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The Influence of Charge Traps Parameters on Bifurcation Scenario of Nonlinear Semiconductor Oscillator

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Abstract– In this work the some results of numerical simulations of a traps parameters influence on complex oscillations in nonlinear semiconductor oscillator are presented. The semiconductor structure that used in nonlinear semiconductor oscillator was Metal-Insulator-Semiconductor structure (MIS-structure). As it were shown the parameters of charge storage traps make essential influence to period-doubling and chaotic oscillation onset.

1. Introduction

Electrical active defects – so-called traps and states - play an important role in processes of thermodynamic non-equilibrium charge transition in semiconductor structures. Such defects can define dynamic characteristics and fast recovery of Schottky Diodes, MIS-structures and Field-Effect Transistors [1]. Particularly, the processes of generation, accumulation, recombination of charge carriers with participation of interface trapping being the reason for occurrence of dynamic behavior in systems with MIS-structure that is known [2,3,4]. The important condition of occurrence of oscillations in a circuit with semiconductor sample is certain ratio between relaxation time of current in an external circuit and relaxation time of charge in a semiconductor sample; first one, as a rule, should be more than second one [5]. In researched structures the effective life time is 10^{-5} – 10^{-6} s and it is determined by accumulation dissipation charge carrier processes. This time is limited by essential influence interface trapping. We specialize to the case of standard interface with thin interfacial oxide layer [6] and surface states densities N_{SS} are about 10^{10} – 10^{11} cm^{-2} eV^{-1}. Limited volume of information on research of influence of parameters of oxide-semiconductor interface and features, connected to it on occurrence of nonlinear oscillations of a current in an RL external non-autonomous circuit, stimulates research in the given direction.

2. The Object of Research

The object of researches was non-autonomous RL-circuit with MIS-diode connected in series. Equivalent circuit of MIS-diode is presented on the fig.1. As can see there is $C_{b,d}(U)$ – capacity of Spice Charge Region and Insulator layer. The expression (1) for $C_{b,d}(U)$ [1] is not corresponding clearly to the MIS-diode capacity, but in common for modeling purposes we suppose it admissible.

$$C_{b,d}(U) = \begin{cases} \dfrac{C_0}{\sqrt{1-(\dfrac{U}{V_{tr}})}}, U < V_{tr} \\ C_0 + I_0 \dfrac{\tau}{\varphi} e^{\frac{qV_{tr}}{kT}}, U \geq V_{tr} \end{cases} \quad (1),$$

Also there is set of voltage controlled switches SW_i that turn on/off according to applied voltage in order to simulate the i-th trap charge accumulation or relaxation processes, where i=1…n. The trap subcircuit also includes the resistance R_{Si} and the capacity C_{Si} for simulation of the trap recharging time constant $\tau_S = R_S C_S$.

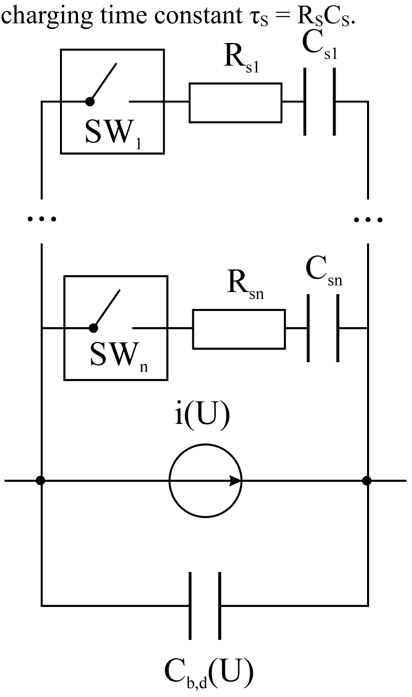

Fig.1. Equivalent circuit of MIS diode structure

3. The Model and Numerical Experiment

Let's construct the mathematical model of the modified nonlinear semiconductor oscillator - RL-circuit in which MIS-structure is used as diode. This model (2) will be presented in the form of the system of the ordinary non-autonomous nonlinear differential equations:

$$\begin{cases} \dfrac{di}{dt} = \dfrac{1}{L}(\varepsilon(t) - iR - U) \\ \dfrac{dU}{dt} = \dfrac{1}{C_{b,d}(U)}(i - i(U) - \dfrac{U - U_S}{R_S}) \\ \dfrac{dU_S}{dt} = \dfrac{U - U_S}{R_S C_S} \\ \dfrac{d\Omega}{dt} = \dfrac{f}{f_0} \end{cases} \qquad (2)$$

where i – current of circuit, i(U) – MIS-diode current according to equivalent circuit of MIS diode structure (fig.1), U - voltage on MIS-structure and U_S - voltage on trap equivalent capacitance, L –inductance, R –resistance, t and Ω – time and phase of external force, f/f_0 - relative frequency of external force ε(t)=E sin ωt. The f_0 is the resonance frequency of circuit under condition E=0.

On the figure 2 the nonlinear circuit with equivalent circuit of MIS diode structure are presented.

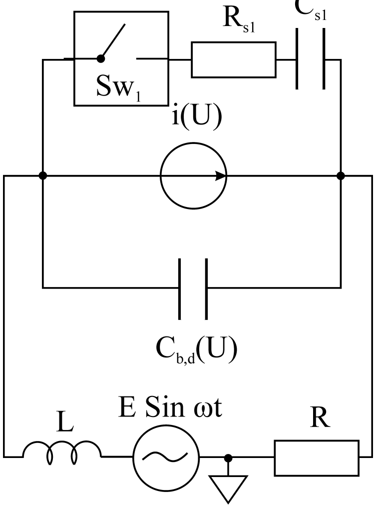

Fig.2. Nonlinear semiconductor oscillator circuit

The constructed model has been investigated numerically under external driven sine wave influence ε(t) for a following set of parameters: L=2mH, C_0=200 pF, $C_0=C|_{U=0}$, V_{tr}=0.2V, $I_0=10^{-12}$A, $\tau=10^{-5}$s, φ=0.026V, R=50 Ohm and a parameter f/f_0 = 0.1. For the comparative analysis of solutions the projections of phase space of system and 1D-bifurcation diagrams for the oscillations in MIS-structure with and without traps was used. In the case of presence of charge storage traps the switching threshold voltage V_{SW} was -0.25 V and -0.75 V. As well, for the each experiments the time constant of the traps $\tau_S=10^{-6}$ and $\tau_S=10^{-3}$ s was used.

For modeling of a case of absence of traps the modified system was used. The third equation for recharge dynamics of a trap has been removed from system (1).

4. Results and Discussion

According to numerical results, the main feature of the charge trap influence on dynamics of the nonlinear semiconductor oscillator is the chaos suppression in the regions of external force with low voltage. As can see from fig.3a,b in the case of presence of the charge traps with $\tau_S = 10^{-3}$ s there is only 1T- and 2T-cycle regimes at region when applied voltage is less then 2 V. In contrast, in the case when no trap is added to equivalent circuit of the MIS-diode the observable region with complex structure with chaotic windows like well known non-autonomous RL-diode circuit [7] is presented (fig.3c). At the case of “fast” traps the similar behavior can be found, see fig.4a,b,c. There is small differences, particularly, the presence of the phase hopping at the low external force voltages about E = 0.5-1.3 Volts.

Described effects can be explained in terms of accumulation and relaxation of charge carriers on the traps. The trap captures the minority carriers charge that leads to decreasing of accumulated charge in the Space Charge Region and near to semiconductor-insulator interface. If the time τ_S is comparable to T/2, where T = 1/f, then such trap can be involved into processes of charge transition in MIS-diode. According to known supposition about the nature of complex oscillations in RL-diode circuit [8], such charge can shift the initial conditions (the common stored charge into diode) for the next period of external force ε(t). The large negative voltage is stored in the $C_{b,d}$(U) capacitance and adds with the external force voltage to produce a large current through the circuit. This current injects minority charge into the MIS-diode Space Charge Region and charges the storage capacitance $C_{b,d}$(U) to a positive voltage. The stored charge permits the diode to conduct in both directions, a transition known as the reverse recovery; during this time the diode acts as a conductor with a small positive emf. The stored charge begins to recombine in the Space Charge Region and to discharge trough the inductor and resistor producing a counterclockwise discharge current which linearly increases with time.

If the above-mentioned charge is “frozen” partially in the trap then there is not enough shift of voltage across diode at the beginning of the next period of external force to produce more complex mode (for example, chaos). In this case the long period charge relaxation regime (for example, nT) arise. Such results can be seen from the discussed numerical and known [4] experiments (fig.5).

5. Conclusion

Observed effects of chaos suppression for the case of presence of traps in MIS-diode can be used in many practical applications of such MIS-structures. For example, the good practical result can be founded in the problem of EMI suppression at power rectifiers or converter circuits. At last, the study of described phenomena represents undoubted interest as a possible new method for the determination of main parameters of MIS-diodes and semiconductor-insulator interfaces.

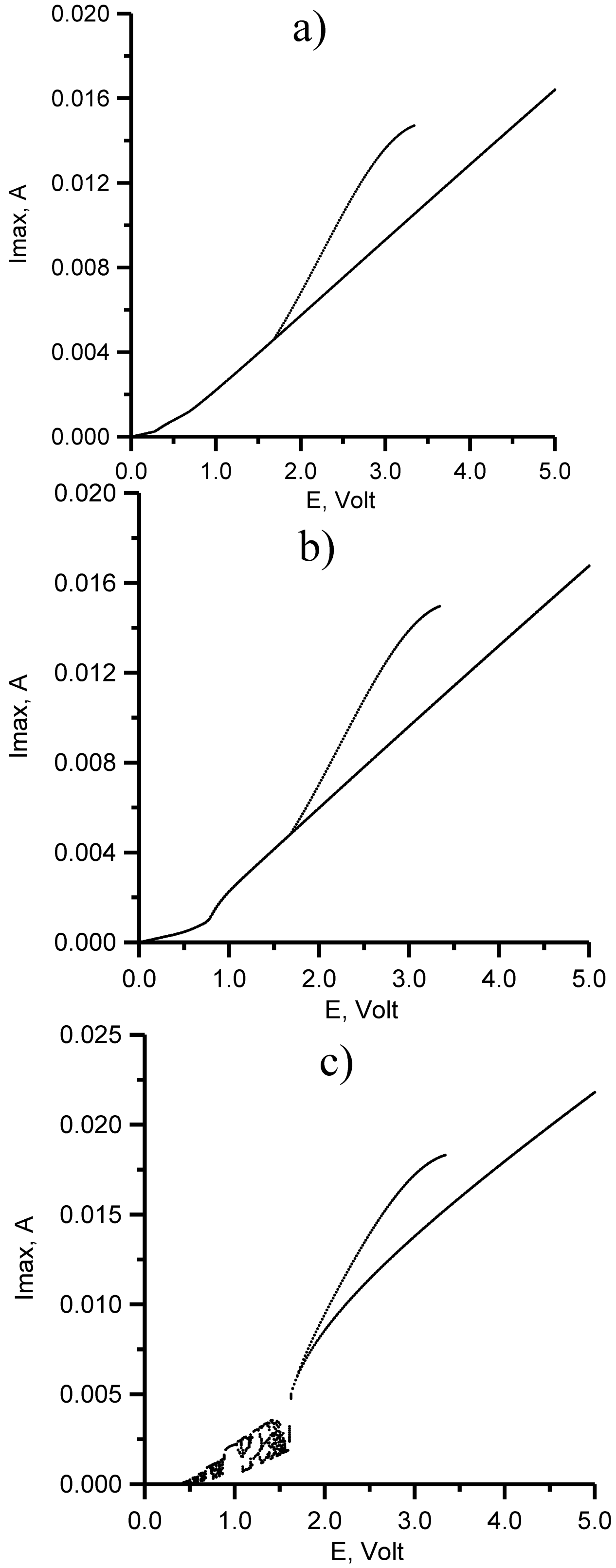

Fig.3. Bifurcation diagram for case of “slow” trap. The control parameter is amplitude of external force. $f/f_0 = 0.1$, $\tau_S = 10^{-3}$ s;
a) $V_{SW} = -0.25$ V b) $V_{SW} = -0.75$ V and c) with no traps

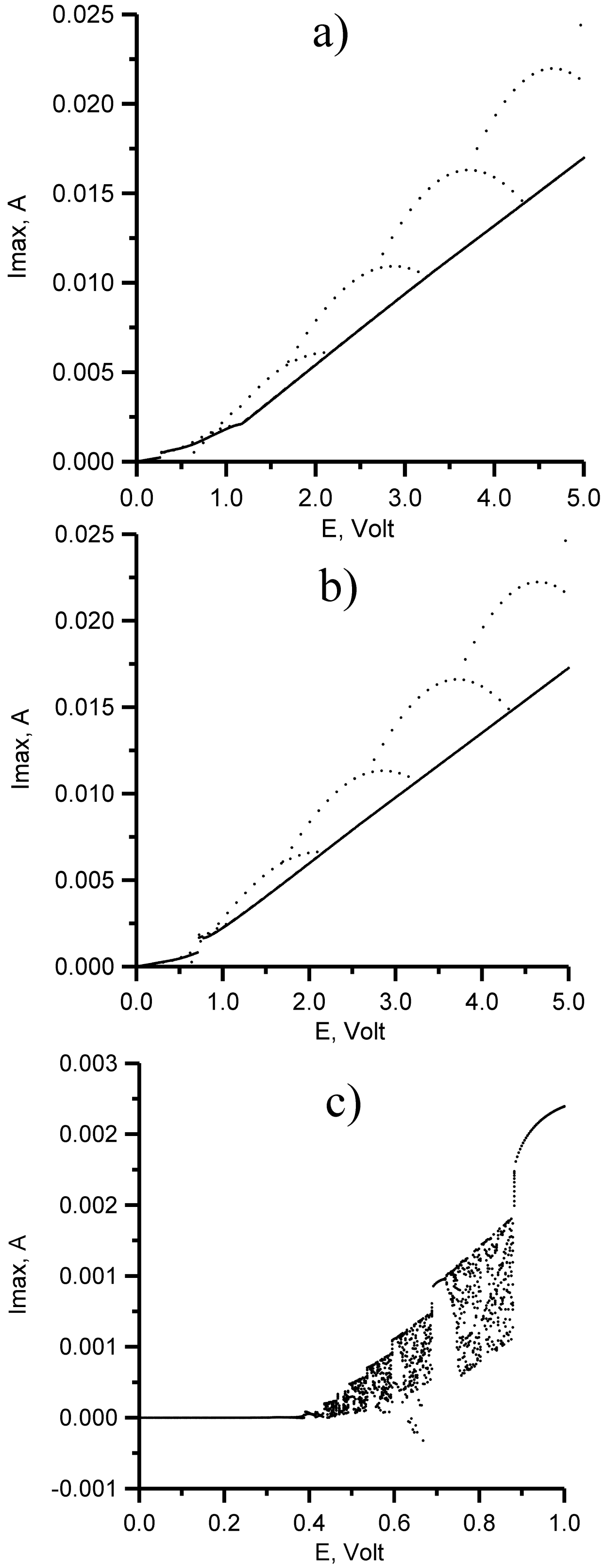

Fig.4. Bifurcation diagram for case of “fast” trap. The control parameter is amplitude of external force. $f/f_0 = 0.1$, $\tau_S = 10^{-6}$; a) $V_{SW} = -0.25$ V b) $V_{SW} = -0.75$ V and c) with no traps, the parameter E scale increased

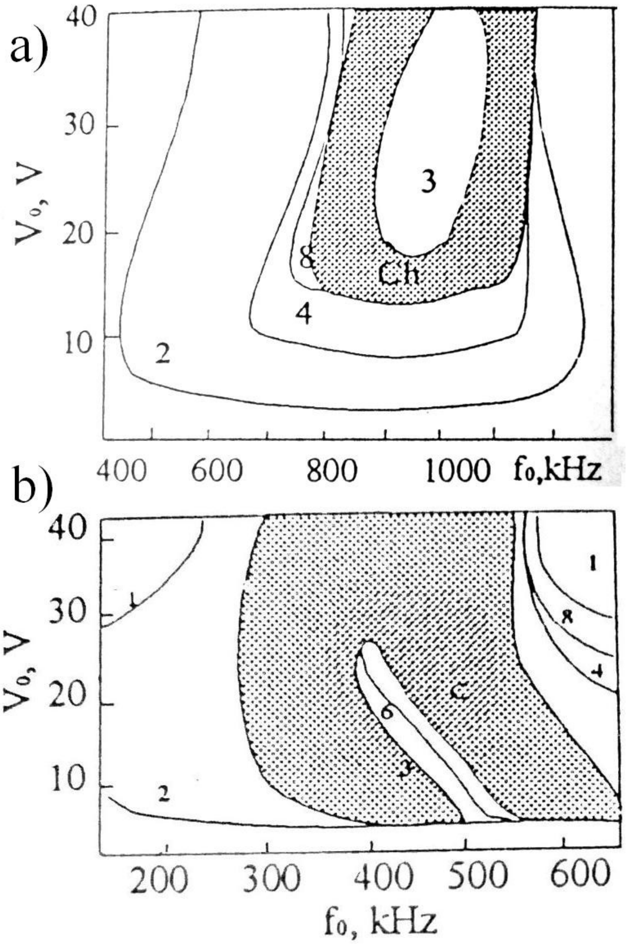

Fig.5. “f_0-V_0” plane for the non-autonomous RL-MIS-circuit obtained from experiment: a) MIS-n-Si with Gd_2O_3 is as oxide, b) MIS-n-Si with Y_2O_3 is as oxide [4].

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