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Investigation of the optical and electrical properties of p-type porous GaAs structure

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ABSTRACT

Porous GaAs layers have been formed by electrochemical anodic etching of (1 0 0) heavily doped p-type GaAs substrate in a HF:C_2H_5-OH solution. The surface morphology of porous GaAs has been studied using atomic force microscopy (AFM).

Nano-structural nature of the porous layer has been demonstrated by X-ray diffraction analysis (XRD) and confirmed by AFM. An estimation of the main size of the GaAs crystallites obtained from effective mass theory and based on PL data was close to the lowest value obtained from the AFM results. The porous p-GaAs samples are characterised by spectroscopic ellipsometry and modulation spectroscopy techniques. The objective of this study is to determine the porosity, refractive index, and thickness. The porosity of GaAs determined by atomic force microscopy confirmed by the value obtained from the spectroscopic ellipsometry. In fact the current–voltage $I(V)$ characteristics of metal–semiconductor Au/p-GaAs are investigated and compared with Au/p-porous GaAs structures. From the forward bias $I(V)$ characteristics of these devices, the main electrical parameters such as ideality factor, barrier height, and series resistance have been determined.

1. Introduction

The discovery of intense visible photoluminescence [1] in porous silicon formed by electrochemical etching has opened new research fields for investigating porous layers in other semiconductor

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materials. Among which we can mention GaAs as it proved to be of large interest because the anodisation of the material results in formation of porous GaAs layers with luminescence in the visible region, at higher energies than porous silicon [2,3]. The influence of technological parameters such as current density, etching time, substrate doping, crystallographic orientation and the etching temperature on morphology and optical properties are investigated. The optical properties of the nanostructured material play an important role in the development of the semiconductor technology devices made on it. Metal–semiconductor (MS) contact is one of the most widely used rectifying contacts in the electronics industry [4,5]. Many experimental studies of the electrical properties of Au/n-GaAs Schottky diodes have been reported in the literature [6–8]. Meanwhile, the electronic transport in porous GaAs has not yet been studied, except in a few numbers of publications dealing with electrical characteristics of porous GaAs/p+-GaAs heterostructures [9], Pd/porous-GaAs Schottky diode gas sensor [10] and Au/porous n-GaAs [11]. In this study, we will investigate the structural, optical and electrical characteristics of porous GaAs layers formed by electrochemical anodic etching of Zn-doped p-type GaAs (100) using anodic etching process in FH solution.

2. Experimental procedure

Porous GaAs is produced by electrochemical etching of (100) p-type GaAs, doped with Zn, up to the concentration of about 10^{18} cm^{-3}. The etching is carried out in an HF and ethanol mixture under galvanostatic condition [12,13]. The sample is etched in a HF:C_2H_5OH = 1:1 solution at etching time 24 s for two different current densities 8 mA cm^{-2} (sample A) and 24 mA cm^{-2} (sample B), respectively. Atomic force microscopy is used to examine surface morphology. The structural properties of the p-type porous GaAs is studied by X-ray diffraction at a scanning rate of 3 s^{-1} using Cu Kα radiation with a wavelength of 1.5406 Å. The XRD of starting GaAs (100) is composed of two peaks located at 31.721 and 66.161 attributed to the (200) and (400) orientations respectively. The optical response of the porous GaAs is investigated by photoluminescence spectroscopy and spectroscopic ellipsometry. The metal contacts are formed by evaporating gold (Au), as circle dots with a diameter of about 1 mm on the front surfaces of p-type GaAs and p-type porous GaAs, by using a vacuum evaporation technique at 133×10^{-5} Pa. The current–voltage $I(V)$ measurement characteristics of the devices are measured by a set up consisting of a computer-controlled KEITHLY (as a DC source measure unit) in the dark and under ambient conditions.

3. Results and discussion

3.1. Microstructural characterisation

Fig. 1 shows the surface morphology of porous GaAs samples as observed by AFM, using a scanning area of 2 μm × 2 μm. The porous GaAs layer exhibits a nano-structured surface morphology, proved to be typical to that found in other works [2–14], since it is formed by crystallites connected to each other that have an average size of about 7.21 nm for sample A and 19 nm for sample B, depending on the etching conditions. The main root square of the roughness (RMS roughness) and the surface porosity are evaluated as 5.6% and 73% of sample A, and 20.6% and 57% of sample B, respectively. We can conclude that when the current density increases, the porosity decreases, and it is possibly due to an increasing of the average size of the GaAs nanocrystallites and the decrease of the density of the pores. Furthermore, the three dimensional images of GaAs porous samples are illustrated in Fig. 2a and b for A and B samples, respectively. It is clear from the figure that the rms roughness increases when the current density increases.

X-ray diffraction is performed to investigate the crystallinity of the porous GaAs Fig. 3 represent typical XRD profile of the starting GaAs substrate, A and B samples. The XRD spectra of starting GaAs is composed of two intense peaks located at 31.75° and 66.1° attributed to the (200) and (400) orientations of the starting GaAs substrate. The porous GaAs (A and B samples) show (400) orientation with a broad peak and low intensity compared to that of the starting GaAs substrate, located at 66.1°. The geometry of peaks is related fundamentally to the positions of the atoms within the crystallite