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Transient dynamic response of transferred electron microwave oscillators

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Abstract : Transient dynamic response (TDR) of the ternary alloy $Ga_{0.47}In_{0.53}As$ has been studied Transferred electron devices made of $Ga_{0.47}In_{0.53}As$ are found to be superior compared to those made of GaAs due to larger negative differential mobility (NDR) and lower threshold field of the former The velocity overshoot in the alloy occurs within 0 1–0 25 ps satisfying the criterion needed for microwave oscillation The TDR study of the author in this paper has established that larger pulse powers can be obtained in the limited space-charge accumulation (LSA) mode at microwave frequencies from integrated circuit chips made of GaInAs as compared to those made of GaAs

Keywords Transient dynamic response, negative differential mobility, limited space-charge accumulation

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1. Introduction

Transferred electron oscillators or Gunn oscillators made of semiconductor materials like GaAs, GaInAs exhibit negative differential mobility when biased above a threshold value of the electric field. Electron transport properties of $Ga_{0.47}In_{0.53}As$ are of considerable importance in view of its applications in high frequency devices. The ternary alloy shows promise for applications in optical fibre communication systems since its band gap corresponds to the minimum attenuation transmission in optical fibres at 1.6 μm wavelength. Its extremely high electron mobility offers a wide range of microwave applications [1]. Moreover the transferred electron devices made of $Ga_{0.47}In_{0.53}As$ are found to be superior compared to those made of GaAs, owing to larger negative differential mobility and lower threshold field of the former.

When excited by a high, spatially uniform electric field at the time instant $t = 0$, the electron ensemble in a semiconductor accelerates to a far from equilibrium distribution. The electron drift velocity in some cases assumes a value for above the steady state giving rise to overshoot phenomena [2]. The manner in which the ensemble evolves in time to the steady state is referred to as transient dynamic response (TDR). The details of the TDR are exceedingly important for microwave semiconductor devices and for submicron scale devices, since for these particular situations, the ensemble may never achieve the quasi-equilibrium steady state. The importance of this effect lies in the fact that in very small devices where the field is high the 'effective' drift velocity of carriers can be significantly higher than that expected from the electrical configuration in the device [3]. The key mechanism for velocity overshoot in semiconductors with satellite conduction valleys, is the transfer of electrons from the low-mass, high-mobility central valley to the high-mass, low-mobility satellite valleys.

2. Results and discussion

Experimental evidence of microwave oscillations based on transferred electron effect was first reported by Gunn [4] in 1963. The mode observed by him is called the negative differential resistance (NDR) mode, and is characterized by a dipole domain which drifts through the device at nearly saturated drift velocity. In 1966, Copeland [5] predicted and observed the existence of the limited space-charge accumulation (LSA) mode of operation. In this mode, the device voltage waveform is controlled so that formation of dipole domains is prevented. The Gunn devices are used as radar local oscillators and as transmitters in the microwave frequency range. The LSA devices are used in the microwave frequency range as beacon transponders and as moderate power-pulsed radar transmitters [6].

The author had observed hot electron velocity overshoot phenomena in the ternary alloy $Ga_{0.47}In_{0.53}As$ which is widely used in microwave oscillators due to its larger negative differential mobility and lower threshold field as compared to GaAs [7]. The overshoot occurs within 0.1–0.25 ps when most of the electrons are transferred to higher satellite valleys for negative differential mobility, which is the criterion requisite for microwave oscillation.

The TDR of hot electrons can be studied either by solving the moment equations based on a displaced Maxwellian distribution function or by using the ensemble Monte Carlo method [3]. The advantage of displaced Maxwellian approach is that it is free from statistical fluctuations and takes less computing time [7]. $Ga_{0.47}In_{0.53}As$ is a direct-gap semiconductor with Γ, L, X ordering of conduct ion-band minima. $Ga_{0.47}In_{0.53}As$ was found to yield higher peak drift velocities [7] and hence higher amplitude microwave oscillations as compared to those in GaAs. The high field domains nucleated at the cathode drift gradually during its growth till it is collected at the anode and this process repeats itself for sustained oscillation. The transit time mode transferred electron oscillator is operated in a low Q circuit at a bias voltage just above the threshold voltage. The quenched and delayed domain modes occur in a high Q resonant cavity biased in the negative mobility region.

In order to enhance the efficiency of operation of practical Gunn oscillators, the device is operated above threshold which prevent domain formation. This is done in the limited space-charge accumulation (LSA) mode. In the LSA mode, a large voltage swing is used in conjunction with a frequency whose period is short compared with dielectric growth time so that it limits the space charge growth during the NDR part of the *r-f* cycle. Since the threshold field of $Ga_{0.47}In_{0.53}As$ is lower compared to GaAs, the microwave oscillators built with GaInAs will give higher efficiency of operation as compared to GaAs when operated in the LSA mode. Moreover due to velocity overshoot, intervalley transfer time becomes very less of the order of 0.25 ps which suggests that the devices have very well promise for applications at microwave frequencies. The relaxation mode LSA microwave oscillator has its operating frequency determined by the cavity as well as the L/R time constant and is given by [6]

$$\frac{1}{f_0} = \gamma \simeq 2\pi . \sqrt{LC} + \frac{L}{R_0 M}, \tag{1}$$

where, L and C represent cavity parameters, R_0 is the diode low-field resistance. The field E is less than threshold voltage E_T and $M = E_B/E_T$ is the bias to threshold multiple. The TDR study of the author reveals that larger pulse powers can be obtained in the LSA mode at microwave frequencies from chips made of GaInAs as compared to those made of GaAs due to larger negative differential mobility of the former.

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