Detectivity Simulation of Long-Wavelength Quantum Well Infrared Photodetectors

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Abstract- **We present the results of a method for the detectivity simulation of multi-period AlGaAs/GaAs Long-wavelength quantum well infrared photodetectors (LW-QWIPs) directly from the characterized device parameters in a self-consistent way. This simulation method takes into account the fundamental mechanisms involved in the detection process. The electrical field distribution, currents and detectivity are carefully calculated and analyzed. The numerical results agree well with our experimental observations.**

1 INTRODUCTION

There has been great interest in electronic phenomena in quantum structure over past two decades [1-5]. As for its device physics and application, it has been intensively studied on the quantum well infrared photodectors (QWIPs) especially multi-period long-wavelength QWIPs (LW-QWIPs) based on intersubband transitions [1-6]. The difficulties in the detectivity modeling of the actual QWIPs step from the coupling between two different regimes. The transportation between adjacent QW is manageable as a semiclassical problem whereas the emission and capture occuring in each well are essentially quantum mechanical. A fully quantum transport theory for the detectivity simulation is not available yet. This work intends to present a detailed numerical modeling of detectivity of LW-QWIPs directly from the characterized device parameters in a self-consistent way.

2 THEOEY CALCULATION

Generally, the detectivity of the QWIPs is given by

$$D^* = R(V)\sqrt{A\Delta f}\,/\,i_n \qquad (1)$$

where $R(V)$ is responsivity of the QWIPs, A is detector area, Δf is the measurement bandwidth and i_n is the noise under operation. The basic balance relation at each period can be written as [7]

$$p_c J_{inj} = J_{th} + J_{op} \qquad (2)$$

where J_{th} and J_{op} are the thermal and optical part of emission current density, respectively. Denote the electric field on the ith barrier by F_i and the electron density in the ith QW by N_i, the following self-consistent set equations (balance relation together with Poisson's Eq.) will be solved at every period

$$\begin{cases} p_c(F_{i-1})J_{inj}(F_0) = J_{th}(N_i, F_i) + qp_e(F_i)N_i\sigma_{\mathrm{op}}\Phi_i \\ N_i - N_S = \varepsilon_r\varepsilon_0\left(F_i - F_{i-1}\right)/q \end{cases} \qquad (3)$$

The self-consistent photo-responsivity at a total bias V is given by the difference between the total current under illumination and the dark current

$$R(V) = [J_{inj}(\Phi, F_0^{\Phi}) - J_{inj}(\Phi = 0, F_0^{dark})]/h\nu\Phi \qquad (4)$$

The electrical noise was expressed as :

$$i_n^{\,2} = 4eIg\Delta f(1 - P_c/2) \qquad (5)$$

where I=$J_{\mathrm{inj}}A$ is the current flowing through the device and g=1/($NP_{\mathrm{c}}(F_i)$) is the photoconductive gain. By inserting the self-consistently solved photo-responsivity $R(V)$ and current noise i_n into Eq.(1), the final detectivity can be determined. The calculation program is written by Fortran 90 language.

3 RESULTS AND DISCUSSIONS

First we present the results calculated for a $Al_{0.22}Ga_{0.78}As$/GaAs LW-QWIPs containing 10 periods with L_{B}=35 nm, L_{W}=6 nm, doping density N_s=1.4×10^{11}cm^{-2} in the QW layer and N_{d}=4.5×10^{17}cm^{-3} in the contacts (peaked at 10.3 μm and denoted as sample A).

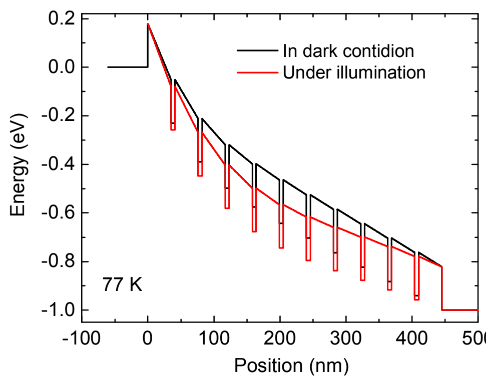

FIG. 1. Comparison of the band diagram of sample A under a total applied bias 1V in dark condition and illuminated condition at 77 K

Figure 1 presents the band diagram of sample A under a total

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applied bias 1V in dark conditions and under illumination (77 K). Figure 2 clearly demonstrate the change of the electric field and carrier distributions in the multi-period QWIPs under illumination.

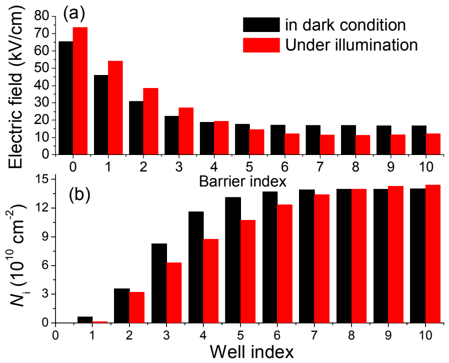

FIG. 2. Self-consistently calculated electric field distributions and carrier density both in dark condition and under illumination at 77 K

Next we present the results for a practical $Al_{0.15}Ga_{0.85}As/GaAs$ LW-QWIPs containing 50 periods with L_B=60 nm, L_W=7 nm, doping density $N_s=1.75\times10^{11}$cm^{-2} in the QW layers and $N_d=2.5\times10^{17}$cm^{-3} in the contacts (peaked at 14.9 μm and denoted as sample B). Individual photodetector elements were processed into 200×200 μm^2 area mesa structures using wet chemical etching and Au/AuGeNi Ohmic contacts were evaporated on the top and bottom contact layers. The measured results are presented in Fig. 3 and 4 (circle dots). The self-consistent calculation of dark currents and photocurrents in the presence of an incoming photo flux $\phi=5.0\times10^{17}$cm^{-2}s^{-1} under different temperatures are shown in Fig.5

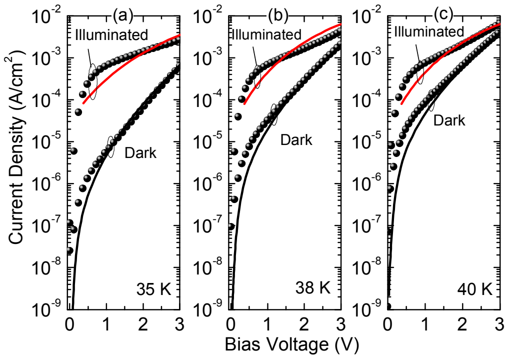

FIG. 3. Comparison of the current densities between experiment and theory for sample B both in dark conditions and illuminated conditions at 35 K, 38 K and 40 K operation temperatures. Circle dots: experimental observations. Solid lines: self-consistently calculated results.

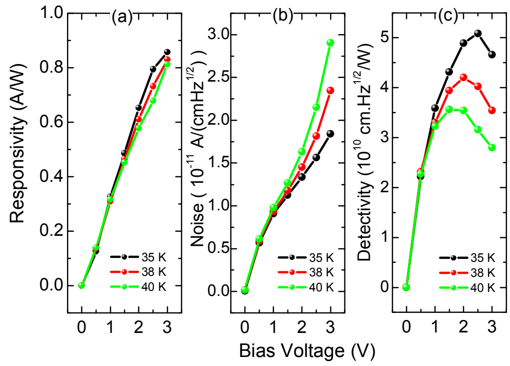

FIG. 4. Measured Responsivity, noise and detectivity of sample B at 35 K, 38 K and 40 K

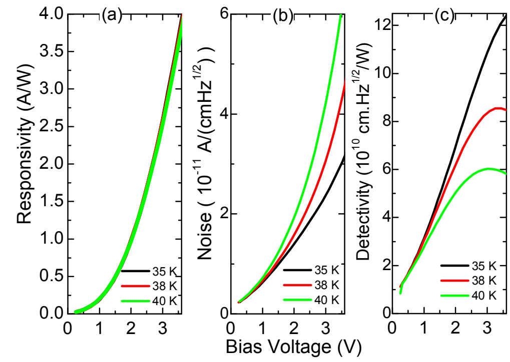

FIG. 5 Self-consistently obtained Responsivity, noise and detectivity of sample B at 35 K, 38 K and 40 K

Figure 3 presents the comparison of the current densities between experiment and theory for sample *B* both in dark conditions and under illumination. Figure 4 shows the measured reponsivities, noise and detectivity at 35 K, 38 K and 40 K operation temperatures, respectively. Figure 5 shows the self-consistently calculated results. A general agreement has been obtained by this self-consistent model between the theory and the experiment.

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