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Study of the material variability and processing techniques on white light photoluminescence sensors based on porous Si, ZnO and carbon dots

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Summary:

This study presents an investigation of the photoluminescence (PL) intensity and peak position of 3 different materials based on their fabrication conditions. These materials are porous Si, ZnO and carbon dots. Combinations of these materials have been shown to produce white light by a single wavelength excitation. Herein, the variability of the PL of each individual material is demonstrated, enabling the design of the combined PL characteristics. Moreover, the patterning of the materials using standard Si processing is demonstrated. The results show the applicability of the presented materials and methods for the development of integrated, PL-based devices.

Keywords: photoluminescence, porous Si, zinc oxide, carbon dots, photodetectors

Introduction

The motivation behind this work is to create pixel-type photoluminescence (PL) based devices, whose emission covers the entire visible spectrum (White Light Emission), using a single wavelength excitation. These devices can be used in multi-analyte sensing schemes based on color changes within the visible spectrum, aiming towards the fabrication sensors [1] as well as optical devices [2].

Recently, we have shown that it is possible to create PL emissions that cover the entire visible spectrum using layered structures of porous Si (pSi), ZnO and carbon q dots (CDs) [3]. These materials are known to be bio-compatible, batch-Si processing compatible and environmentally friendly. They are known to emit within different spectral ranges, specifically in red, blue and green, respectively.

In this work, we advance beyond our previous publication, studying the variability of the 3 materials' PL properties according to their fabrication conditions. This variability will be necessary in creating sensor devices with application-tailored properties. Moreover, we demonstrate the ability to process these materials in CMOS-compatible manner, creating simple structures and devices on Si substrates. The achievements described herein constitute a significant step beyond the state-of-the art and allow the creation of property-tailored sensor devices.

Materials and Methods

Porous Si (pSi) layers were formed by anodization of p-type Si substrates, of different conductivities. Conductivities ranging from a few Ωcm to a few mΩcm were used. Oxidation in different conditions was used to increase the variability of samples. ZnO films were grown on the surface of the different pSi substrates by a two-step process. Finally, different types of CDs were synthesized via a hydrothermal method by varying the type of precursor materials and the type of doping (i.e. N-doping, P-doping etc.).

PL characterization of the samples was performed by two different excitation lasers, namely one at 337nm and one at 532nm. The influence of the processing conditions on the PL signal was evaluated both independently for each material (pSi, ZnO, CDs) as well as for combinations of them. The definition of patterns using the above materials was performed using standard Si processing photolithography and etching techniques.

Results

The effects of oxidation conditions on the PL intensity and peak position for pSi samples on p+ Si substrates (0.001 Ωcm) are presented in figure 1. It can be clearly seen that the oxidation conditions can be used to effectively control the PL emission characteristics very effectively. This allows for tailoring the emission of this material in the red part of the visible spectrum or even for the complete removal of PL signal.

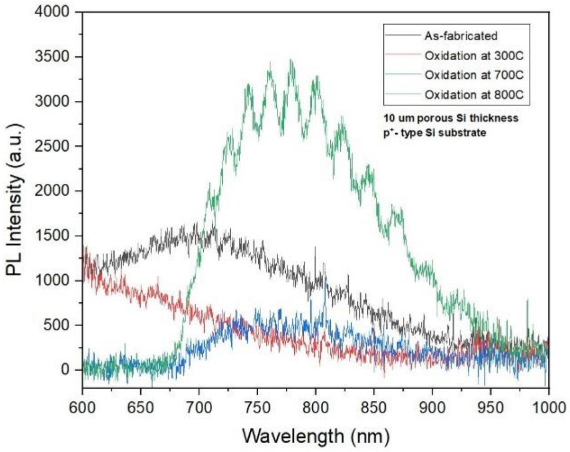

Fig. 1. Graph of PL spectrum of porous Si samples with 10μm thickness on p^+- type Si, for different oxidation conditions.

The PL intensities of two different kinds of CDs on Si substrate are presented in Fig. 2. The N,P-co-doped CDs exhibit peak PL at around 450 nm, while P-doped CDs exhibit two PL peaks at around 450 nm and 550 nm.

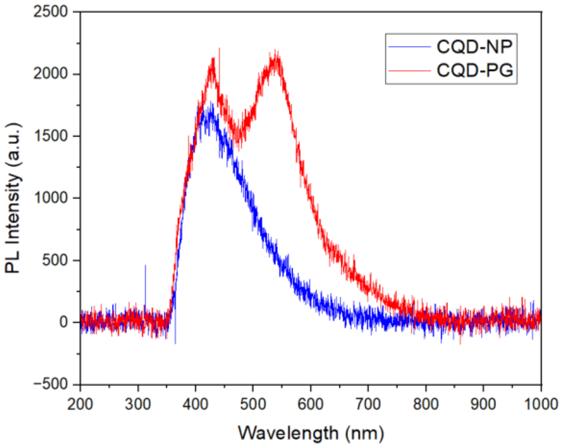

Fig. 2. Graph of PL spectrum of different CDs. NP refers to N,P-co-doped CDs and PG refers to P-doped CDs.

So, as in the case of PSi the tunability of the PL intensity as a function of fabrication conditions is demonstrated for this material.

The advantage of the proposed approach is that all materials can be either patterned (ZnO, CDs) or locally formed (pSi) using standard microelectronics processing. Figure 3 is an SEM image of a patterned ZnO layer on top of a pSi layer on a Si substrate using photolithography and etching. This enables the development of devices with precisely engineered PL properties tailored to the specific application. Results will be presented at the conference.

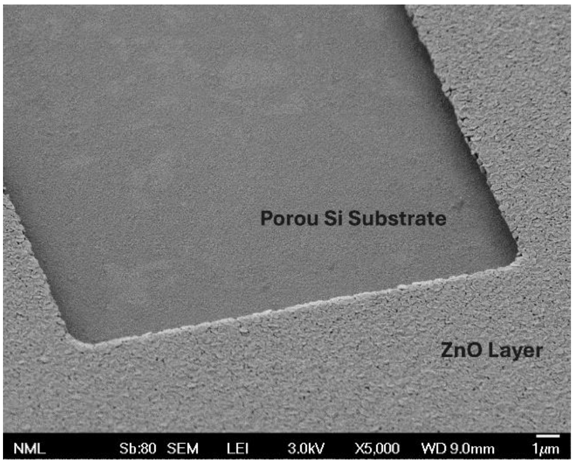

Fig. 3. Representative 45°-angle SEM image of a ZnO film grown on a porous Si substrate

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