STRESS IN THIN FILMS OF POLYCRYSTALLINE SILICON

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Introduction

Decreasing of the silicon wafer thickness is one of the most effective method leading to significant reduction of the wafer unit cost. However, decreasing of the wafer thickness results in the excessive wafer warping if polycrystalline silicon layer is deposited on the wafer back side (Fig. 1). Wafer warping is caused by high residual stress of the polycrystalline silicon layers. Hence, understanding of the origin of residual stress induced in polycrystalline silicon layers and the possibilities of its control during its deposition is highly appreciated.

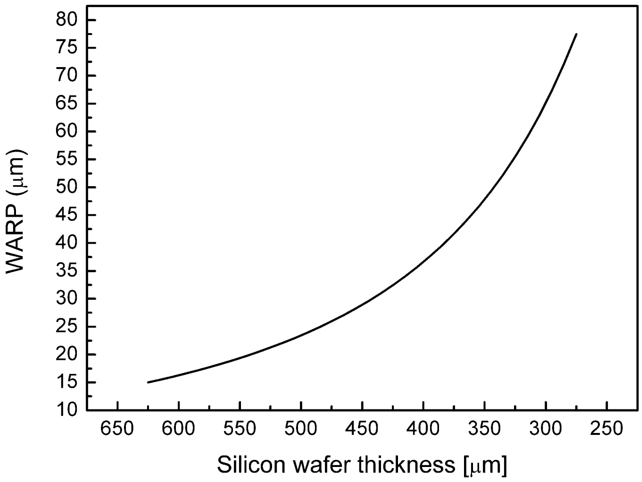

Fig. 1: Dependence of the silicon wafer warping on the thickness of the silicon wafer. Wafer warping is caused by 1 μm thick polycrystalline silicon layer deposited on the wafer backside. *WARP* is parameter characterizing warping of the wafer [1].

LPCVD (Low Pressure Chemical Vapor Deposition) is the technique widely used for deposition of the polycrystalline silicon layers on the back side of silicon wafers. The most important parameters of this deposition technique, which determine structure and physical properties of the growth layer, are deposition temperature and deposition pressure [2]. Hence, knowledge of the dependence of residual stress on the deposition temperature and deposition pressure is necessary for further development of the deposition process with respect to optimization of the residual stress.

Residual stress measurement

Residual stress of the polycrystalline silicon layer σ_f is can be calculated from the silicon wafer curvature radius *R* using Stoney's equation [3]:

$$\sigma_f = \frac{E}{6(1-\nu)} \cdot \frac{t_s^2}{t_f} \cdot \left(\frac{1}{R} - \frac{1}{R_0} \right), \tag{1}$$

where E is Young’s modulus, ν is Poisson’s ratio, t_s is thickness of the silicon wafer, t_f is thickness of the layer and R_0 is initial curvature radius.

Using this method is of advantage, because radius of curvature can be easily calculated from the wafer warping defined by *WARP*. Wafer warping is standardly measured for each produced wafer, which means that we can easily calculate residual stress of the polycrystalline silicon layers of all produced wafers. *WARP* is indirectly proportional to curvature radius R:

$$WARP = \frac{D^2}{8R}, \tag{2}$$

where D is wafer diameter.

Origin of the residual stress

Generally, residual stress in thin films can be compressive (negative values) or tensile (positive values). Thin films of polycrystalline silicon deposited by LPCVD technique in the range of deposition temperatures 600 – 660°C and deposition pressures 50 – 300 mTorr have always compressive residual stress [2]. Typical value of the residual stress for polycrystalline silicon layers with thickness about 1µm is in the order of -10^2 MPa.

Compressive stress of the polycrystalline silicon layers is the consequence of Vollmer – Weber mode of the thin film growth. During the deposition chemical potential of grain boundaries μ_{gb} is lower than chemical potential of as-deposited surface μ_s. Difference in chemical potentials provides the driving force for diffusion of adsorbed particles into the grain boundary. Accumulation of the particles in the grain boundary areas (Fig. 2) induces residual compressive stress of the layer [4].

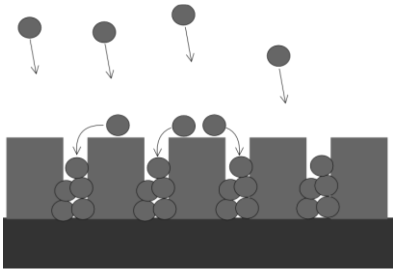

Fig. 2: Scheme of the origin of compressive residual stress in the polycrystalline silicon layers. Adsorbed particles diffuse into grain boundary area, which results in compressive residual stress induction.

The described mechanism to take place, the diffusion length of the adsorbed particles has to be high enough to reach the grain boundary area. This condition is satisfied if the deposition proceeds under surface-reaction-rate-limited regime [5].

Polycrystalline silicon layers prepared by crystallization of the initially amorphous silicon layer induce tensile residual stress. Crystallization of amorphous silicon is followed by volume contraction of the layer, which results in tensile stress [6]. Transition deposition temperature between deposition of amorphous and polycrystalline silicon layer is approximately 590°C, using LPCVD technique. If the layer is deposited near the transition temperature (in the range 575 – 590°C), amorphous layer partially crystallizes during its deposition resulting in the tensile residual stress of as–deposited layer. Such layer is then partly amorphous and partly polycrystalline [2]. Further annealing is then necessary to reach fully polycrystalline layer.

Experiment

Dependences of the residual stress of the polycrystalline silicon layers on the deposition temperature were determined for two constant deposition pressures of 110 and 280 mTorr. The range of the deposition temperature was from 570 to 627°C. Deposition temperatures below 600°C were selected intentionally in order to obtain amorphous silicon layers. The thickness of the layers was 1.1 µm.

From the dependences of the residual stress on deposition temperature (Fig. 3) is evident that layers deposited at temperatures above 600°C for deposition pressure 280 mTorr as well as layers deposited above 580°C for deposition pressure 110 mTorr show compressive residual stress. Those layers (right from the grey areas in Fig. 3) are polycrystalline. Absolute value of the residual stress of the polycrystalline silicon layers decreases with increasing deposition temperature. This can be explained by decreasing of the grain boundaries density. Decreasing of the grain boundary density is a consequence of the increasing lateral grain size with increasing deposition temperature.

Layers deposited at 577°C and 570°C for deposition pressure 280 mTorr are amorphous and show compressive residual stress. Layers deposited at 580°C and 577°C for deposition pressure 110 mTorr are amorphous and show tensile residual stress. Layer deposited at 585°C and 280 mTorr is amorphous and shows tensile residual stress as well. Resolutions whether layer is polycrystalline or amorphous were done using SEM and is reported elsewhere [2].

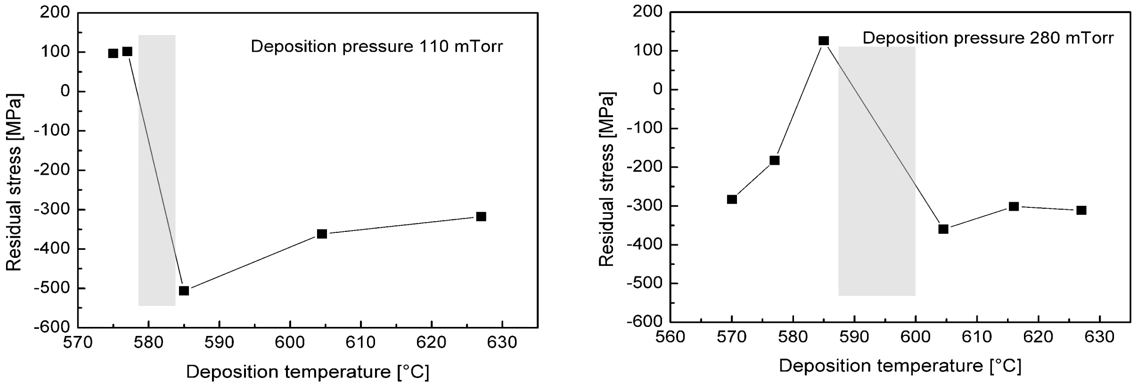

Fig. 3: Residual stress of the amorphous and polycrystalline silicon layers deposited on the backside of the silicon wafer. On the left side from the grey areas were layers amorphous. Grey areas denote transition region between amorphous and polycrystalline silicon. Polycrystalline layers are on the right from the grey area.

Transition region moves toward lower deposition temperature at lower deposition pressure (Fig. 3). This is the consequence of the lower deposition rate at the lower deposition pressure. Adsorbed particles can diffuse on the as-deposited surface longer before they are immobilized by further incoming particles.

Conclusions

We studied thin films of amorphous and polycrystalline silicon deposited by LPCVD technique in the range of deposition temperatures 570 – 627°C and deposition pressures 110 and 280 mTorr. As–deposited polycrystalline silicon layers always show compressive residual stress. Polycrystalline silicon layers prepared by crystallization of the initially amorphous silicon layers show tensile residual stress. Residual stress of the polycrystalline silicon layers can be pre-determined by proper adjustment of the deposition temperature and deposition pressure.

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