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A4-3 Control of Two-Dimensional High Field Domain in Gunn Effect Functional Devices

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Introduction It has been considered that a transverse extension velocity of a high field domain is much higher than a domain propagation velocity, and a high speed carry generator utilizing the transverse extension has been proposed. It has been demonstrated with the aid of a computer simulation that a comb-shaped Gunn effect device is promising as a carry generator to be operated in a full adder or subtracter circuit. It is a purpose of this paper to confirm a possibility to control the two-dimensional extension of a high field domain and to approach device applications.

Comb-shaped carry generator Figure 1 shows an N-bit full adder circuit composed of exclusive-OR gates and a comb-shaped carry generator utilizing a transverse extension of a high field domain. This carry generator consists of N-bits of tooth-like Gunn devices bridged at their cathodes. Each stage of the comb-shaped device is provided with a Schottky gate to control a high field domain and ohmic gate electrodes are set opposite to the common cathode in each bridge section. It is the most important feature for this carry generator to control the two-dimensional extension of the high field domain with the ohmic gates.

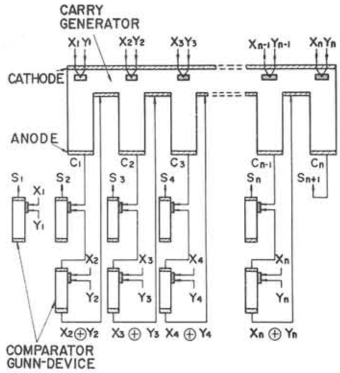


Fig.1 An N-bit full adder composed of a comb-shaped carry generator and exclusive-OR (comparator) using Gunn effect

Design of optimum gate size In order to decide the width of the bridge section between two bits and to decide the length from cathode to ohmic gate, we should estimate a transverse extension velocity of an immature domain. The transverse extension of a mature high field domain has been discussed by Shoji, and the extension velocity has been estimated to be in order of 10^8 cm/sec. However, it is not obvious that the extension velocity of an immature domain in a stage of a nucleation is so fast as that of a mature high field domain, so that it is necessary to discuss a two-dimensional domain intiation and to introduce the transverse extension velocity of the immature domain. We estimated them in a small signal approximation and got results that the transverse extension velocity is 1.3×10^8 cm/sec for the doping density $n_0=10^{16}cm^{-3}$, and that is 4.2×10^7 cm/sec for $n_0=10^{15}cm^{-3}$. On the other hand, since the field dependence of the diffusion coefficient of electrons is negative in the field region above the threshold of the negative differential mobility, the drift velocity of the immature domain toward the bias field is 1.7×10^8 cm/sec for $n_0=10^{16}cm^{-3}$, and that is 3.5×10^7 cm/sec for $n_0=10^{15}cm^{-3}$. Therefore, the length of the bridge section should be larger than a marginal distance for the immature domain to travel in a domain formation time. We estimate this marginal distance to be 3 μm for $n_0=10^{16}cm^{-3}$, and 10 μm for $n_0=10^{15}cm^{-3}$. The width of the bridge section should be comparable with or less than the bridge length because of the fact that the transverse extension velocity is not so fast compared with the longitudinal propagation velocity in the stage of the domain formation.

Computer simulations We have simulated a 2-bit comb-shaped carry generator to confirm its logical operation and the two-dimensional domain controllability.

Figure 2 shows time variations of field distributions in the device. The width and the length of the bridge section are set equal to 10 μm and 8 μm respectively, the length from cathode to anode is 24 μm, and the doping density in the active region is $10^{15} cm^{-3}$. When the applied voltage for the bridge section is 3.0 volts, the electric field is high enough to sustain the transverse extension of the domain nucleated in the first stage and a new domain is formed in the second stage. On the other hand, when that is 2.5 volts, the domain does not extend toward the bridge section. It is confirmed in these simulations that the domain can be controlled to extend by changing the electric field in the bridge section. When the device size is decreased into a half dimensions, however, the domain could not be controlled to extend toward the higher stage. This is an expected result from the small signal calculations.

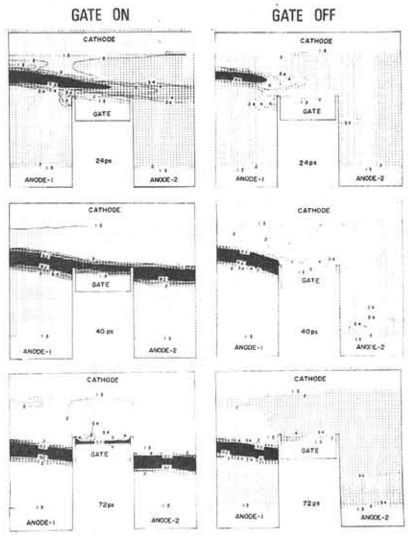
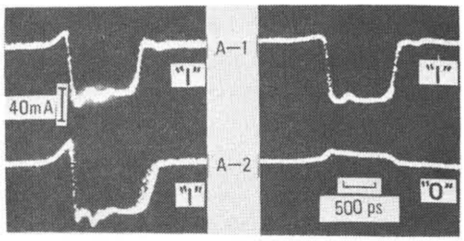


Fig.2 Computer simulated electric field distributions in 2-bit carry generator. Left three figures are for gate 'ON', and right three are for gate 'OFF'.

<u>Experiments</u> We fabricated 2-bit comb-shaped planar Gunn devices and confirmed the logical operation as a carry generator. Typical dimensions of the device are as follows; the length from cathode to anode is 100 μm, the width and the length of the bridge section are 50 μm and 25 μm respectively. The doping density of the active region is $7\times10^{15} cm^{-3}$. The first stage is provided with a Schottky gate to nucleate a domain.



GATE — ON GATE — OFF

Fig.3 Current waveforms for each stage in 2-bit carry generator. Upper two traces are those for the first stage when the ohmic gate is 'ON' and 'OFF'. Lower two traces are for the second one.

The current waveforms for each stage are shown in Fig.3. When the gate voltage was about 9 volts against the cathode, the domain nucleated in the first stage did not extend toward the second stage as shown in right two traces in Fig.3. On the other hand, when that was increased by 0.5 volts, the domain extended toward the second stage and a new domain was formed. The delay time of the domain formation between two stages was less than 50 psec. We confirmed the logical operation in the device stated above, but in a device with other gate size much different from the above dimensions, the domain could not be controlled. The domain could not be suppressed to extend in a device with a longer gate length than 50 μm, and it could not be extended in a device with a shorter gate length than 10 μm.

We also fabricated a 4-bit comb-shaped carry generator and confirmed the logical operation. The delay time of the domain formation between the first stage and the fourth stage was about 100 psec.

<u>Conclusion</u> Two-dimensional domain extension can be controlled by changing the electric field at the position where the domain is to extend. These controllabilities are confirmed both with computer simulations and experiments. But it must be noted that the design of the bridge section of the carry generator is the most important factor to control the domain extension.