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Zero-bias offsets in *I*–*V* characteristics of the staircase type quantum well infrared photodetectors

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ABSTRACT

In this work, observed zero-bias offsets in *I*–*V* characteristics and differences in *J*–*V* characteristics of staircase quantum well infrared photodetectors were investigated. Temperature and voltage sweep rate dependence of the zero-bias offsets were studied on mesa structures shaped in different diameters. Furthermore, effect of mesa diameter on *J*–*V* characteristics was investigated. The temperature, initial bias voltage and voltage sweep rate dependence of the zero-bias offsets were explained by a qualitative model, which is based on a *RC* equivalent circuit of the quantum well infrared photodetector.

1. Introduction

Quantum well infrared photodetectors (QWIPs), in some respects, have superior properties over conventional infrared photodetectors. For example, their multi spectral detectivity makes them applicable to multicolor focal plane array (FPA) imaging systems [1]. Furthermore, QWIPs have good uniformity over large areas, which make them suitable for high volume production [1]. Among proposed several kind of QWIP structures, staircase-like QWIPs have lower dark currents, because ground state sequential tunneling is reduced due to the misalignment of the ground state energy levels in the quantum wells [2]. Moreover, staircase-like structure of the QWIP makes the forbidden intersubband transitions such as $1 \rightarrow 3$, $2 \rightarrow 4$ possible.

In this work, temperature and voltage sweep delay (SD) dependence of the zero-bias offsets observed in *I*–*V* characteristics of a QWIP device having quantum wells with asymmetric barriers were studied. It was observed that at a given simulation time and temperature, zero-bias offsets and corresponding current values strongly depend on the initial bias voltage. Moreover, it was measured that zero-bias offsets were dependent on the voltage sweep rate at a given temperature and initial bias voltage. *J*–*V* and *I*–*V* characteristics of the mesa structures having different diameters were also studied. Highly asymmetric band profile of the structures resulted in interesting zero-bias offset behavior that is different from observed in QWIPs with a symmetric band profile [3,4]. Furthermore, in order to present the capacitance change of the QWIPs, we proposed an equivalent circuit model for the QWIP device and carried out transient analysis of the equivalent circuit by using Ngspice circuit simulator [5].

2. Experimental details

The schematic layer structure and conduction band profile of the investigated device is given in Fig. 1. The device consists of 30 periods of stepped barriers. In each period, three different well thicknesses with four different barrier compositions constitute three asymmetric quantum wells shown in Fig. 1b. Each period is separated with a 50 nm GaAs layer doped with Si at 1.0×10^{18} cm^{-3} concentration. n^+ GaAs layers prevent band bending and constitute ohmic contacts to the device. Details of the asymmetric staircase-like QWIP structure can be found elsewhere [2].

I–*V* characterization of the device was carried out at temperatures between 37 and 300 K. In order to measure dark current, window of the cryostat was covered with Al foil. In addition, a radiation shield was used inside the cryostat. In order to clarify sweep

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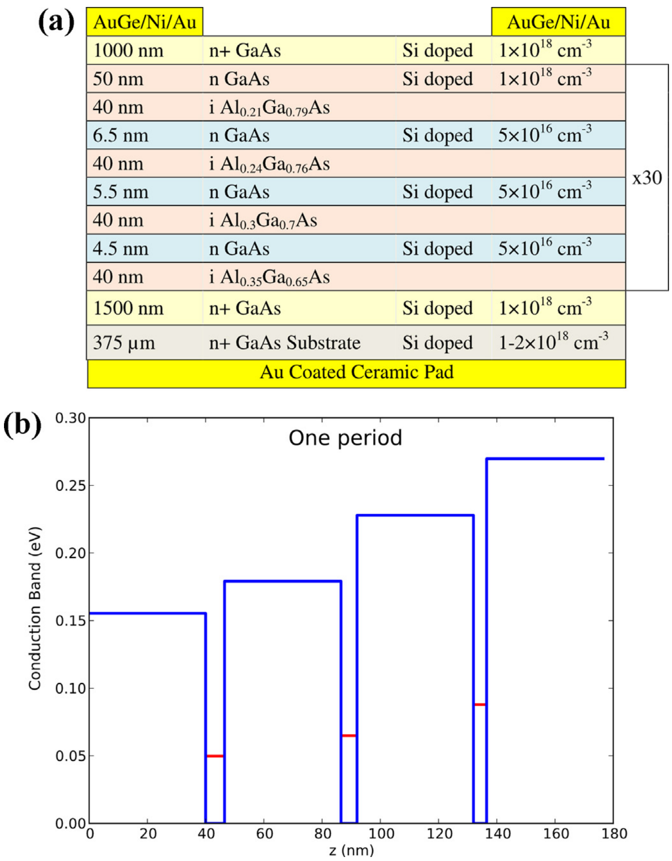

Fig. 1. (a) Schematic layer structure of the staircase type QWIP. (b) Staircase-like quantum wells formed in the conduction band in a period of the QWIP. Red lines are ground states of the quantum wells. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

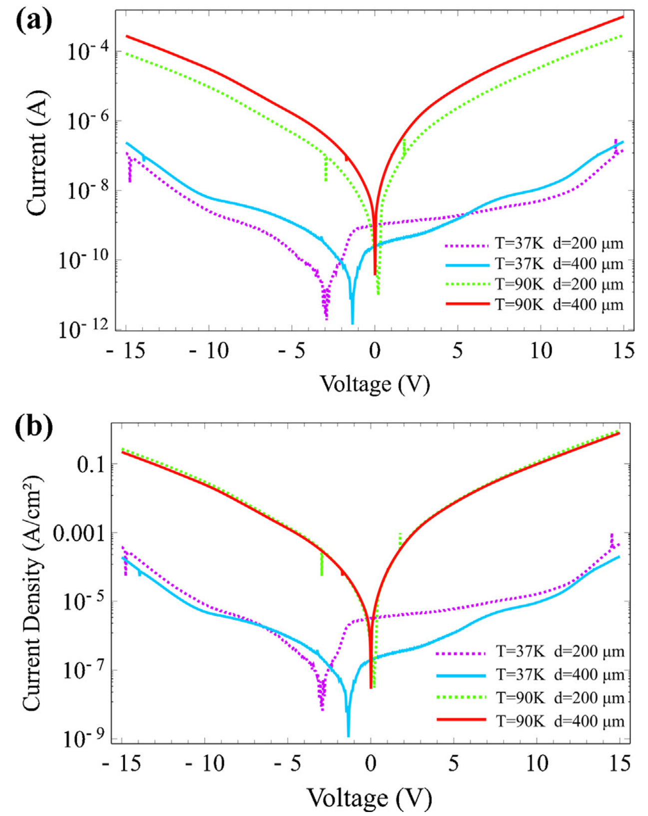

Fig. 2. *I–V* (a), *J–V* (b) characteristics of two mesa structures with diamenters $d = 200\ \mu m$ and $400\ \mu m$ at $T = 37$ and 90 K. Sweep delay time is 5 ms.

delay time dependence of zero-bias offsets, the voltage was swept from −15 V to +15 V with 5 ms and 350 ms sweep delay times in ~7.5 s and ~175 s, respectively. In all *I–V* measurements, forward bias was defined by applying a positive voltage onto the top contact of a mesa with respect to the common bottom contact of the whole device. All voltage sweeps were started from a minimum value, increased to 0 V and without waiting, increased up to a positive maximum value. *I–V* characterization was carried out using a Keithley 2635A source-meter, which is capable of measuring current values in the fA range by virtue of a built-in analog filter.

3. Results and discussion

Dark current measurement of QWIPs demonstrates two current transport mechanisms: tunneling and thermionic emission current. Tunneling current prevails at low temperature range, whereas, as the temperature increases, electronic transport is dominated by thermionic emission [3,6]. We also observed these transport mechanisms and similar temperature dependent characteristic changes at *I–V* measurements. In Fig. 2, *I–V* characteristics of two mesa structures having diameters 200 μm and 400 μm were compared at temperatures 37 K and 90 K. At 37 K, below ±10 V bias voltages dark current is dominated by tunneling current. Above ±10 V bias voltages thermally assisted tunneling and/or impact ionization followed by avalanche multiplication electronic transport mechanisms are dominant [6,7]. At 90 K, dark current is mainly caused by thermionic emission as seen from the characteristic of the *I–V* curve.

Theoretically, for mesa type devices, current density J under electrical potential V can be calculated by $J = V/\rho\, t$, where ρ is the total resistivity of the layers under electric field, t is the thickness of the mesa structure between top and bottom contacts. For mesa structures having different cross-sections, ρ and t are constant so the current density must be also constant. If current values are compared at a given temperature, it is seen that more current flows from the larger mesa. This is an expected result because, as mentioned above, current density should be independent from the cross-section and more current flows from the mesa having larger cross-section. Comparison of current densities as seen from Fig. 2b revealed that, at 90 K, current density is almost independent of the cross-section of the mesa for all bias voltages, whereas at 37 K for a wide range of bias voltages, current density of mesa having 200 μm diameter is larger than that of 400 μm diameter. This can be due to the contact geometry. As seen from Fig. 3, top contact of the mesa does not cover the entire surface, which is ring shaped and located at the edge of the mesa. The perpendicular distance between the top and bottom surface is the same for all mesa structures. However, if the location of the top contact is considered; as the diameter increases the distance between the top contact and the center of the bottom contact and the curvature of the electric field lines increases. This can cause decrement of the electric field as well as the current density according to $E = \rho J$.

In Fig. 4a, *I–V* characteristics of a mesa having 200 μm diameter at three different temperatures with two different sweep delay times are presented. Voltage sweep delay time affects the *I–V* characteristics of the investigated staircase type QWIPs especially at temperatures below 90 K. As seen from Fig. 4a at 90 K, measured current values in the *I–V* characteristics obtained by fast and slow sweeps do not differ from each other very much. On the other hand, at temperatures 50 K and 70 K, in a certain high potential range, under slow sweep more current flows through the device than that of the fast sweep. This can be explained as follows. Because voltage sweeps were initiated from a maximum value of the reverse