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THE GUNN EFFECT

J. B. Gunn, "Microwave Oscillation of Current in III-V Semiconductors",

Solid State Commun., 1 88 (1963)

The Gunn Effect

In some materials (III-V compounds such as GaAs and InP), after an electric field in the material reaches a threshold level, the mobility of electrons decrease as the electric field is increased, thereby producing negative resistance. A two-terminal device made from such a material can produce microwave oscillations, the frequency of which is primarily determined by the characteristics of the specimen of the material and not by any external circuit. The Gunn Effect was discovered by J. B. Gunn of IBM in 1963.

The Gunn Diode

In certain semiconductors, notably GaAs, electrons can exist in a high-mass low velocity state as well as their normal low-mass high-velocity state and they can be forced into the high-mass state by a steady electric field of sufficient strength. In this state they form clusters or domains which cross the field at a constant rate causing current to flow as a series of pulses. This is the Gunn effect and one form of diode which makes use of it consists of an epitaxial layer of n-type GaAs grown on a GaAs substrate. A potential of a few volts applied between ohmic contacts to the n-layer and substrate produces the electric field which causes clusters. The frequency of the current pulses so generated depends on the transit time through the n-layer and hence on its thickness. If the diode is mounted in a suitably tuned cavity resonator, the current pulses cause oscillation by shock excitation and r.f. power up to 1 W at frequencies between 10 and 30 GHz is obtainable.



-0.10	-5.0	200	41.5
-0.10	-5	270	45.2
-0.10	-6	742	46.1
-0.10	0	514	45.0
-0.10	-1.5	704	44.6

Figure 1 JB Gunn's lab notebook with the entry „noisy" on the line for 704 V

Web Resources:

<http://www.marconitech.com/microwave/data/anngunn.pdf>

<http://www.ee.sun.ac.za/elec/wjperold/Research/Semiconductors/MC%20PDF/mtt98.PDF>

http://www.st-and.ac.uk/~www_pa/Scots_Guide/RadCom/part5/page1.html

The following is a summary of the above mentioned documents.

Gunn Diode Theory

The Gunn diode is a so-called transferred electron device. Electrons are transferred from one valley in the conduction band to another valley.

In order to understand the nature of the transferred electron effect exhibited by Gunn diodes, it is necessary to consider the electron drift velocity versus electric field (or current versus voltage) relationship for GaAs (see Figure 2). Below the threshold field, E_{th} , of approximately 0.32 V/mm, the device acts as a passive resistance. However, above E_{th} the electron velocity (current) decreases as the field (voltage) increases producing a region of negative differential mobility, NDM (resistance, NDR). This is the essential feature that leads to current instabilities and Gunn oscillations in an active device and is due to the special conductance band structure of direct band gap semiconductors such as GaAs (see Figure 3).

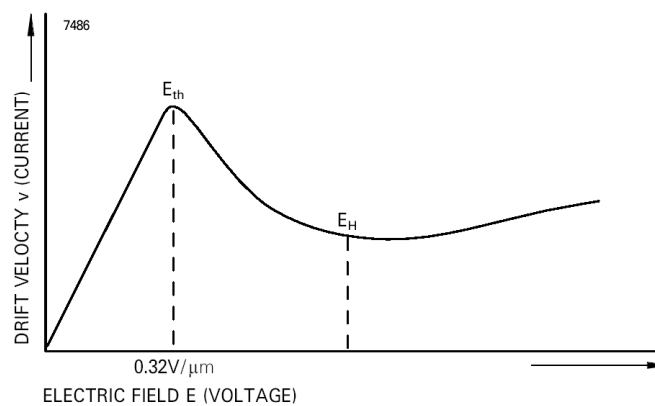


Figure 2

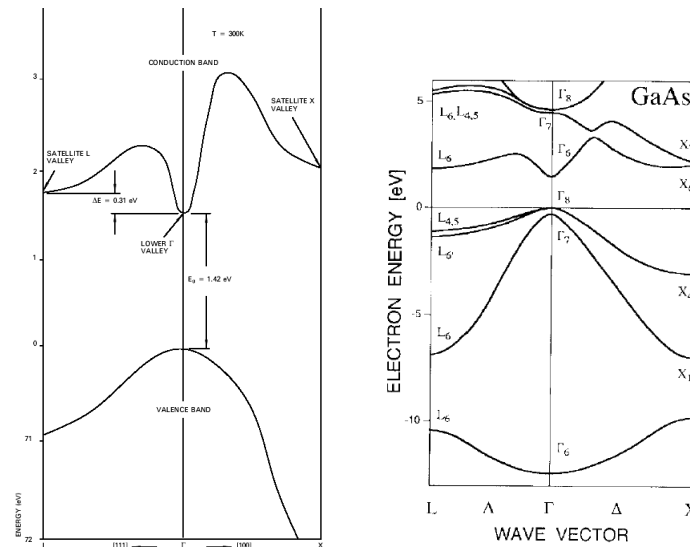


Figure 3

The energy-momentum relationship contains two conduction band energy levels, Γ and L (also known as valleys) with the following properties:

- In the lower Γ valley, electrons exhibit a small effective mass and very high mobility, μ_1 .
- In the satellite L valley, electrons exhibit a large effective mass and very low mobility, μ_2 .
- The two valleys are separated by a small energy gap, ΔE , of approximately 0.31 eV.

In equilibrium at room temperature most electrons reside near the bottom of the lower Γ valley.

Because of their high mobility ($\sim 8000 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$), they can readily be accelerated in a strong electric field to energies in the order of the Γ -L intervalley separation, ΔE . Electrons are then able to scatter into the satellite L valley, resulting in a decrease in the average electron mobility, μ , as given below:

$$\mu = (n_1\mu_1 + n_2\mu_2) / (n_1 + n_2)$$

where n_1 = electron density in Γ valley, n_2 = electron density in L valley

Above the high field, E_H , most electrons reside in the L valley and the device behaves as a passive resistance (of greater magnitude) once again.

In a practical Gunn diode, electrons are accelerated from the cathode by the prevailing electric field. When they have acquired sufficient energy, they begin to scatter into the low mobility satellite valley and slow down.

The question of exactly how the NDR phenomenon in GaAs results in Gunn-oscillations can now be answered with the aid of Figure 4. A sample of uniformly doped n-type GaAs of length L is biased with a constant voltage source V_0 . The electrical field is therefore constant and its magnitude given by $E_0 = V_0/L$. From the bottom graph in Figure 4 it is clear that the electrons flow from cathode to anode with

constant velocity v_3 .

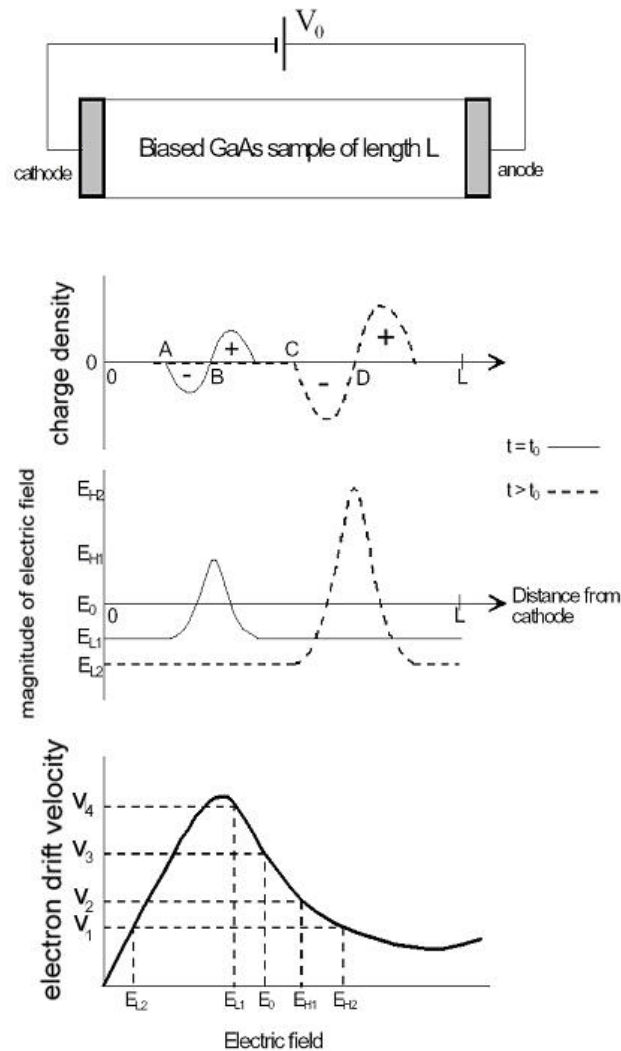


Figure 4

It is now assumed that a small local perturbation in the net charge arises at $t = t_0$, indicated by the solid curve in Figure 4. This non-uniformity can, for example, be the result of local thermal drift of electrons. The resulting electrical field distribution is also shown (solid curve). The electrons at point A, experiencing an electric field E_{L1} ,

will now travel to the anode with velocity v_4 . The electrons at point B is subjected to an electrical field E_{H1} . They will therefore drift towards the anode with velocity v_2 which is smaller than v_4 .

Consequently, a pile-up of electrons will occur between A and B, increasing the net negative charge in that region. The region immediately to the right of B will become progressively more depleted of electrons, due to their higher drift velocity towards the anode than those at B. The initial charge perturbation will therefore grow into a dipole domain, commonly known as a Gunn-domain. Gunn

domains will grow while propagating towards the anode until a stable domain has been formed. A stable Gunn-domain is shown at a time instance $t > t_0$, indicated by the dashed curve. At this point in

time, the domain has grown sufficiently to ensure that electrons at both points C and D move at the same velocity, v_1 , as is clear from the bottom graph in Figure 4. It is important to note that the sample had to be biased in the NDR region to produce a Gunn-domain. Once a domain has formed, the electric field in the rest of the sample falls below the NDR region and will therefore inhibit the formation of a second Gunn-domain. As soon as the domain is absorbed by the anode contact region, the average electric field in the sample rises and domain formation can again take place. The successive formation and drift of Gunn-domains through the sample leads to a.c. current oscillations observed at the contacts.

Applications

Gunn diodes are reliable, relatively easy to install and the lower output power levels fall well below the safety exposure limits. They are ideally suited for use in low noise sources such as local oscillators, locking oscillators, low and medium power transmitter applications and motion detection systems. Higher power varieties can be used in phase-locked oscillators or as reflection amplifiers in point-to-point communication links and telemetry systems. Microwave sources have the advantages over ultrasonic detectors of size and beamwidth, and over optical systems of working in dusty and adverse environments. The low voltage requirements of Gunn oscillators mean that battery or regulated mains supplies may be used, (battery drain can be reduced by using low current devices or by operation in a pulsed mode). However, microwaves are reflected from metal surfaces and partially reflected from many others e.g. brick, Tarmac and concrete, and they are attenuated by oxygen, water or water vapour.

The range of application of Gunn sensors for industrial and commercial use is extensive and the following is only a brief list:

Collision avoidance radar

Vehicle ABS

Traffic analyser sensors

'Blind spot' car radar

Pedestrian safety systems

Elapsed distance meters

Automatic identification

Presence/absence indicators

Movement sensors

Distance measurements

Slow-speed sensors
 Level sensors
 Traffic signal actuators
 Proximity movement detectors
 Door opening sensors
 Barrier operation
 Process control devices (object counting)
 Intruder/burglar alarms
 Perimeter protection
 Train derailment sensors
 Contactless vibration transducers
 Rotational speed tachometers
 Linear distance indicators
 Moisture content measurement

Gunn Oscillators

Usually the Gunn diode is mounted on a post structure between the waveguide walls, either $\lambda_g/2$ from an iris or $\lambda_g/2$ from a short circuit (see Figure 5). Some alteration is necessary to set the exact frequency to allow for diode and package parasitics and manufacturing tolerances. Tuning screws (either metal or dielectric) are used to modify the cavity resonant frequency. Power output variations are achieved by adjusting the coupling between diode and load using variations in post size or tuning screws.

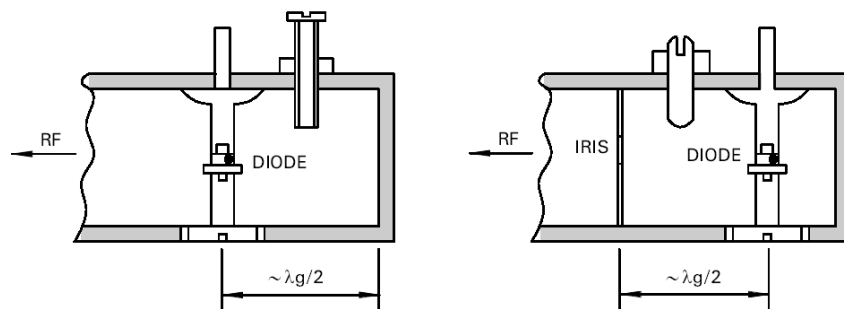


Figure 5

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