Available online at www.sciencedirect.com
SCIENCE @ DIRECT®
Applied Surface Science 252 (2006) 5808–5813
applied surface science
www.elsevier.com/locate/apsusc

Excitation mechanisms and localization sites of erbium-doped porous silicon

A. Najar [a], H. Elhouichet [a,*], N. Lorrain [b], M. Oueslati [a]

[a] *Unité de recherche de Spectroscopie Raman, Département de Physique, Faculté des Sciences de Tunis, Elmanr 2092, Tunis, Tunisia*
[b] *Equipe "Matériaux poreux et dispositifs pour l'Optique guidée", Laboratoire d'Optronique, UMR 6082, 22300 Lannion, France*

Received 27 June 2005; received in revised form 29 July 2005; accepted 29 July 2005
Available online 21 September 2005

Abstract

Porous silicon (PS) is doped with erbium by electrochemical anodisation. The penetration of erbium into the PS layer is confirmed by Rutherford backscattering spectroscopy (RBS) and energy dispersive X-ray (EDX) measurements. Efficient green and infrared emissions were observed at room temperature. The investigations are focused on the evolutions versus temperature and pump intensity of the green photoluminescence (PL) corresponding to the $^4S_{3/2} \rightarrow {}^4I_{15/2}$ transition. It was found that an erbium related level defect can be involved on the excitation and emission processes of erbium. Pump intensity dependent PL studies revealed that for the electrochemical incorporation, most of the Er^{3+} ions are localized inside the Si nanocrystallites and not in stoichiometric SiO_2. The optical cross-section is close to that of erbium in Si nanocrystallites.

Keywords: Porous silicon; Erbium; Excitation mechanisms; Cross-section

1. Introduction

Erbium-doped silicon has been studied for over a decade for possible applications in optoelectronics and in telecommunication because erbium can emit photons at 1.54 μm due to an intra 4f shell transition between the $^4I_{13/2}$ and the $^4I_{15/2}$ levels. This emission is particularly attractive since its wavelength falls inside a window of maximum transmission for silica optical fibers. The development of practical, silicon-based light emitting devices, however, has been severely limited by a low erbium concentration and strong quenching of photoluminescence (PL) intensity. Several alternative ways are currently being pursued in order to deal with its inability to luminescence efficiently. Porous silicon (PS) is considerate an appropriate material for erbium doping because its visible PL is efficient and is compatible with standard silicon processes in making integrated optoelectronic devices [1]. It's very large surface area to volume ratio makes the PS matrix very accessible for erbium doping, as well as a host for large concentrations of oxygen necessary for erbium emission. Doping of PS

---

* Corresponding author. Tel.: +216 71872600; fax: +216 885073.
E-mail address: habib.elhouichet@fst.rnu.tn (H. Elhouichet).

0169-4332/$ – see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.apsusc.2005.07.071

with rare-earth (RE) ions has been achieved by ion implantation [2], diffusion [3], dip-coating [4] and electrochemical deposition [5,6]. Cathodic electrochemical deposition is preferred because it offers the advantages of deeper erbium penetration (10–20 μm), lower cost, and simplicity of processing. The question here is where in PS are located Er^{3+} ions, when PS consists of various crystalline and amorphous phase, and how Er^{3+} ions are excited from the c-Si nanocrystallites?

In this work, we have doped PS with erbium by electrochemical deposition. Erbium profile in the PS layer is studied from the Rutherford backscattering spectroscopy (RBS) and energy dispersive X-ray (EDX) measurements. The dependencies of PL intensity versus temperature and pump intensity are investigated. The processes of erbium excitation and de-excitation in porous silicon are discussed.

2. Experimentation

We used PS samples prepared by anodising a p-type (1 0 0) silicon substrate (0.7–1.3 Ω cm) in a mixture of HF (40%) and ethanol ($HF:C_2H_5OH = 1:1$) with a current density of 12 mA/cm^2. The anodisation time is chosen to obtain a PS thickness less than 4 μm. Using the gravimetric method, the porosity of the PS layer is estimated to 65%.

Erbium is introduced into the PS by electrochemical deposition from a saturated chloride solution of erbium ($ErCl_3:C_3H_5OH$) for 30 min at a current density of 0.1 mA/cm^2. After erbium deposition, the sample is rinsed with ethanol in order to clean the surface, and then is subjected to two classic thermal annealing (CTA) at 300 °C for 30 min and at 1000 °C for 20 min to activate the erbium ions in the matrix.

In order to study the incorporation of erbium in the PS, the penetration was controlled by Rutherford backscattering spectroscopy (RBS) of $^4He^+$ ions delivered by a 2 MeV Van de Graf accelerator and energy dispersive X-ray (EDX) analysis.

Photoluminescence (PL) measurements are performed by using the 488 nm Ar^+ line as excitation source, a triple monochromator for light analysis and a "GaAs" photomultiplier. For infra-red PL measurements, an InGaAs photodiode is used. The sample temperature was controlled from 20 to 300 K by a closed cycle He cryostat.

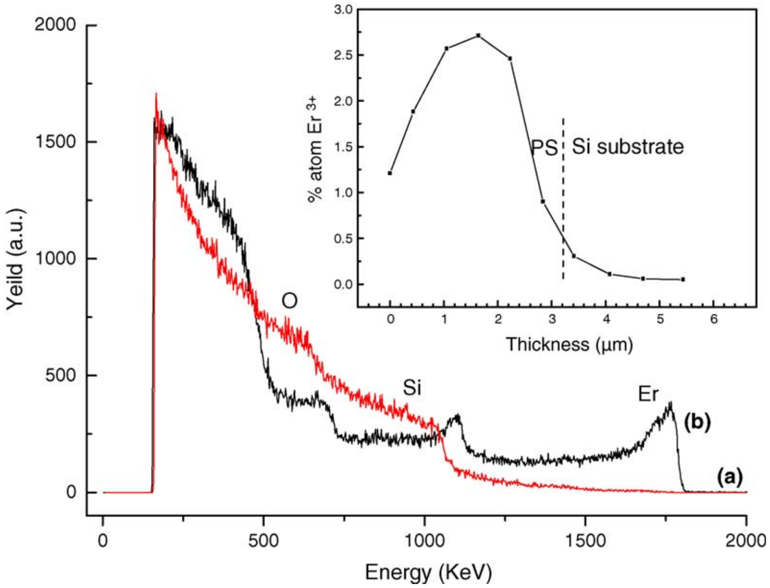

Fig. 1. RBS spectra of porous silicon (a) and erbium-doped porous silicon (b). Inset: concentration of erbium, deduced from EDX analyses, in different region of the PS layer.