit time will be possible in the next few years.

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