A Self-consistent Algorithm for InGaAs/GaAs strained multi-period Quantum Well Infrared Photodetectors

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Abstract- **This work presents a self-consistent algorithm for the simulation of responsivity and detectivity of InGaAs/GaAs strained multi-period Quantum Well Infrared Photodetectors. This algorithm takes into account the fundamental mechanisms involved in the InGaAs/GaAs detector detection process. We have calculated a practical InGaAs/GaAs detector by using this algorithm. The obtained results were in good agreement with the experiments at low temperature below 3.5 V.**

I. INTRODUCTION

There has been great interest in electronic phenomena in quantum structure over past three decades. As for its device physics and application, it has been extensively studied on the AlGaAs/GaAs quantum well infrared photodectors (QWIPs) especially multi-period long-wavelength QWIPs (LW-QWIPs) based on intersubband transitions [1-6]. Quantum well (QW) and quantum dot (QD) structures based on strained $In_xGa_{1-x}As$ layers grown on GaAs substrate have also attracted much attention because of their interesting physical properties and potential for high-speed and optoelectronic device applications[7-9]. Compare with the $Al_xGa_{1-x}As$/GaAs LW-QWIPs, it is much more interesting to consider GaAs as the barrier material since the carrier transport in binary GaAs is expected superior to that of a ternary alloy, as was found to be in the $In_{0.53}Ga_{0.47}As$/InP binary barrier structures. It has been demonstrated that strain layer heterostructures can be grown for lower In concentrations ($x<0.3$), which results in lower heterobarrier heights and meets the need for LW-QWIPs designing and application [9]. However, due to the difficulty in ascertaining the real parameters and the theoretical design of strained $In_xGa_{1-x}As$/GaAs LW-QWIPs, quantitative understanding and design of $In_xGa_{1-x}As$ /GaAs LW-QWIPs are still very limited. In this work we present a self-consistent algorithm for InGaAs/GaAs strained LW-QWIPs. Based on the theoretical calculation and experimental data, we try to establish a practical algorithm for the InGaAs/GaAs strained LW-QWIPs, from which the photoresponsivity and detectivity can be directly obtained. The directly obtained responsivity and detectivity is of great importance for the design and optimization of InGaAs/GaAs strained LW-QWIPs.

II. RESULTS AND DISCUSSIONS

Let us consider a LW-QWIP consisting of N identical $In_xGa_{1-x}As$/GaAs QWs of width L_w and barrier width L_B, with a donor density $N_s(cm^{-2})$ in each QW and a doping density $N_d(cm^{-3})$ in the GaAs contacts. Based on our practical $In_xGa_{1-x}As$/GaAs strained LW-QWIPs, An assumption was made: The GaAs barrier height and the InGaAs QW width are such that only one bound state of energy E_1 is present in the well. Although the excited state above the barrier is observed to be quasi-confined [10], we approximate the states above the GaAs barrier to be continue. The responsivity was calculated by the difference between the total current under illumination and the dark current. As for the noise and detectivity calculation, each $In_xGa_{1-x}As$ QW has been thought as a local noise generator contributing to the total electrical noise power duo to the fact that the InGaAs QWs in the LW-QWIPs are fixed and localized recombination centers.

Fig. 1. presents the dark current of our sample at 43 K. The red line is the simulated result, and the black line is experimental measurement. A fine agreement has been observed between the theory and the experiment below 3.5 V which is suitable for the device operation voltage. Fig. 2-6 presents the obtained results: photocurrent, band edge, carrier density distribution, responsivity and detectivity, respectively. By use of practical $In_xGa_{1-x}As$/GaAs detector parameters, we are able to predict the dependence of the photocurrent and responsivity and detectivity on the applied bias for different structures and operation temperatures with a fine precision below 3.5 V.

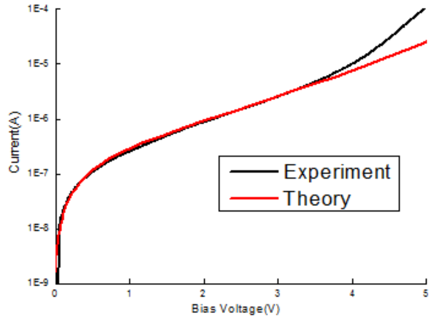

FIG. 1. Dark current of our sample at 43 K. The red line is the calculated results, and the black solid line is experimental measurement.

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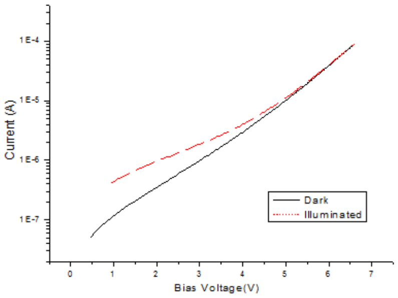

FIG. 2. Comparison of the I-V character in dark conditions and under illumination. The black solid line is in dark conditions, and the red dashed line is under illumination by an incident photon flux $10^{22}\text{cm}^{-2}\ \text{s}^{-1}$.

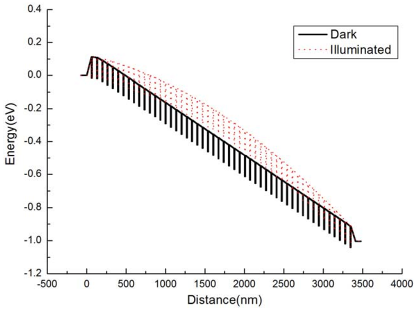

FIG. 3. Comparison of the band diagrams of the sample in dark conditions and under illumination by an incident photon flux $10^{22}\text{cm}^{-2}\ \text{s}^{-1}$

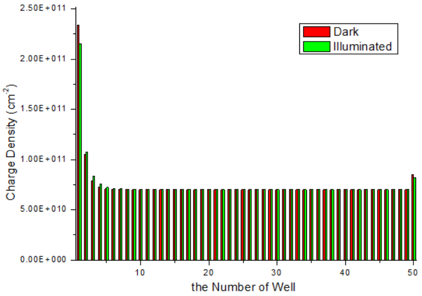

FIG. 4.Comparison of the corresponding carrier density in each well in dark conditions and under illumination.

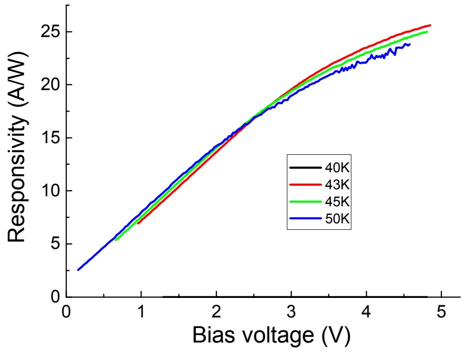

FIG. 5.Comparison between different low temperatures (From 40 K to 50 K) for the responsivity of the sample.

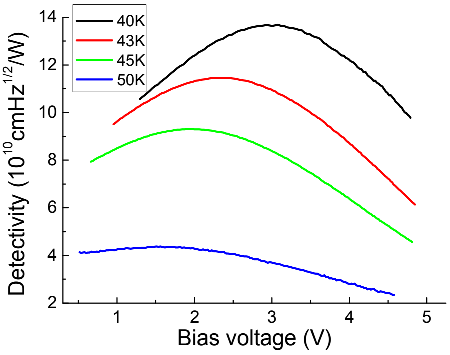

FIG. 6.Comparison between different low temperatures (From 40 K to 50 K) for the detectivity of the sample.

III. CONCLUSION

We have presented the results of a self-consistent algorithm for the $In_xGa_{1-x}As/GaAs$ strained multi-period LW-QWIPs. The dark currents, photocurrents, responsivity and detectivity are carefully calculated and analyzed. The numerical results can explain well our experimental observations. By use of practical detector parameters, we are able to predict the dependence of the responsivity and detectivity on the applied bias for different structures and operation temperatures with a fine precision at low temperature. This algorithm can be considered as a useful tool for the design and optimization of InGaAs/GaAs strained LW-QWIPs.

Acknowledgements:

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