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Chapter 1

Introduction and objectives

Porous silicon was discovered in 1956 by Uhlir [1] while performing electropolishing experiments on silicon wafers using an electrolyte containing hydrofluoric acid. Its development was first justified for technological reasons, in particular, localized isolation in microelectronics. A renewed interest in porous silicon occurred in 1990 when its photoluminescence and electroluminescence properties were demonstrated [2,3]. The optical properties of porous silicon have been extensively investigated [3,4,5,6] and promising electroluminescent devices have been fabricated [7].

Porous silicon is usually designed in a complex shape, using suitably doped structures and then dissolved selectively to leave silicon membranes, beams or trenches [8-9]. Depending on the anodization conditions [10], this material presents a porous texture with pore diameters varying from 2 to 15 nm, density varying from 20 % to 80 % and specific surface area varying from 100 to 600 m^2 cm^{-3}.

It has been established that the most important parameters which fix the characteristics of porous silicon obtained by electrochemical anodization are the electrolyte composition, particularly the hydrofluorhydric concentration, the

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current density across the wafer, and the time of current application. Whereas the time determines the thickness of the porous silicon layer, the current determines the refractive index. In a first approximation, as the silicon dissolution only occurs at the pore tips, at the interface between the silicon substrate and the electrolyte, the porous silicon layer already formed is not affected by the subsequent conditions of fabrication. Therefore, any kind of profile can be prepared, being the easiest way the current modulation during the porous silicon fabrication process. This makes of porous silicon a very suitable material for the fabrication of multilayers.

In this context, this thesis focuses on the study of multilayer optical devices made of porous silicon. In order to achieve this objective, different steps have been realized. Firstly, the theoretical study of multilayers has been developed because by choosing, in an appropriate way, the thicknesses and the refractive indices of the various layers, it is possible to fabricate different optical devices, such as filters, microcavities, waveguides, etc. With the simulation, we study the suitability of porous silicon for the fabrication of the optical devices. Once simulated and designed the porous silicon multilayer devices, we fabricate them. For this purpose, a fabrication system has been established and calibrated and several porous silicon monolayers and multilayers have been fabricated. Finally, these fabricated layers have been characterized to determine their physical and optical properties. All these steps are necessary to achieve our main and final objective: the fabrication and characterization of porous silicon multilayer optical devices.

The thesis is organized as follows:

In Chapter 2 an introduction to porous silicon basics and the underlying theory that governs their unusual optical properties are explained. The physics of the porous silicon formation and the different parameters of the process that influence on the final characteristics of the fabricated layers are discussed. Different applications of porous silicon are presented, especially the optical applications that have been studied during this work.

Chapter 3 is focused on the development of different programs for the simulation of multilayers. An overview of the mathematical methods used for

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the simulation of multilayers is explained, specially the transfer matrix method, that is explained in detail because it is the method implemented for our theoretical study. Several programs that use the transfer matrix method have been realized and are explained in this chapter. The performance of the programs is studied by comparing the simulated optical responses of well-known multilayer structures with the ones obtained in the literature.

Chapter 4 presents the theoretical study of two different optical devices: omnidirectional mirrors and waveguides. For each device, the different physical parameters that influence on its optical characteristics are analyzed and the suitability of porous silicon for their fabrication is discussed. For the case of omnidirectional mirrors, three different new multilayer structures have been proposed for the widening of the omnidirectional bandgap. For the case of waveguides, the modal study of porous silicon waveguides based on total internal reflection has been developed whereas waveguides based on the properties of photonic crystals have been widely studied, proposing the use of omnidirectional mirrors and DBR for the cladding. All these devices have been designed for 1.55 μm applications, a wavelength widely used in telecommunications

Chapter 5 gives a complete description of the porous silicon fabrication system that we have established in the Department of Electronic, Electric and Automatic Engineering at the University Rovira i Virgili. The influence of the elements of the system on the properties of the fabricated porous silicon layers is discussed. The most important element of the system is the electrochemical cell, for this reason a study of this element is realized and the differences between two types of electrochemical cells are presented. The calibration of the fabrication system, that is the study of the relations between the anodization parameters and the two most important physical characteristics of porous layers (refractive index and thickness) is presented. To conclude this chapter, the different methods used for the characterization of porous silicon layers are explained.

Chapter 6 is dedicated to the characterization of porous silicon monolayers and multilayers using spectroscopic ellipsometry. This work has

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been realized during one stage at the Ecole Polytechnique (Palaiseau, France) under the supervision of Dr. Enric Garcia-Caurel. This technique has been used to determine the main physical characteristics of the porous layers: porosity (and therefore refractive index) and thickness. In addition, spectroscopic ellipsometry allows the analysis of the anisotropy of the porous layers. Whereas the thickness and porosity of the layers have been also obtained with the characterization methods explained in chapter 5, the anisotropy can only been analyzed with ellipsometry, providing additional information about the fabricated porous layers.

Chapter 7 describes some of the optical devices fabricated with porous silicon multilayers. DBRs, microcavities and omnidirectional mirrors are designed, fabricated and characterized. The comparison between the optical properties of the fabricated device and the simulations are presented for each device.

Finally, chapter 8 presents the conclusions of our work.