Stress Analysis of Vertical LPCVD Poly-Si for MEMS Applications

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Abstract

Polycrystalline Si (poly-Si) films were deposited on temperature range of 650ºC to 850ºC (thickness of 1400 to 6200 Å) using Hydrogen diluted Silane by vertical LPCVD on 5000 Å thermally oxidized <100>, n-type single crystalline silicon substrates aiming stress analysis for applications in Micro Electro Mechanical Systems (MEMS). Scan Profiler and micro-Raman techniques were used to evaluate deposition temperature influence on stress. A higher deposition temperature leads to a less tensile stress films, as required for MEMS applications and post annealing induces an increase in tensile stress.

1. Introduction

Poly-Si thin films are greatly used as structural layer in Micro Electro Mechanical Systems (MEMS) due to its excellent piezoelectric and mechanical properties [1]. Stress in poly-Si films is the mechanical characteristic of greatest importance to MEMS device performance. Deposition parameters such as substrate temperature, gas flow and pressure should be controlled as they can affect the residual final stress [2]. Films obtained by LPCVD are highly dependent on the deposition parameters and on the chamber reactor geometry. For standard horizontal furnaces, poly-Si films are compressively stressed [3] and further thermal steps are required for stress relaxation [4].

In this work Scan Profiler and micro-Raman techniques are used to evaluate stress of undoped poly-Si thin films deposited at different temperatures. Low tensile stressed films, as required for MEMS devices are obtained at deposition temperature above 800 °C.

2. Experimental

Poly-Si thin films were deposited by LPCVD in a Pancake Vertical Reactor on 5000 Å thermally oxidized <100>, n-type, 1-10 Ω.cm single crystalline silicon (c-Si) substrates. The reaction atmosphere was Hydrogen diluted Silane (flow rates of 4800 sccm, 40 sccm, respectively). The CVD apparatus has been described elsewhere [5]. Temperature deposition ranged from 650ºC to 850ºC with 50ºC steps.

The stress of the wafer by scan profiler can be calculated by the sample curvature using the mathematical approach presented by Nakabayashi et al [6]. Data were extracted from a 3 cm length profile using a Dektak 6M scan profiler.

Then the samples were annealed by RTP process, performed in N_2 atmosphere with a 50ºC/s temperature rise rate and 40s annealing baseline. Annealing temperatures were T+50ºC, where T is the temperature of deposition of each sample.

After the annealing step stress of poly-Si film was evaluated using micro-Raman spectroscopy as presented by R. C. Teixeira, I. Doi et al [5].

3. Results and Discussion

Figure 1 shows stress calculated by scan profiler technique and deposition rate behaviors as a function of the reciprocal deposition temperature. It can be observed that deposition rate increases from 197 Å/min to 880 Å/min as temperature raises from 650 °C to 850 °C while stress decreases from 50 MPa to 3 MPa. This behavior is in agreement with the observed in the literature [7].

High stress values obtained for low deposition temperatures are due to the difference between the deposition and crystallization rates during the CVD process. Poly-Si obtained by LPCVD is deposited in the amorphous phase with concurrent solid phase crystallization (SPC) during the deposition process. Since the amorphous Silicon bond length is larger than the crystalline one (2.55 Å for amorphous against 2.35 Å for crystalline) the transition from amorphous to crystalline phase stretches the bond length during the SPC process leading to a tensile stressed film.

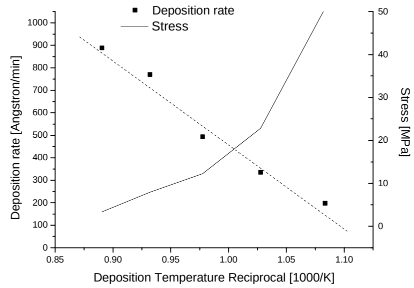

Figure 1: Stress by scan profiler and deposition rate dependency on deposition temperature.

The higher the deposition temperature the faster the crystallization rate that can be even faster than the deposition rate [3], i.e., the Silicon film is directly deposited in the crystalline phase and no phase transition is observed [7]. So that samples deposited at high temperatures lead to a low tensile stressed poly-Si films.

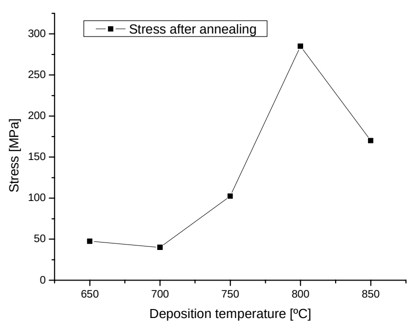

Figure 2: Stress by micro-Raman.

Stress analysis by micro-Raman spectroscopy after annealing step is presented in figure 2. One can observes an increasing stress from 50 MPa at 650 °C up to 280 MPa at 800 °C deposition temperature followed by a decrease after that. This behavior can be explained by the annealing process that converts the remaining amorphous phase into crystals. The higher the deposition temperature the higher the annealing temperature, increasing the amount of energy supplied for phase transition. The decrease at 850ºC can be attributed to out diffusion of hydrogen atoms incorporated during the deposition process.

The stress magnitude difference between scan profiler and micro-Raman techniques should also be attributed to the influence of the thermally oxidized layer compressive stress, as Scan Profiler technique evaluates the wafer stress and not only the poly-Si film as micro-Raman technique.

4. Conclusions

In this work authors investigated deposition temperature influence on stress and on deposition rate of poly-Si films deposited by vertical LPCVD on thermally oxidized substrates. The samples exhibited low tensile stress (above 50 MPa) that decreases with increase of deposition temperature due to deposition and crystalline growth rates proximity.

Annealing process induced an increase in tensile stress due to phase transition. Scan profiler and micro-Raman exhibited different stress magnitudes as they evaluate extrinsic and intrinsic stress, respectively.

The samples stress obtained are suitable for MEMS applications as they are tensile and bellow 500MPa.

5. Acknowledgments

Authors thank CCS-UNICAMP staff, for the technical assistance, and to Prof. F. Iikawa of IFGW-UNICAMP for performing the micro-Raman analysis. One of the authors, Cleber Scoralick Júnior, acknowledges the fellowship from CNPq-PIBIC to carry out this research.

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