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RBS characterization of the deposition of very thin $SiGe/SiO_2$ multilayers by LPCVD

A. Muñoz-Martín [a], A. Climent-Font [a,b], A. Rodríguez [c,*], J. Sangrador [c], T. Rodríguez [c]

[a] Centro de Micro-Análisis de Materiales, Edificio 22, Campus de Cantoblanco, 28049 Madrid, Spain
[b] Departamento de Física Aplicada, C-XII, Universidad Autónoma de Madrid, Campus de Cantoblanco, 28049 Madrid, Spain
[c] Departamento de Tecnología Electrónica, E.T.S.I. de Telecomunicación, U.P.M., Ciudad Universitaria s/n, 28040 Madrid, Spain

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Abstract

Multilayer structures consisting of several alternated layers of SiGe and SiO_2 with thickness ranging from <5 to 25 nm were deposited by LPCVD. The samples were analyzed by RBS to determine the composition and thickness of each layer. The deposition of SiGe on SiO_2 or Si as well as the deposition of SiO_2 on Si show negligible incubation times. The deposition of SiO_2 on SiGe, however, exhibits an incubation time of several minutes, which would be related to the oxidation of the surface necessary for the SiO_2 deposition to start. In all cases the film thickness increases linearly with deposition time, thus allowing the growth rates to be determined. These data allow the deposition process of these very thin layers to be accurately controlled.

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Keywords: $SiGe/SiO_2$ multilayers; LPCVD; RBS; Incubation times; Growth rates

1. Introduction

$SiGe/SiO_2$ multilayers with film thicknesses below 5 nm are of interest for the fabrication of electronic and optoelectronic devices which can be easily integrated with the Si-based electronic circuits. Photoluminescence and electroluminescence emission via the interface states and the recombination of electron–hole pairs in the Si layers has been observed in $SiO_2/Si/SiO_2$ single and multilayer structures [1] and nc-Si/SiO_2 super-lattices [2]. These structures have been fabricated by: sputtering and annealing [3], LPCVD and thermal oxidation [1] and PECVD [4]. The key

* Corresponding author. Tel.: +34 91 5495700x565; fax: +34 91 3367216.
E-mail address: andresr@etsit.upm.es (A. Rodríguez).

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parameters to control the energy of emission in these multilayers are the layer thickness, which affect the carrier confinement characteristics, and the materials properties. SiGe presents several advantages respect to Si, e.g. the possibility to tune the band gap by the control of the Ge fraction (x) of the alloy, and the reduction of the exciton lifetime with the corresponding increase of the radiative recombination efficiency.

In this work we propose a simple and low cost procedure for the fabrication of continuous $SiGe/SiO_2$ multilayers with layer thickness in the range of nm. Multilayers are deposited in a single process at a constant temperature using a LPCVD reactor equipped with a system for deposition of SiO_2 at low temperature (LTO), compatible with well established semiconductor device manufacturing technologies. The thickness and composition of the resulting multilayers are characterized using RBS techniques.

2. Experimental

Multilayers consisting of a stack of alternated amorphous SiGe and SiO_2 films were deposited in a single run process using a hot wall LPCVD reactor. Si wafers dipped in HF prior to their loading in the reactor were used as substrates. The SiGe films were deposited using pure disilane (Si_2H_6) and germane (GeH_4) as precursor gases. No carrier gas was used. The pressure was 300 mTorr, the temperature was 390 °C, the germane to disilane ratio was set to 0.82 and the total flow was kept constant at 10 sccm. The SiO_2 films were deposited using Si_2H_6 and O_2 as precursor gases and N_2 as carrier gas. The flows were set to 2, 10 and 90 sccm, respectively. The pressure was 185 mTorr and temperature was also 390 °C, so only a short purge time is needed for shifting from one deposition type to another. More details on the deposition system and processes are available elsewhere [5].

The samples were characterized using Rutherford backscattering spectrometry (RBS) and the collected spectra were analyzed using the RBX code from Kótai [6]. In our experiment, a 2 MeV $4He^+$ ion beam was used with an incident angle of 75°. The detector, with a FWHM of 14 keV, was placed at a scattering angle of −170° in IBM geometry. This configuration, with the detector at 5° from the surface of the sample, was chosen to improve as much as possible the depth resolution of the technique. However, some problems related to the unambiguous determination of the composition and thickness of the SiGe and oxide films from the acquired spectra still hold. Some strategies have been followed to try to circumvent the difficulties associated to the determination of the compositions of the layers, thus allowing the spectra analysis to be mainly focused on the accurate determination of the thickness of the SiGe and SiO_2 layers. Concerning the oxide, it was previously established by Fourier transform infrared spectroscopy that stoichiometric SiO_2 films are grown using the selected gas flows, so the composition of the oxide was used as a data to fit the RBS spectra. With regard to the SiGe films, the samples were specifically designed to allow the determination of the composition of the SiGe alloy by including a thick layer at the bottom of the stack. A first set of multilayers consisting of Si (substrate)/SiO_2/SiGe (thick and with constant thickness)/SiO_2/SiGe (thin and with variable thickness)/SiO_2 were deposited (see inset of Fig. 1). The deposition time for the inner SiGe layer was selected to obtain a layer thick enough to allow a clear determination of the composition of the SiGe alloy and the layer thickness. The thickness of the outer SiGe film, which differs from sample to sample, was determined from the RBS spectra fitting assuming the same composition than that of the thick film located beneath, which was deposited in the same conditions and in the same run. The structure of the samples, with the thin SiGe layer located near the surface of the sample, minimizes the effect of the energy straggling on the determination of its thickness. The SiO_2 layers allow to check for the repeatability of the oxide deposition process within the sample and from one sample to another as well as to determine possible differences in the deposition of SiO_2 on SiGe and on Si. A second type of samples consisting of Si (substrate)/SiGe/SiO_2 (thick and with constant thickness)/SiGe/SiO_2 (thin and with variable thickness)/SiGe were fabricated (see inset of