Journal of Crystal Growth xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Journal of Crystal Growth

journal homepage: www.elsevier.com/locate/crys

Laterally biased structures for room temperature operation of quantum-well infrared photodetectors

Álvaro Guzmán [a,*], Raquel Gargallo-Caballero [b], Xiang Lü [a], Holger T. Grahn [a]

[a] *Paul-Drude-Institut für Festkörperelektronik, Leibniz-Institut im Forschungsverbund Berlin e. V., Hausvogteiplatz 5–7, 10117 Berlin, Germany*
[b] *Instituto de Sistemas Optoelectrónicos y Microtecnología (ISOM), ETSI Telecomunicación, Avda. Complutense 30, 28040 Madrid, Spain*

ARTICLE INFO

Article history:
Available online xxxx
Communicated by Jean-Baptiste Rodriguez

Keywords:
A1. Nanostructures
A3. Molecular beam epitaxy
A3. Quantum wells
B1. Arsenates
B2. Semiconducting III–V materials
B3. Infrared devices

ABSTRACT

Laterally biased quantum-well infrared photodetectors (LBQWIPs) are expected to exhibit a photoresponse at room temperature. In these devices, the photocurrent is collected by means of two lateral Ohmic contacts on each side of an undoped quantum well (QW), which is coupled by tunneling to another *n*-doped QW. Photoexcited electrons from the *n*-doped QW tunnel through to the undoped QW and are swept out via a lateral bias voltage. Up to now, the practical development of these structures has not been yet achieved due to the difficulty of contacting single QWs separated by a few nanometers. In this paper, we report on a viable technology to fabricate LBQWIPs. We present two procedures to contact individual QWs, which are sufficiently close to be coupled by tunneling. The final devices exhibit very low dark-current values and clear infrared absorption peaks at 300 K, in good agreement with the results of numerical simulations. This work demonstrates the practical functionality of the laterally biased structure and paves the way for future developments of room temperature QWIPs.

1. Introduction

Quantum-well infrared photodetectors (QWIPs) have been proposed as a feasible alternative to fabricate focal plane arrays for infrared (IR) cameras. In fact, hybrid devices combining a GaAs/(Al,Ga)As QWIP detector array bonded together with a read out integrated circuit made of Si are already available on the market [1].

Nevertheless, infrared cameras based on QWIPs still exhibit an important disadvantage: the necessity of reducing the operating temperature to cryogenic regimes to minimize the dark current. As a consequence of this drawback, the QWIP-based cameras are generally mounted inside costly and heavy cryostats, resulting in a very bulky equipment, which cannot be easily carried by a single person so that their application is restricted to surveillance or security systems.

To overcome the need of cryogenic operation, many efforts have been devoted to the development of QWIPs which can operate at room temperature. For example, it has been proposed to use quantum dots in the active region of the detector [2]. In fact, there are some reports in the literature on quantum-dot devices operating at room temperature [3,4]. Quantum-cascade detectors have also been demonstrated to exhibit room temperature operation [5]. However, quantum-dot-based detectors and quantum-cascade detectors are very demanding in terms of reproducibility over a large number of layers.

In 2007, Alsing et al. [6] proposed a novel QWIP detector structure with a lateral biasing scheme, which is expected to operate at higher temperatures. The device principle is shown in Fig. 1(a). It consists of two quantum wells (QWs), which are grown sufficiently close to each other so that they are coupled by tunneling. One QW is *n*-doped, while the other QW is undoped (ud). In a standard QWIP, the photoexcited current is collected parallel to the growth direction by means of two contacts, one at the top and the other one at the bottom of a mesa structure. In contrast, the photocurrent in the laterally biased QWIP (LBQWIP) is detected laterally (perpendicular to the growth direction, i.e. parallel to the QW plane). Hence, it is necessary to process contacts (collectors) on each side of the QWs. The operation principle of the LBQWIP is shown in Fig. 1(b). It consists of the following sequence of events: (i) photoexcitation of carriers within the doped QW, (ii) tunneling of photoexcited carriers into the undoped QW, and (iii) photocurrent detection by the lateral bias at the contacts. In this scheme, only the undoped QW is biased in order to reduce the dark current.

The challenge in the development of this structure is the fabrication of the lateral collector contacts, since it is very demanding to

---

* Corresponding author at: Instituto de Sistemas Optoelectrónicos y Microtecnología (ISOM), ETSI Telecomunicación, Avda. Complutense 30, 28040 Madrid, Spain.

E-mail address: guzman@die.upm.es (Á. Guzmán).

http://dx.doi.org/10.1016/j.jcrysgro.2017.04.023
0022-0248/© 2017 Elsevier B.V. All rights reserved.

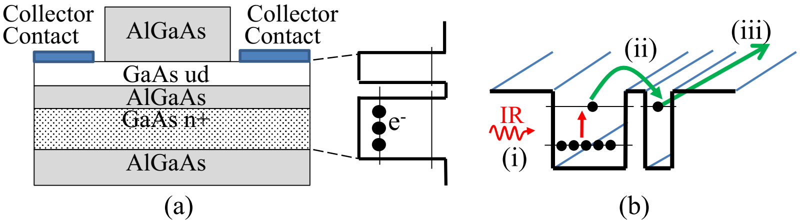

Fig. 1. (a) Structure of the LBQWIP (left) and its potential profile (right). (b) Operating principle of the lateral-bias device: (i) absorption by photoexcitation, (ii) tunneling, and (iii) photocurrent detection.

contact only a single QW due to the spatial separation of about 10 nm or less between the two QWs. In fact, Cardimona et al. [7] have proposed a modified structure where both the doped and the undoped QW are short-circuited by the collector contact. In addition, they use a third electrode (pinch off gate) to create a field-induced depletion barrier, which blocks the direct conduction through the doped QW. Using a similar structure, we have achieved photocurrent detection at room temperature [8].

Here, we describe two viable technologies to create contacts at both sides of a single QW, which is separated a few nm from another QW. The first procedure entails the use of highly accurate etching using an inductively coupled plasma (ICP). The second procedure comprises successive steps of growth by molecular beam epitaxy (MBE) and etching by focused ion beam (FIB) in two connected high-vacuum chambers.

2. Sample fabrication

We have investigated two different samples, which were grown by MBE on undoped GaAs (100) substrates in a RIBER 32 system equipped with an As valved cracker cell. After oxide desorption at 580 °C, the substrate was outgassed for 15 min. Subsequently, the GaAs/Al$_{0.3}$Ga$_{0.7}$As structure was grown at a substrate temperature of 610 °C.

The structure of sample I is shown in Fig. 2. It consists of two GaAs QWs with thicknesses of 7.5 and 2.5 nm separated by a 4-nm-thick (Al,Ga)As barrier, which are buried between two 30 nm (Al,Ga)As layers. A 100-nm-thick GaAs cap layer was grown on top (Fig. 2(a)). This sample was grown in a single run. It was then processed using standard photolithography, ICP etching, and metal evaporation. We have achieved a high degree of accuracy during the ICP etching using a mixture of SiCl$_4$ and Ar with 7.5:11 sccm, a plasma power of 45 W, and a DC bias of 100 V. These parameters provided a measured etching rate of 30 nm/min. An end-point laser detector was used to stop the etching in the first GaAs QW as indicated in Fig. 2(b). Finally, two AuGe/Au contacts with thicknesses of 70/200 nm were deposited at each side of the undoped QW as indicated in Fig. 2(c). These contacts were not alloyed in order to avoid the diffusion of the metal into the barrier and the doped QW.

The structure of sample II is displayed in Fig. 3. It was fabricated using successive steps of growth by MBE and etching by FIB using an Ar sputter gun (SPECS IQE 12/38). The Ar gun was placed in a high-vacuum chamber (etching chamber), which is directly connected to the growth chamber of the RIBER 32 MBE system. A transfer rod permits the transfer of samples between both chambers preventing the exposure of the sample to the atmosphere between growth and etching steps. The Ar beam spot can be focused to a circular spot with a diameter of 100 μm and also be deflected to different parts of the substrate surface. With a precise selection of the etching parameters, an etching rate of 20 nm/min could be achieved. After the native oxide desorption, the bottom (Al,Ga)As layer, the undoped GaAs control QW, the first (Al,Ga)As barrier, and the first active *n*-doped QW were grown as indicated in Fig. 3(a). In the next step, the sample was transferred to the etching chamber, where part of the top GaAs layer on the left side was removed as shown in Fig. 3(b). Subsequently, the second (Al,Ga)As barrier and the second *n*-doped GaAs active QW were grown in the growth chamber as shown in Fig. 3(c). Furthermore, part of the top GaAs layer on the right side was removed in the etching chamber as indicated in Fig. 3(d). In the next step, the top (Al,Ga)As barrier was grown followed by a 10-nm-thick GaAs layer to prevent the (Al,Ga)As layer from oxidation as displayed in Fig. 3(e). Finally, two In droplets were deposited on both sides of the device and alloyed in order to diffuse the In into the structure and create the Ohmic contacts as indicated in Fig. 3(f).

The top GaAs layer in sample I (cf. Fig. 2(a)) and the GaAs control QW in sample II (cf. Fig. 3(a)) were grown to verify the accuracy of the etching process by scanning electron microscopy (SEM) as discussed below. We have also grown a reference standard QWIP (sample R) consisting of 10 periods of a 7.5-nm-thick *n*-doped GaAs QW and a 30-nm-thick (Al,Ga)As barrier, sandwiched between two *n*-doped 500-nm-thick GaAs layers. This structure was processed into photodetectors by standard photolithography and mesa etching. Two AuGe/Au contacts were

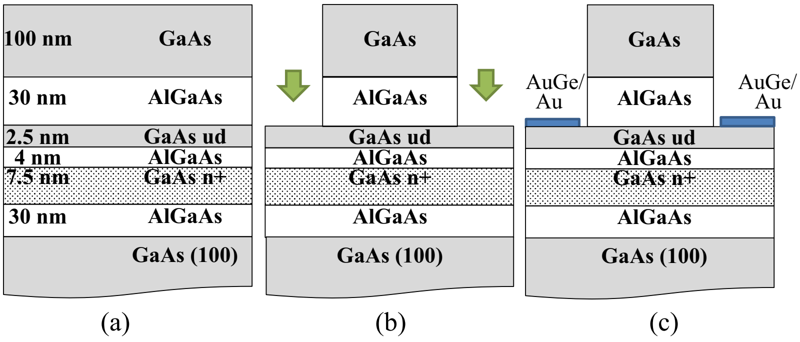

Fig. 2. Structure and fabrication of sample I: (a) after growth by MBE, (b) after etching by ICP, and (c) after metallization of the contacts.

Please cite this article in press as: Á. Guzmán et al., Laterally biased structures for room temperature operation of quantum-well infrared photodetectors, J. Cryst. Growth (2017), http://dx.doi.org/10.1016/j.jcrysgro.2017.04.023