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Annealing effects in samples of silicon implanted with helium by plasma immersion ion implantation

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Abstract

Silicon samples were implanted with helium using plasma immersion ion implantation (PIII). The effects of implantation were analyzed by Raman spectroscopy, scanning electron microscopy (SEM), atomic force microscopy (AFM) and reflectance measurements before and after PIII, and after annealing (325 °C, for 30, 60 and 90 min and 450 °C for 30 min, in nitrogen atmosphere). After annealing, large bubbles were observed from SEM images and a connection between surface microstructure and materials properties was analyzed through AFM measurements. It was observed a reduction of the reflectance and an increase of the peak intensity of the photoluminescence (PL) with the increasing of the annealing time.

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Keywords: PIII; Ion implantation; Photoluminescence; Annealing

1. Introduction

Among countless plasma surface modification techniques that have been studied recently, plasma immersion ion implantation (PIII) stands out because it is a non-line-of-site technique, allowing the high energy ion treatment of three-dimensional complex shaped substrates. Metal, polymer, ceramic and semiconductor materials have been treated with a variety of gas plasmas for wear, corrosion and oxidation resistance [1,2]. For semiconductor processing, PIII has been explored for many features, including fabrication of high-quality p+/n diodes with junction depths below 100 nm [3], conformally doped sidewalls of silicon

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trenches [4], hydrogenation of polycrystalline silicon thin film transistors [5] and studies related to surface modification of silicon and porous silicon by nitrogen PIII implantation [6–8]. In this way, silicon nitride formation occurs after nitrogen implantation and could be used as antireflective coatings or devices passivation.

In the present work, silicon samples have been implanted with helium by PIII at low energies. At this time, the major studies of noble-gas implantation into silicon have been reported using the conventional implantation processes based on a target exposed to a controlled ion beam, for example: investigation of formation of cavities which have been found to be effective gettering sites for metallic impurities and the effect of annealing conditions [9], "Smart-Cut" process based on proton implantation and wafer bonding [10], hydrogen implantation to silicon on insulator material technology [11] and formation of helium bubbles in silicon as a function of implantation temperature [12]. Using PIII process, helium implantation was obtained for higher energies, between 20 and 100 keV [13,14].

In PIII, the ions to be implanted into the near surface of materials are extracted directly from the plasma in which the samples or industrial components to be processed are immersed without the need of extraction or acceleration grids. The three-dimensional ion implantation is achieved by applying repetitively a negative high voltage pulse (typically 10–100 kV, 10–50 μs duration, 10–3000 Hz repetition frequency) to the sheath formed between the plasma and the sample holder or the component itself [1].

2. Experimental

CZ silicon (1 0 0) n-type wafers with resistivity of 1 Ω cm were implanted with helium by PIII. The PIII treatments were carried out in a reactor where the helium plasma was produced by a DC glow discharge source. The plasma was obtained typically at 6.4×10^{-4} mbar pressure, with plasma densities of about 2.5×10^{10} cm^{-3} and temperatures of 5 eV. The plasma potential reached less than 100 V at the center of the chamber where the PS samples were placed for treatment. The high voltage pulser was run at the peak voltage of 5 kV, with square shaped pulses of about 50 μs duration and 300 Hz repetition frequency. The silicon samples were loaded onto a supporting holder made of stainless steel (SS) AISI304 and PIII implanted with helium for 30 min. The implantation dose obtained from the collected current and the sheath propagation model were 1.2×10^{17} cm^{-2}. After implantation, the samples were annealed at 325 °C for 30, 60 and 90 min and 450 °C for 30 min in a tubular quartz furnace in nitrogen atmosphere. Before and after annealing, measurements were carried out in order to determine changes in photoluminescence, reflectance and structural modifications using Raman spectroscopy, SEM, AFM and spectrophotometer.

Micro-Raman measurements were carried out using a Raman Renishaw microscopy system 2000. The Raman spectra were recorded in the backscattering configuration at room temperature employing an argon-ion laser excitation line (514.5 nm). The laser beam was focused on the sample using a spot size of 5.0 μm in diameter. In order to avoid sample inhomogeneities and to improve the statistics of Raman data, the summation method was used. Scanning electron microscope, JEOL, JSM 5310, with secondary electron contrast was used for SEM images. A SPM2- Shimadzu atomic force microscopy was used to analyze the surface modifications. The total reflectance was measured between 200 and 800 nm using a Hitachi U-3501 Spectrophotometer equipped with an integrating sphere.

3. Results and discussion

Fig. 1 shows the Raman spectra in the vicinity of the Si peak before and after annealing time at 325 °C, 30 min. The spectrum corresponding to the crystalline silicon (square) is also plotted as a reference. After implantation the peak intensity decreased and after annealing it was partially recovered. The damaged crystalline structure produced only by PIII implantation has an important amorphous part that affects the Raman intensity. After annealing there was a structure modification