Enhancement of Photoluminescence of Nanocrystalline Porous Silicon by High-Pressure Water Vapor Annealing

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Enhancing the efficiency and stability of nanocrystalline porous silicon (PS) luminescence is required in order to enable optoelectronic applications [1], such as light-emitting devices, optical interconnects, displays and lab-on-chip. Complete PS surface passivation is especially important to suppress non-radiative recombination centers. A possibility is to cover the nanocrystalline Si surface with a high quality SiO_2 layer with minimum interfacial defect concentration.

A high-pressure H_2O vapor annealing technique that is useful for improving the electrical properties of poly-silicon film devices [2] has been applied to nanocrystalline PS in order to enhance its luminescence efficiency. The annealing effects on the photoluminescence (PL) of p-type PS of various initial porosities have been studied as a function of the annealing temperature, pressure, and treatment time. Moreover, the effect of electrochemical oxidation prior to the high-pressure treatment has also been studied.

The nc-Si PS layers are formed by anodization of p-type Si in HF solutions. Some samples are then electrochemically oxidized under constant current density until the electrical contact between PS and the substrate is isolated by the grown oxide. This partial oxidation process is in some cases very efficient in increasing the PL efficiency of the as-anodized nc-Si layer while preserving the original Si nanocrystals. Then, the high pressure water vapor annealing is carried out. PS is put inside a closed container with the amount of water necessary to get the desired pressure when the temperature is raised. This system is left at constant temperature for several hours. The temperature, experiment duration and pressures have been varied. The pressure is given in unit of P_0, where $P_0=10^5$ pa (~atmospheric pressure).

As a typical example, the remarkable effect of annealing in water vapor on the PL efficiency is shown in **Fig. 1** for a conventionally anodized PS sample with a porosity of 70 %. The temperature, pressure, and experiment time were 150°C, 5 P_0, and 3 h, respectively. The PL peak intensity of the annealed sample is drastically enhanced compared to that of as-prepared one, while both the emission band and the peak wavelength remain almost unchanged.

Figure 2 shows the PL spectra of PS samples with an original porosity 50 %, which have been electrochemically oxidized and submitted to the high pressure treatment during 3 h at 260 °C under different pressures. The PL integrated intensities of the annealed samples are all very much enhanced compared to that of as-prepared one. From such experiments, the optimum pressure for high efficiency can be determined.

The results may be attributed mainly to a significant reduction in the number of non-radiative defects at nanocrystalline silicon surfaces in PS and a consequent increase in the localization of photo-excited carriers. This hypothesis is supported by some experimental analyses of optical and interfacial properties of annealed samples.

In summary, The PL of p-type PS has been drastically enhanced by employing a post-treatment based on high-pressure water vapor annealing at relatively low temperatures. This treatment is very useful to quench non-radiative defects at the nanocrystalline Si surfaces and to enhance the carrier localization effects in Si nanocrystals without affects on the emission wavelength.

References

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2. T. Sameshima, M. Satoh, K. Sakamoto, K. Ozaki and K. Saitoh, Jpn. J. Appl. Phys. **37,** L1452 (1998)

Figure 1*: PL spectra of PS samples with a porosity of 70%, before and after the high-pressure treatment at 150 °C, under 5 P_0, for 3 hours. The PS sample was not electrochemically oxidized.*

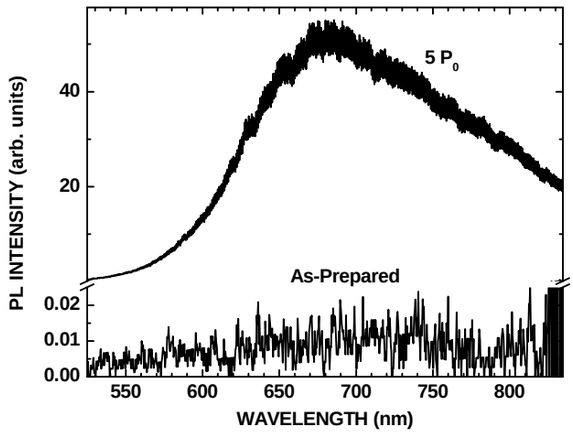

Figure 2*: PL spectra of different PS samples with a porosity of 50%, before and after the high-pressure treatment at 260 °C, for 3 hours, under different pressure conditions. All samples have been electrochemically oxidized after PS formation and before the high- pressure treatment.*