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Nonlinear Dynamics of Periodic Electric-Field Domains in Quantum Well Infrared Photodetectors

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1. Introduction

Analysis of quantum well infrared photodetectors (QWIPs) based on multiple QW structures has been done in many publications. However, both experimental and theoretical studies of physical phenomena accompanying the operation of QWIPs are as before under way. Recently, a novel effect - the formation of periodic and near periodic electric-field domains in QWIP structures under illumination - has been predicted in computer simulations [1,2]. The occurrence of periodic distributions of the electric field with a period equal to twice the QW structure period is attributed to the excitation of recharging waves [1-3]. The formation of periodic electric-field domains can significantly influence the characteristics of QWIPs, particularly, when they operate at elevated intensities of infrared radiation. The latter takes place in QWIP applications for photomixing and heterodyne detection. The transition from smooth monotonic electric-field distributions to spatially periodic one's with increasing intensity can explain some nonlinear effects in QWIPs [4]. In this paper, we investigate the formation and evolution of periodic electric-field domains in QWIPs excited by infrared radiation. Our study is based on the ensemble Monte Carlo (MC) particle simulator developed and used previously [1,2].

2. Results

We consider $Al_{0.22}Ga_{0.78}As/GaAs$ QWIPs with different structural parameters (number of QWs N, QW donor concentration Σ_d, etc.) at different bias voltages corresponding to different average electric field E. We show that depending on the structural parameters and the radiation intensity the dynamics of the domain formation can be quite different. In some cases, the formation of stable periodic electric-domains occurs after a long period of chaotic spatio-temporal pulsations. The established stable domain structures exhibit relatively small oscillations of their amplitude. These oscillations appear to be chaotic as well. Figure 1 shows the evolution of the electric-field distribution in a QWIP with 21 QWs in response to a step-like pulse of infrared radiation (with intensity $I = 10^{23}$ cm^{-2}s^{-1}) resulting in the creation of rather perfect periodic structure. Figure 2 shows the transient photocurrents in QWIPs with $N = 20$ and 21 at the same conditions as above. In a QWIP with 21 QWs the formation of the domain takes about 50 ns (see Fig. 1). After that the photocurrent exhibits fairly moderate oscillations.

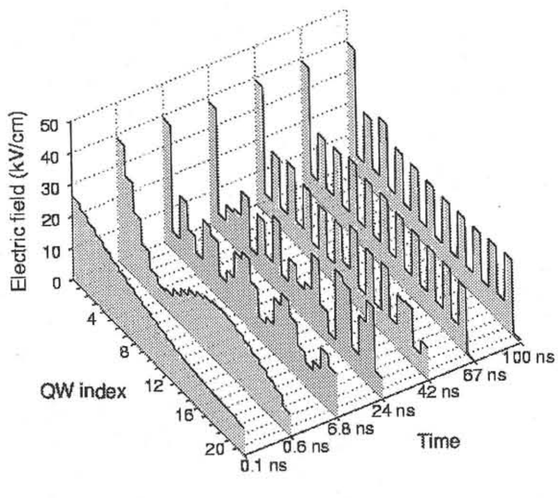

Figure 1: Evolution of the electric-field distribution ($E =$ 15 kV/cm).

Contrary to this, in a QWIP with $N = 20$ the photocurrent reveals strong chaotic pulsations and a periodic structure formed after a long period ($t > 415$ ns). Such pulsations are accompanied by the variations of the electric field in the inter-well barriers. Figure 3 shows the variations of the electric field in 5th and 6th barriers in QWIPs with different N. One can see, that in a QWIP with $N = 20$ the electric-field oscillations of the electric field in the 5th and 6th barriers markedly change at $t > 415$ ns, i.e., when the domain is formed. The phase space attractors constructed from time-dependent electric fields in neighboring and faraway barriers for $N = 21$ are shown in Fig. 4. This

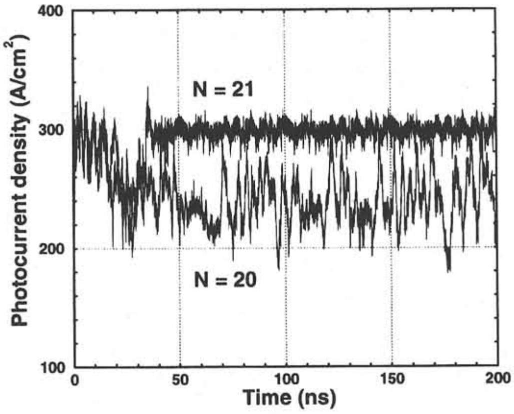

Figure 2: Transient photocurrents in QWIPs with 20 and 21 QWs.

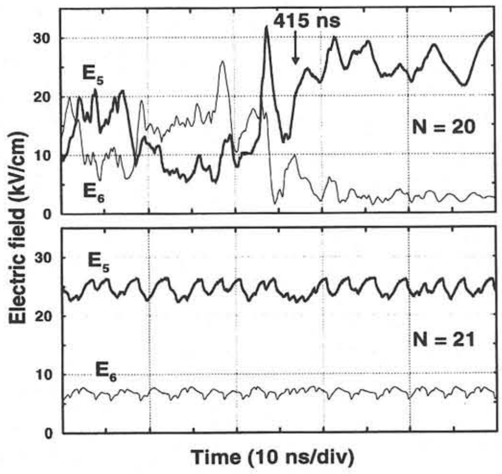

Figure 3: Variations of the electric field in different barriers.

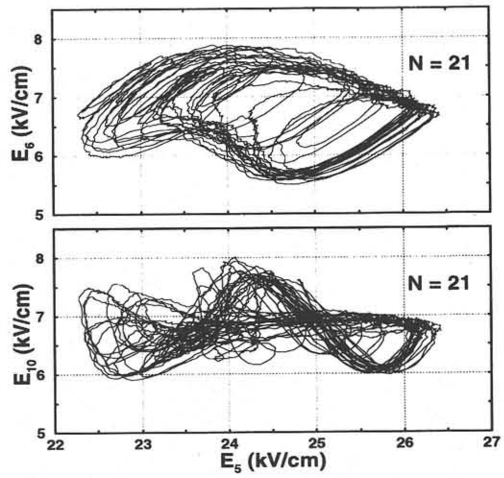

Figure 4: Phase space attractors for a QWIP with 21 QWs (400 ns $\leq$ t $\leq$ 500 ns).

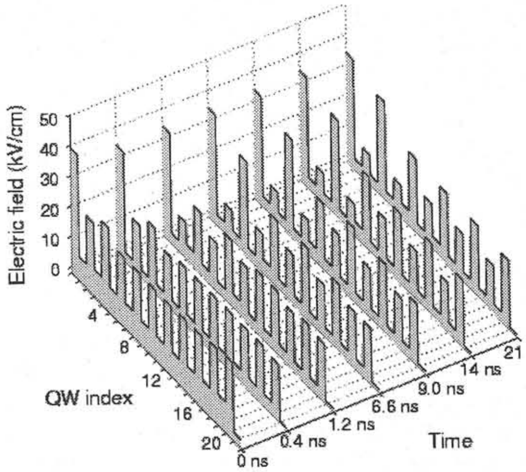

Figure 5: Transformation of the periodic domain in response to a step-like voltage pulse.

figure demonstrates relatively irregular behavior of the periodic domain amplitude. Figure 5 shows the transformation of a periodic domain structure when the applied voltage changes (with the decrease in the average electric field from $E = 15$ to 10 kV/cm).

3. Conclusion

We studied transient processes in optically excited QWIPs using the MC simulations and demonstrated different modes of the periodic-electric-field domains formation, irregular (chaotic) oscillations of such domains, and the transformation of the domains by varying bias voltage.

References

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